Neighborhood Design and the Energy Efficiency of Urban Lifestyle in China: Treating Residence and Mobility as Lifestyle Bundle

By

Yang Chen

Master in City Planning, University of Pennsylvania (2006)
Bachelor of Science, Peking University (2003)

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Urban and Regional Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2012

Author____

Department of Urban Studies and Planning
August 9, 2012

Certified by ____

Professor P. Christopher Zegras
Department of Urban Studies and Planning
Dissertation Supervisor

Accepted by____

Professor JoAnn Carmin
Chair, PhD Committee
Department of Urban Studies and Planning

Neighborhood Design and the Energy Efficiency of Urban Lifestyle in China: Treating Residence and Mobility as Lifestyle Bundle

By

Yang Chen

Submitted to the Department of Urban Studies and Planning
on 25 August 2012, in partial fulfillment of the requirements for the
Degree of Doctor of Philosophy in Urban and Regional Planning

Abstract

China and the rest of the world are facing the challenge of meeting energy demand sustainably. Household-level energy consumption is a large ultimate driving force of a nation's energy use. Realizing a sustainable energy future will require behavioral change on the consumption side. In this context, examining the role of neighborhoods is important since neighborhoods are the building blocks of China's urban growth and the neighborhoods we build now will have a long-lasting effect on households' lifestyles of energy consumption. This research uses Jinan as a context for Chinese cities, and tries to understand how neighborhood design influences households' direct energy consumption, including travel and in-home energy use, through the influence on urban households' lifestyle.

This research utilized an approach combining qualitative and quantitative methods, and finds that: (1) Household residential and vehicle ownership choice is made as a bundle reflecting the chosen lifestyle, making the combined evaluation of both travel and residential energy use possible; (2) Households belonging to different lifestyle groups have different decision-making mechanisms, suggesting the need for targeted design and policies; and, (3) Neighborhood design influences household direct energy consumption both through the ownership component choice and the usage component. By enabling more lifestyle bundle choices and providing new experiences and feedback, breaking old habits and creating new ones, energy-efficient neighborhood design can "lock in" households' lifestyles for a longer period of time via the lifestyle bundle choice effect. Design, therefore, likely has a larger and more robust impact in the long run than one-time or short-term incentives.

This qualitative-quantitative mixed-method study contributes to a bridging of the literatures on consumer behavior, lifestyle, built environment and travel behavior, residential energy consumption, and energy demand analysis. It also provides new insights into the interaction of residence and mobility as a lifestyle bundle, and enriches the empirical findings in the developing world. For policy makers and designers, this research presents a theoretical basis for the development of potential evaluation tools and a standard for energy efficient neighborhood design and offers a pilot method for the selection, and suggested range, of indicators for energy efficient neighborhood design.

Thesis Supervisor:	P. Christopher Zegras Associate Professor of Transportation & Urban Planning
Thesis Committee Member:	Joseph Ferreira Professor of Urban Planning and Operations Research
Thesis Committee Member:	Dennis Frenchman Leventhal Professor of Urban Design and Planning

Acknowledgement

My wholehearted thanks go to my advisor Prof. P. Christopher Zegras. Thanks for guiding me through the six years of my Ph.D. journey at MIT, as a mentor, friend, and role model, teaching me everything from theory, methods, analytical thinking, presentation, writing, communication, to everyday life. I am grateful to my committee members: Prof. Dennis Frenchman, an idealist and realist, who made the Jinan project a fruitful success linking design and energy modeling with great passion; and Prof. Joseph Ferreira, with all the intellectual insights that inspired many aspects of my research.

I am thankful to the "Making Clean Energy City in China" project funded by the Energy Foundation. I owe a great deal to colleagues and friends in Jinan. The household survey as well as the interviews would not have been completed without Professor Ruhua Zhang, Professor Jianhui Gu, Professor Jinyan Wang, and the student team in Shandong University. I also appreciate the work in GIS data collection and analysis done by the Beijing Normal University especially Tao Zhang. I also thank other team members in the Jinan project: Dong Wang, Feifei Yu, Cressica Brazier, Genevieve Rosie Sherman, Yang Chu, Zheng Jia, for all your hard work, technical and logistic support, and innovative ideas that make the project a continuous success.

I thank Prof. Karen R. Polenske, Prof. Ralph Gakenheimer, Prof. Joan Walker, Prof. Moshe Ben-Akiva, Prof. Frank Levy, Prof. Tunney Lee, as well as other DUSP professors and visiting scholars for valuable inputs that drove my research into a promising direction.

I cannot express my gratitude enough to my friends: Xin Li family, Zhan Guo family, Jinhua Zhao family, Weifeng Li family, Zhiyu Chen, Mi Diao family, Xiongjiu Liao, Yi Zhu family, Shan Jiang family, Wanli Fang, Jingsi Xu, Jieping Li, Zheng Jia….and many many more, for the encouragement, help, knowledge, insights, and joy. And my officemate Kathy, thanks for the "energy transfer" every time when I am under stress.

I am grateful to the DUSP community, especially Sandy Wellford, Karen Yegian, and Kirsten Greco. I also thank CRON staff, MIT libraries, the saferide shuttle, and MIT campus police.

Lastly, I would like to thank my family. With Aaron born on the 4th year of my Ph.D. journey, my family fully supported me with childcare and housework so that I could focus on my dissertation. I am so grateful to my parents and my parents in law who traveled across the ocean from China to help me taking care of Aaron. I am so lucky to have heartfelt support from my husband. I would never be able to finish my dissertation without you. So this is dedicated to you.

Table of Contents

Chapter 1 Introduction 17

1.1 Background and Research Question 17

1.1.1 Global and National Challenge for Sustainable Energy Consumption........................ 17

1.1.2 Lifestyle, Lifestyle Bundle, Lifestyle Group, and Neighborhood Design 21

1.2 Thesis Organization.. 23

Chapter 2 Theory and Evidence: Lifestyle and Urban Residents' Energy Consumption............. 25

2.1 A Review of Theories and Evidence on Lifestyle, Travel and Residential Energy Consumption, and Neighborhood Design 25

2.1.1 Lifecycle Energy Analysis 25

2.1.2 Consumer Behavior and Location Choice 27

2.1.3 Form and Travel.. 29

2.1.4 Form and Residential Energy.. 34

2.1.5 The Missing Link: Theory and Practice of Lifestyle Concept.................................... 37

2.2 Initial Theoretical Model and Mixed-Method Approach... 43

Chapter 3 Research Context and Research Methods 45

3.1 The Case City of Jinan 45

3.1.1 The city of Jinan.. 45

3.1.2 Growth, Urbanization, Motorization, and Lifestyle Change 45

3.1.3 Interaction with the Supply Side 47

3.1.4 Neighborhood typology 51

3.2 Qualitative and Quantitative Analysis Methods.. 52

3.2.1 Qualitative Methods 53

3.2.2 Quantitative Modeling Methods 54

3.2.3 Elasticities and Simulation.. 63

3.3 Data 65

3.3.1 Quantitative Data 65

3.3.2 Qualitative Data 69

Chapter 4 Urban Lifestyle and Household's Decision-making 73

4.1 The Hierarchy of Lifestyle 73

4.1.1 Housing and Vehicle Demand, Purchase Behaviors 74

4.1.2 Usage Behaviors, Attitudes, Perceptions, and Preferences.. 77

4.1.3 Values... 78

4.2 Lifestyle Groups and Lifestyle Indicators 78
4.2.1 Lifestyle Groups and Indicators 79
4.2.2 Dynamics between Household Members 87
4.3 Lifestyle Bundle and Decision-making Mechanism 87
4.4 Lifestyle Change, Neighborhood Design, and Direct Energy Consumption 91
4.5 Conclusion 96
Chapter 5 Household Vehicle Portfolio Choice 99
5.1 Introduction 99
5.1.1 Background 99
5.1.2 Vehicle Ownership Literature 101
5.2 Vehicle Portfolio Choice in Jinan 103
5.2.1 Household Vehicle Portfolio Ownership Pattern in Jinan 103
5.2.2 Basic Household Characteristics and Vehicle Portfolio Choice (MNL) 106
5.2.3 Role of Residential Choice 108
5.2.4 Neighborhood Design and Vehicle Portfolio Choice 109
5.3 Estimated Relative Effects via Simulation 112
5.3.1 Simulated Effects of Household Socioeconomics, Demographics and Housing Conditions 112
5.3.2 Simulated Effects of Neighborhood Characteristics 115
5.4 Conclusion 120
Chapter 6 Household Lifestyle Bundle Choice of Residence and Vehicle Ownership 121
6.1 Introduction 121
6.1.1 Overview 121
6.1.2 Lifestyle Bundle Structure 121
6.1.3 Hypotheses 125
6.2 Lifestyle Bundle Choice of Residence and Vehicle Ownership in Jinan 125
6.2.1 Lifestyle Bundle Pattern in Jinan 125
6.2.2 Neighborhood Design and Lifestyle Bundle—Baseline: Joint MNL 128
6.2.3 Lifestyle Group and Neighborhood Design—Latent Class Model (LCM) 132
6.3 Conclusion 148
Chapter 7 Household Direct Energy Consumption 149
7.1 Introduction 149
7.1.1 Overview 149
7.1.2 Energy Consumption pattern in Jinan 151
7.1.3 Hypotheses 156

7.2 Neighborhood Design and Households' Direct Energy Consumption 158
7.2.1 Total Energy Consumption with lifestyle bundle choice as IV's 158
7.2.2 SEM with lifestyle bundle choice as IV's.. 164
7.3 Conclusion 177
Chapter 8 Policy Implication and Conclusion 179
8.1 Summary of Findings... 179
8.2 Towards Energy Efficient Neighborhood Design.. 179
8.2.1 Policy Background: Low-carbon City and Urban Planning Process in China 179
8.2.2 Policy Implications 182
8.3 Limitations and Future Work 186
8.3.1 On Data and Methods 186
8.3.2 On Policy Implication 188
8.4 Concluding Remarks... 188
Appendix.. 189
A1 Interview Protocol.. 189
A2 Energy Calculation... 190
1. Travel Energy 190
2. In-home Energy 191
A3 Regional Accessibility Calculation... 193
A4 Simulation-based Wind and Solar Indices 193
A5 Summary of Interviewed Household Characteristics.. 194
A6 Correlation Matrix of OLS Model of Total Direct Energy 195
A7 More Information about the SEM of Energy Consumption 197
A8 More on the Energy Proforma.. 201
References 203

List of Figures

Figure 1.1 Primary Energy Consumption of the World and China from 1965 to 2011 17
Figure 1.2 Per-Capita Energy Production and Consumption in China 18
Figure 1.3 Percentage of Net Energy Import over Total Energy Supply in China 19
Figure 1.4 Growth in GDP per capita and Motor Vehicles in China: 1990-2010 20
Figure 1.5 Motorized Vehicle Ownership of Urban Households in China from 1990 to 2010 21
Figure 1.6 Household Appliance Ownership of Urban Households in China 22
Figure 2.1 "Lifestyle-oriented" Energy and Emission Model Structure 27
Figure 2.2 The "Needs-Opportunities-Abilities" Model of Consumer Behavior by Vlek et al., 1997 29
Figure 2.3 Causal Pathways between Urban Form and Residential Energy Consumption 35
Figure 2.4 Conceptual Framework for Residential Energy Consumption by Guerra-Santin, 2011 41
Figure 2.5 Theoretical Model of Residential Energy Use by van Raaij and Verhallen, 1983b 42
Figure 2.6 Initial Theoretical Model of Urban Household's Direct Energy Consumption 44
Figure 3.1 Economic Growth and Urbanization in Jinan from 1976 to 2010 46
Figure 3.2 Vehicle Portfolio of Urban Household in Jinan from 2000 to 2010 47
Figure 3.3 Housing Investment and Living Area Per Capita in Jinan from 2000 to 2010 48
Figure 3.4 Real Estate Market Price and Income Growth Trend in Jinan from 2000 to 2010 48
Figure 3.5 Length of Urban Road and Road Area Per Private Car in Jinan 49
Figure 3.6 Jinan BRT System Map (2012) 50
Figure 3.7 Numbers of Buses and Taxis in Jinan 50
Figure 3.8 Citywide Residents' Energy Consumption in Jinan 51
Figure 3.9 Analytical Challenges and Methods Adopted 56
Figure 3.10 MNL Model Structure 59
Figure 3.11 Latent Class Choice Model Structure 60
Figure 3.12 Model Structure for SEM Approach (a): with Latent Variable but no IV's 61
Figure 3.13 Model Structure for SEM Approach (b): with Latent Variable and IV's 62
Figure 3.14 Model Structure for SEM Approach (c): with IV's but no Latent Variable 63
Figure 3.15 GIS information Collected in a Sample Neighborhood in Jinan 67
Figure 3.16 Interviewee Household Characteristics 70
Figure 4.17 Hierarchy of Lifestyle Concept 73
Figure 4.18 Lifestyle Hierarchy of Direct Energy Consumption 88
Figure 4.19 Influence of Neighborhood Design on the Lifestyle Hierarchy 91
Figure 4.20 The Experience/habit Channel of Lifestyle Change 94
Figure 5.1 Vehicle Ownership of Urban Residents in China from 1990 to 2010 99
Figure 5.2 China Urban Household Motorized Vehicle Ownership Trend from 1990 to 2010 . 100
Figure 5.3 Household Vehicle Ownership in Jinan by Neighborhood Type 103
Figure 5.4 Household Vehicle Portfolio Ownership Pattern in Jinan by Neighborhood Type .. 103
Figure 5.5 Household Vehicle Portfolio Ownership in Surveyed Neighborhoods in Jinan 104
Figure 5.6 Household Income Distribution in Jinan by Neighborhood Type 105
Figure 5.7 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Household Income Level 112
Figure 5.8 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With/Without Child 113

Figure 5.9 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With/Without Older Adult ... 113
Figure 5.10 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With Access to Company Car ... 114
Figure 5.11 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, Renting Home or Not ... 114
Figure 5.12 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Housing Unit Area ... 115
Figure 5.13 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Residential Density ... 116
Figure 5.14 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Underground Parking ... 116
Figure 5.15 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Surface Parking ... 117
Figure 5.16 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Average Building Footprint ... 117
Figure 5.17 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Average Distance between Neighborhood Entries ... 118
Figure 5.18 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Roads with Trees ... 118
Figure 5.19 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Residential Buildings with Street-level Shops ... 119
Figure 5.20 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Roads with Walking Facilities ... 119
Figure 6.1 "Lifestyle Bundle Structure" in the Theoretical Model ... 121
Figure 6.2 Stylized Presentation of Likelihood of Residential Condition over a Household's Life Course ... 122
Figure 6.3 Histogram of Housing Unit Size (<300 m^2) ... 124
Figure 6.4 Lifestyle Bundle Choice Structure ... 124
Figure 6.5 Lifestyle Bundle Pattern in Jinan Sample ... 126
Figure 6.6 Lifestyle Bundle Pattern by Neighborhood Type ... 128
Figure 6.7 Household Vehicle Portfolio Probabilities: Simulated Variation by Household Income Levels (MNL) ... 130
Figure 6.8 Housing Unit Size Probabilities: Simulated Variation by Household Income Level (MNL) ... 130
Figure 6.9 Household Vehicle Portfolio Probabilities: Simulated Variation by Underground Parking (MNL) ... 130
Figure 6.10 Housing Unit Size Probabilities: Simulated Variation by Underground Parking (MNL) ... 131
Figure 6.11 Household Vehicle Portfolio Probabilities: Simulated Variation by Percentage of Roads with Walking Facilities (MNL) ... 131
Figure 6.12 Housing Unit Size Probabilities: Simulated Variation by Percentage of Roads with Walking Facilities (MNL) ... 131
Figure 6.13 Choice Pattern of Three Classes in the LCM ... 134

Figure 6.14 Household Vehicle Portfolio and Housing Unit Size Probabilities (Class-specific Models): Simulated Variation by Household Income for Three Classes of Households (Budget-oriented, top row; Typical urban, middle row; Amenity-oriented, bottom row) 137
Figure 6.15 Household Vehicle Portfolio Probabilities: Simulated Changes due to Combined Class Membership and Choice Model Effects of Household Income (LCM) 139
Figure 6.16 Housing Unit Size Probabilities: Simulated Changes due to Combined Class Membership and Choice Model Effects of Household Income (LCM) 139
Figure 6.17 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Underground Parking (LCM) 140
Figure 6.18 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Underground Parking (LCM) 140
Figure 6.19 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Surface Parking (LCM) 141
Figure 6.20 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Surface Parking (LCM) 141
Figure 6.21 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Trees (LCM) 142
Figure 6.22 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Trees (LCM) 142
Figure 6.23 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Walking Facilities (LCM) 143
Figure 6.24 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Walking Facilities (LCM) 143
Figure 6.25 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Average Distance between Entries (LCM) 144
Figure 6.26 Housing Unit Size Simulation with Average Distance between Entries (LCM) 144
Figure 6.27 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income, by Company Car Access (LCM)... 145
Figure 6.28 Housing Unit Size Probabilities: Simulated Variation due to Household Income, by Company Car Access (LCM).. 145
Figure 6.29 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income, by Whether Renting (LCM) 146
Figure 6.30 Housing Unit Size Probabilities: Simulated Variation due to Household Income, by Whether Renting (LCM) 146
Figure 6.31 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income (Median Household Approach).. 147
Figure 6.32 Housing Unit Size Probabilities: Simulated Variation due to Household Income (Median Household Approach)... 147
Figure 7.1 "Energy Use" Component in the Theoretical Model 149
Figure 7.2 SEM Structure with Bundle Choice as IV's 150
Figure 7.3 Total Direct Energy Consumption in Jinan Neighborhoods by Type 151
Figure 7.4 Per Household Total Direct Energy Consumption Composition by Source 152
Figure 7.5 Per Capita Travel Energy Consumption in Jinan Compared with Other Cities 152
Figure 7.6 Breakdown of Travel Energy Consumption by Neighborhood Type 153
Figure 7.7 Per Capita In-home Energy Consumption in Jinan Compared with Other Countries 154
Figure 7.8 Breakdown of In-home Energy Consumption by Neighborhood Type 155

Figure 7.9 Household's Direct Energy Consumption in Jinan Sampled Neighborhoods 156
Figure 7.10 Household Total Direct Energy Use: Simulated Variations by Household Income 162
Figure 7.11 Household Total Direct Energy Use: Simulated Variations by Underground Parking 162
Figure 7.12 Household Total Direct Energy Use: Simulated Variations by Surface Parking ... 163
Figure 7.13 Household Total Direct Energy Use: Simulated Variations by Building Height Irregularity 163
Figure 7.14 Household Total Direct Energy Use: Simulated Variations by Average Building Footprint 164
Figure 7.15 Household Total Direct Energy Use: Simulated Variations by Façade Continuity 164
Figure 7.16 Household Direct Energy Consumption: Simulated Variations by Household Income 169
Figure 7.17 Household Direct Energy Consumption: Simulated Variations due to Household Income, With Kids or Not 169
Figure 7.18 Household Energy Consumption: Simulated Variations due to Household Income, With Seniors or Not 170
Figure 7.19 Household Direct Energy Consumption: Simulated Variations due to Household Income, Renting or Not 170
Figure 7.20 Household Direct Energy Consumption: Simulated Variations due to Household Income, Access to Company Car 171
Figure 7.21 Household Direct Energy Consumption: Simulated Variations by FAR 171
Figure 7.22 Household Direct Energy Consumption: Simulated Variations by Underground Parking 172
Figure 7.23 Household Direct Energy Consumption: Simulated Variations by Surface Parking 172
Figure 7.24 Household Direct Energy Consumption: Simulated Variations by Building Footprint 173
Figure 7.25 Household Direct Energy Consumption: Simulated Variations by Façade Continuity 173
Figure 7.26 Household Direct Energy Consumption: Simulated Variations by Entry Interval Distance 174
Figure 7.27 Household Direct Energy Consumption: Simulated Variations by Percentage of Roads with Walking Facilities 174
Figure 7.28 Household Direct Energy Consumption: Simulated Variations by Percentage of Road with Trees 175
Figure 7.29 Household Direct Energy Consumption: Simulated Variations by Percentage of Roads with Street-level Shops 175
Figure 7.30 Household Travel Energy Consumption: Simulated Variations by Household Income (Candle Stick Graph) 176
Figure 7.31 Household In-home Energy Consumption: Simulated Variations by Household Income (Candle Stick Graph) 176
Figure 8.1 Flowchart of Planning Process in Chinese Cities 181
Figure 8.2 A Model for Lifestyle and Behavior Change Policy 182
Figure 8.3 Household Energy Reduction Potential of Neighborhood Design Indicators 184
Figure 8.4 Forms with Different Continuity and Footprint 185

Figure A.1 Input of the "Energy Proforma" Tool 201
Figure A.2 Sample Output of the "Energy Proforma" Tool 202

List of Tables

Table 3.1 Summary of Form Features across Four Neighborhood Typologies in Jinan 52
Table 3.2 Summary Statistics of Variables in the Jinan Household Survey................................ 66
Table 3.3 Summary Statistics of Neighborhood Design, Form and Location Indicators 68
Table 3.4 Comparison of Household Characteristics of Sample and Population 71
Table 4.1 Lifestyle Group Characteristics and Possible Indicators 97
Table 5.1 City Comparisons of Vehicle Ownership (2006 data) 100
Table 5.2 Vehicle Portfolio Ownership Estimation with Household SED Characteristics 106
Table 5.3 Vehicle Portfolio Ownership Estimation with Residential Choice 108
Table 5.4 Vehicle Portfolio Ownership Choice Model Result with Neighborhood Design Indicators 111
Table 6.1 Categories of Housing Unit Size 123
Table 6.2 Means of Selected Household Characteristics by Bundle Choice 127
Table 6.3 MNL Estimation Result 129
Table 6.4 LCM Class Membership Model Result [a] 132
Table 6.5 LCM Choice Model Result 133
Table 6.6 Membership Profile (Means of Explanatory Variables) in LCM 135
Table 7.1 Lifestyle Bundle Choices as Instrumental Variables 159
Table 7.2 OLS Estimation Result on Total Direct Energy Consumption (ln[MJ]) 160
Table 7.3 Model Summary and Regression Coefficient Estimations of SEM 166
Table 7.4 Elasticity of Energy Consumption 167
Table 7.5 Simulated Effects of Dummy Variables on Household Energy Consumption 168
Table A.1 Jinan Public Transit Operation Performance Statistics 190
Table A.2 Energy Intensity Factors 191
Table A.3 Factor Values for Gas-related Energy Calculation 191
Table A.4 Summary of Interviewee Household Characteristics 194
Table A.5 Correlation Matrix of Independent Variables in the OLS Model..............................195
Table A.6 Standardized Coefficient Estimation... 197
Table A.7 Covariance Estimation for SEM 198

Chapter 1 Introduction

1.1 Background and Research Question

1.1.1 Global and National Challenge for Sustainable Energy Consumption

Energy is a crucial production factor and strategic resource for an industrial society (Wei et al., 2009). The scarcity of non-renewable resources, notably coal and oil, and climate change concerns due to related greenhouse gas emissions, have made meeting energy demand sustainably one of the greatest challenges the world has ever faced. China today accounts for almost a quarter of global greenhouse gas emissions (Steckel et al. 2011), and the International Energy Agency (IEA 2009) has estimated that about half the growth in global energy-related carbon dioxide (CO_2) emissions from now until 2030 will come from China (SEI report, 2012).

During the first twenty years since the economic reforms and opening up of its economy in the late 1970s, China was able to keep energy consumption relatively low while sustaining a rapid economic growth (Figure 1.1). However, from 2002, China's energy consumption growth rate began to outpace that of the world. After topping the list of CO_2 emitting countries in 2006 (PBL, 2007), China overtook the United States and became the world's largest energy consumer in 2009 (IEA, 2010). In 2011, China consumed 21.3% of world's total primary energy (BP, 2012), and maintained a steady growth rate of more than 8% even when the world's economy was in recession.[1]

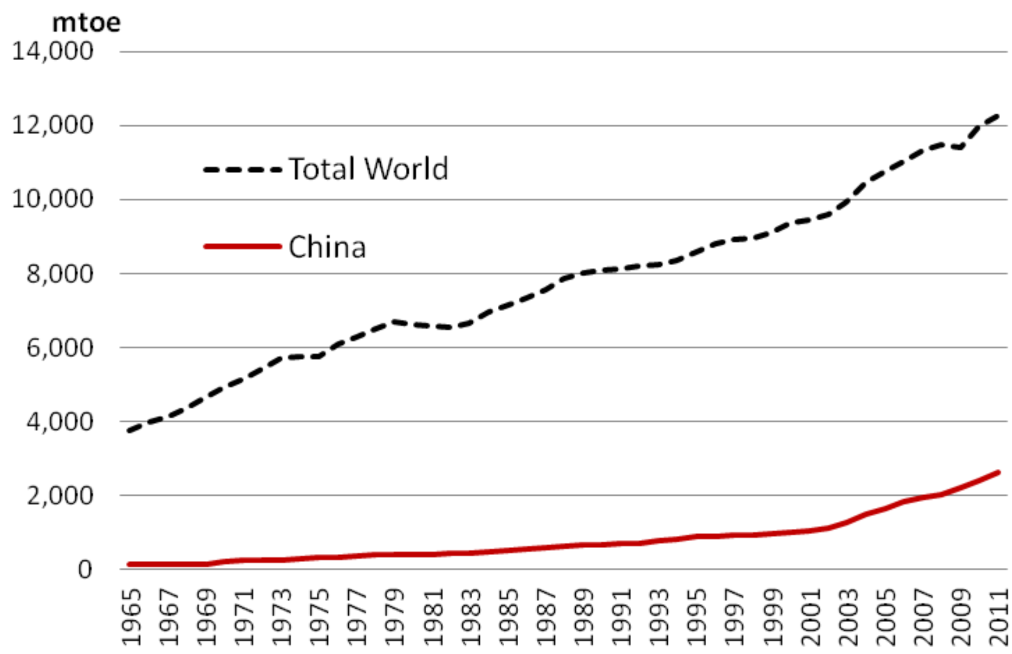


Figure 1.1 Primary Energy Consumption of the World and China from 1965 to 2011

Data Source: BP Statistical Review of World Energy 2012

Facing this energy demand challenge, China's energy efficiency measures have focused on heavy industry with considerable resources spent to improve industrial energy efficiency

[1] China's primary energy consumption increased by 8.7% while the world's total consumption declined (BP, 2010).

since the passage of the Energy Conservation Act in 1997.[2] Chinese energy consumption began exceeding production in the early 1990s and, despite the Chinese government's measures to reduce the economy's energy intensity, per-capita energy consumption began to sharply increase since 2002 (Figure 1.2), exhibiting a strong demand-side force that outweighs the substantial supply-side efforts such as industrial restructuring, technological innovation, or renewable energy development. Given the current still relatively low level of per-capita energy consumption compared to the OECD countries (less than 1/3 of the OECD average),[3] we expect to see this rapid "catch-up" growth in energy consumption to continue. As a result, we can expect the trend to continue of China relying more and more on energy production from abroad to meet its escalating energy demand (Figure 1.3). In 2009, 13.4% of China's total primary energy supply was imported, net (IEA, 2010).

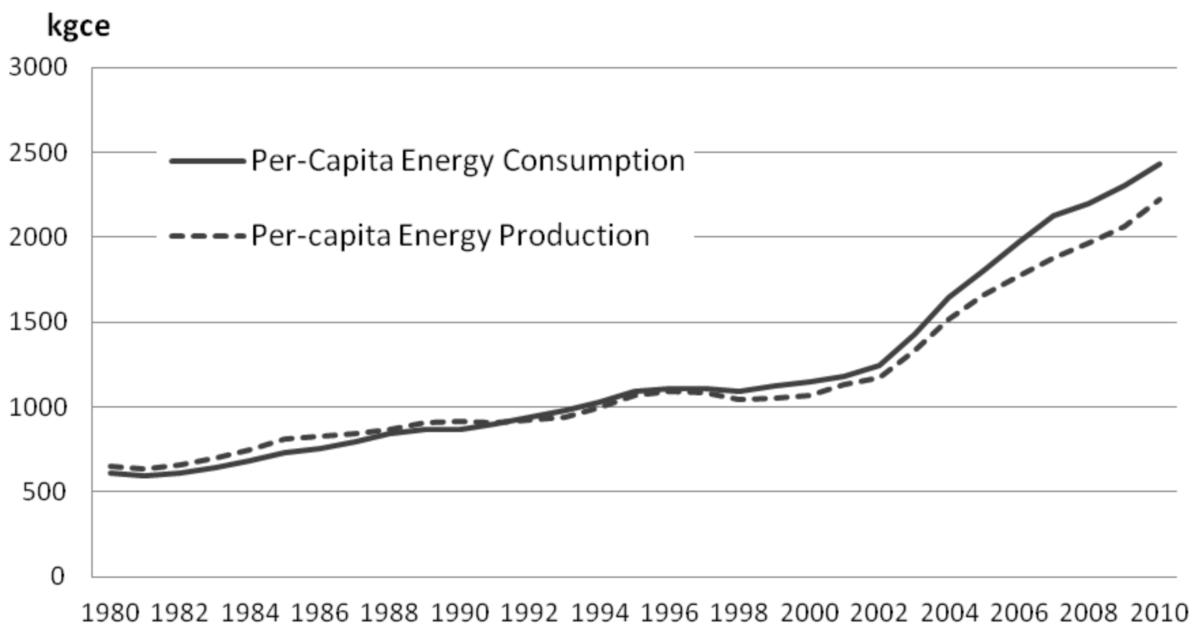


Figure 1.2 Per-Capita Energy Production and Consumption in China

Data Source: China Energy Statistical Year Book 2011

---

[2] China Daily, 2010, China should choose low-carbon urbanization, www.chinadaily.com.cn/china/2011npc/2010-11/05/content_12074102.htm; and Lei, Hongpeng, Zhuang Guiyang & Zhang Chu, 2011, Understanding Low-Carbon City Development in China: Strategy and Method, Beijing: China Environmental Science Press, http://www.wwfchina.org/wwfpress/publication/climate/lowcity_report.pdf, last accessed on June 10, 2011. Full content of the 1997 Energy Conservation Act see: http://www.law-lib.com/law/law_view.asp?id=364, last accessed on July 8, 2012

[3] International Energy Agency (IEA Statistics © OECD/IEA, http://www.iea.org/stats/index.asp), and China Energy Statistical Year Book 2011

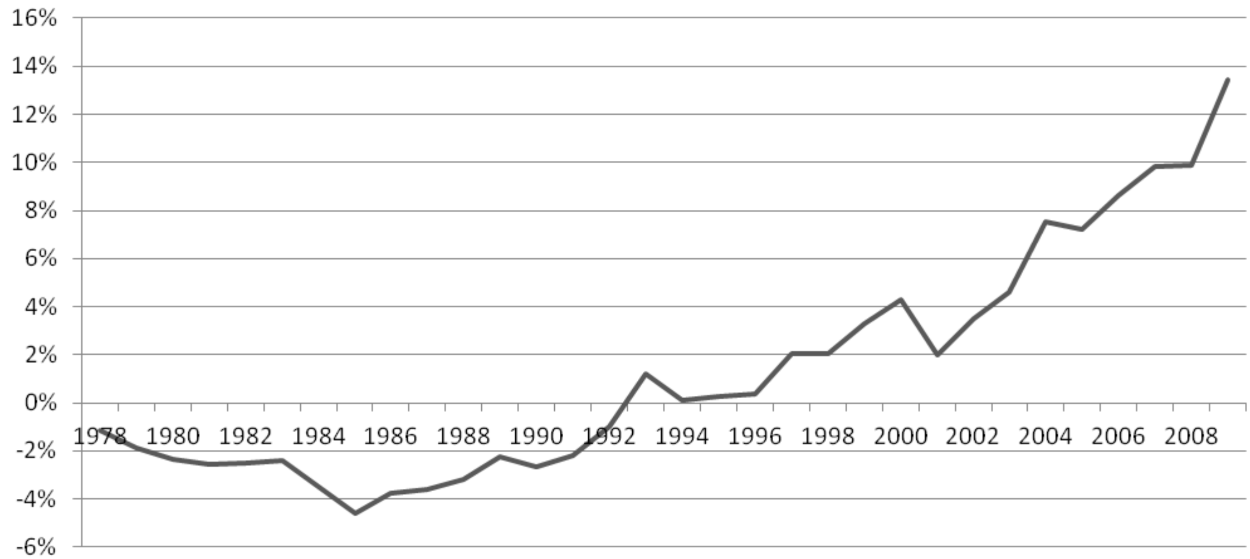


Figure 1.3 Percentage of Net Energy Import over Total Energy Supply in China

Data Source: IEA (2010), "World Indicators", IEA World Energy Statistics and Balances (database)

Supply-side measures alone cannot likely be the solution to China or the world's energy challenge. As such, better understanding the demand-side is necessary to design relevant policies to potentially influence the behaviors of energy end-users. Towards this end, and undertaken as part of the "Making the Clean Energy City in China" project (MIT, 2012), this dissertation takes a first step to understanding the potential role of urban design in helping to meet residential energy demand sustainably. Specifically, I aim to answer the question: ***how does neighborhood design influence household's direct energy consumption in Chinese cities***?

In-home energy use and personal travel are the two main direct sources of household energy consumption, and they are the focus of this research. In rapidly developing countries like China, urbanization and motorization are probably the two major forces driving up domestic energy demand (e.g., Figure 1.4 shows how the recent exponential growth of private motor vehicles in China has been exceeding the nation's economic growth rate).

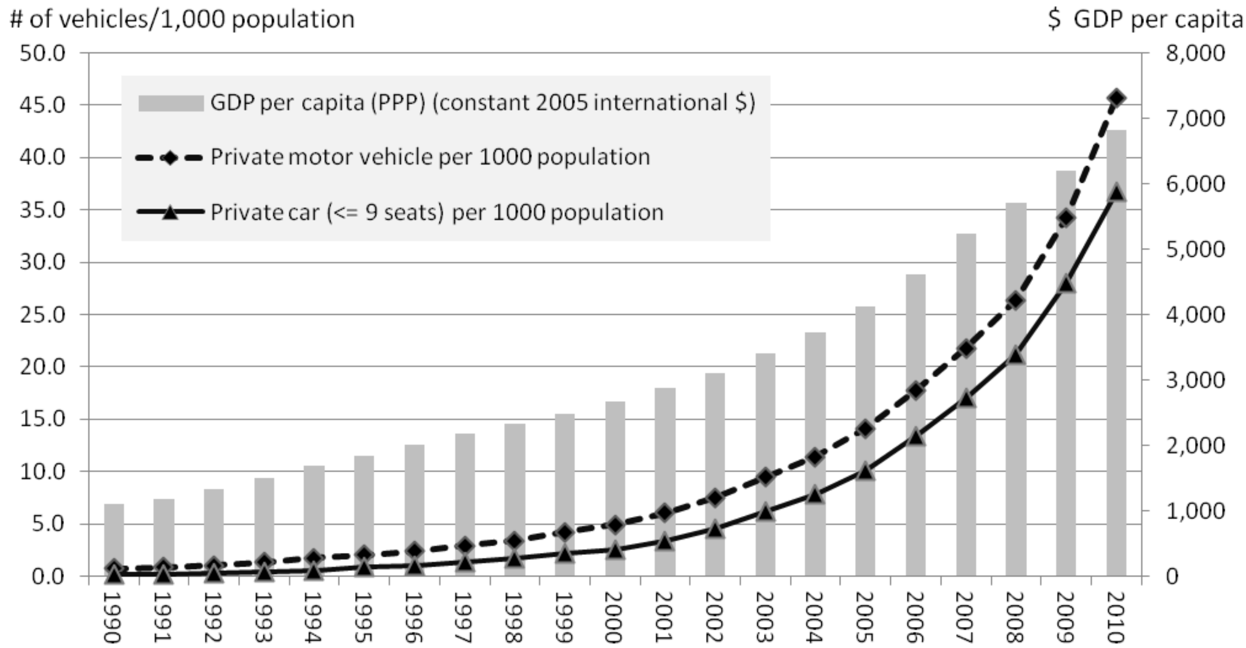


Figure 1.4 Growth in GDP per capita and Motor Vehicles in China: 1990-2010

Data Source: Vehicle number and population data: China Statistical Year Book 2007 to 2011; PPP data: World Bank, International Comparison Program database

When China's economy opened up in 1978, the urbanization rate was merely 18%. By the end of 2011, China's urban population reached 690 million, exceeding rural population for the first time (China NBS, 2012). It is expected that by 2030 there will be one billion people living in Chinese cities (McKinsey, 2009). With higher incomes and access to expanding urban infrastructure, people in cities have much higher direct energy demand than their rural counterparts due to higher ownership of motorized vehicles and home appliances,[4] and probably more usage.[5] How shall we design neighborhoods in cities to accommodate these urban households in a sustainable way in terms of energy use? Does neighborhood design have any effect on residents' energy consumption? In this research, I attempt to help answer these questions.

In academia, although abundant studies and practices focus on energy efficiency at metropolitan and building scales, fewer studies have been undertaken at the "urban development" scale, i.e. "the scale of neighborhoods, commercial districts, and real estate projects, which are the fundamental building blocks of urban growth."(MIT, 2012) Furthermore, few studies consider in-home energy and travel energy together, using empirical evidence. This research aims to fill these blanks in the literature, by developing and testing, with empirical evidence from China's urban context, a theoretical framework to integrate the two main sources of household's direct energy consumption so that policy suggestions can be made on the energy-related benefits of urban planning and design guidelines.

[4] This claim is supported by results of the Urban and Rural Residents' Survey on durable goods ownership provided by China Statistical Year Books (NBS, 2012).

[5] Urban residents in China use 1.5 to 5 times the residential energy of rural residents on a per capita basis, according to data from 1980 to 2010 in the China Energy Statistical Year Book 2011 (NBS, 2012).

1.1.2 Lifestyle, Lifestyle Bundle, Lifestyle Group, and Neighborhood Design

Lifestyles, the ways of living adopted by individuals or groups, consist of patterns of consumption, activities, attitudes, preferences, and values. The meanings and contents of "lifestyle" vary according to different purposes (see Chapter 2 for detailed discussion). In this research, lifestyle is the centerpiece concept, connecting neighborhood design to urban residents' direct energy consumption. I adopt Weber's insight that the central feature of lifestyle is the dialectical interplay of choice and chance (Weber, 1968), keeping my focus on only those aspects (behaviors, attitudes, preferences, and values) related to households' energy consumption. The concepts of *lifestyle bundle* and *lifestyle group* of urban residents are in turn defined in that manner.

Lifestyle is revealed by consumption. Twenty years ago, the average urban resident in China had a disposable income of 1,510 yuan (US $284) per year, which increased to 6,280 yuan (US $758) ten years ago, and 19,109 (US $2,986) today;[6] the average living area per urban resident was 13.7 m^2, 20.3 m^2, and 31.6 m^2 in 1990, 2000, and 2010, respectively (NBS 1991, 2001, and 2011). As people in the cities get richer, they demand bigger homes, more appliances (Figure 1.6), private cars (Figure 1.5), and more of the unprecedentedly vast number and variety of other consumer products. In short, some fundamental lifestyle change is taking place under China's transition to a market economy; this will continue contributing to increases in the nation's energy demand.

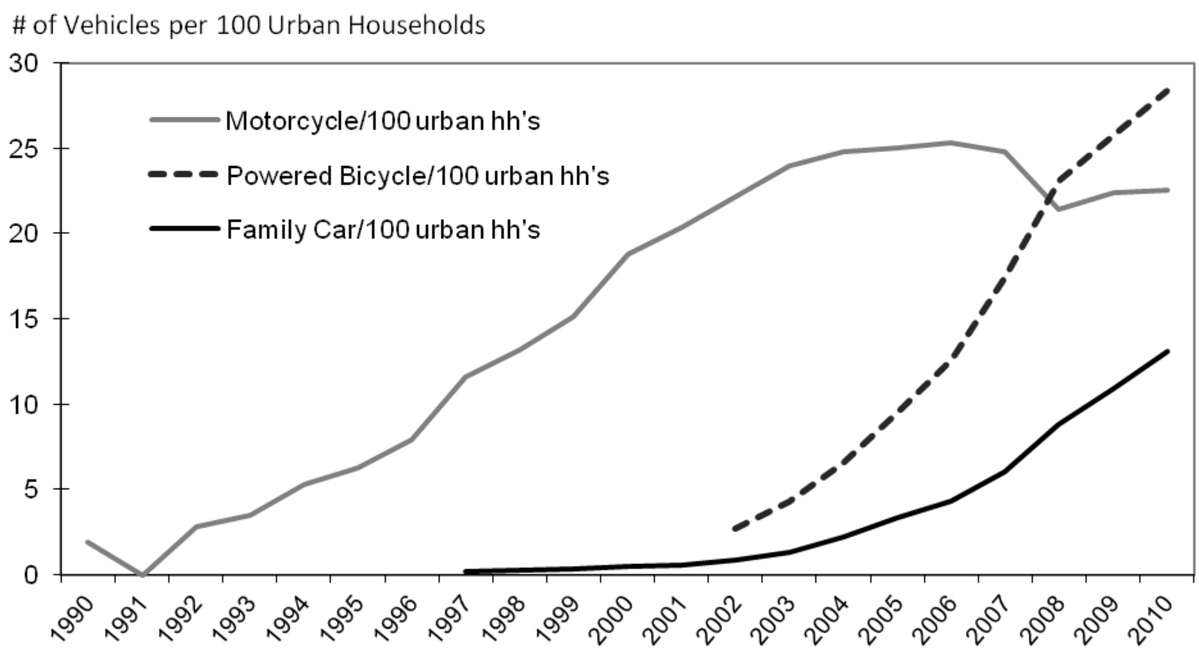


Figure 1.5 Motorized Vehicle Ownership of Urban Households in China from 1990 to 2010

Source: author's calculation based on China Statistical Year Book 2007, 2008, 2009, 2010, and 2011

[6] Unless otherwise noted, all rmb yuan are converted to US $ using nominal exchange rate at that year.

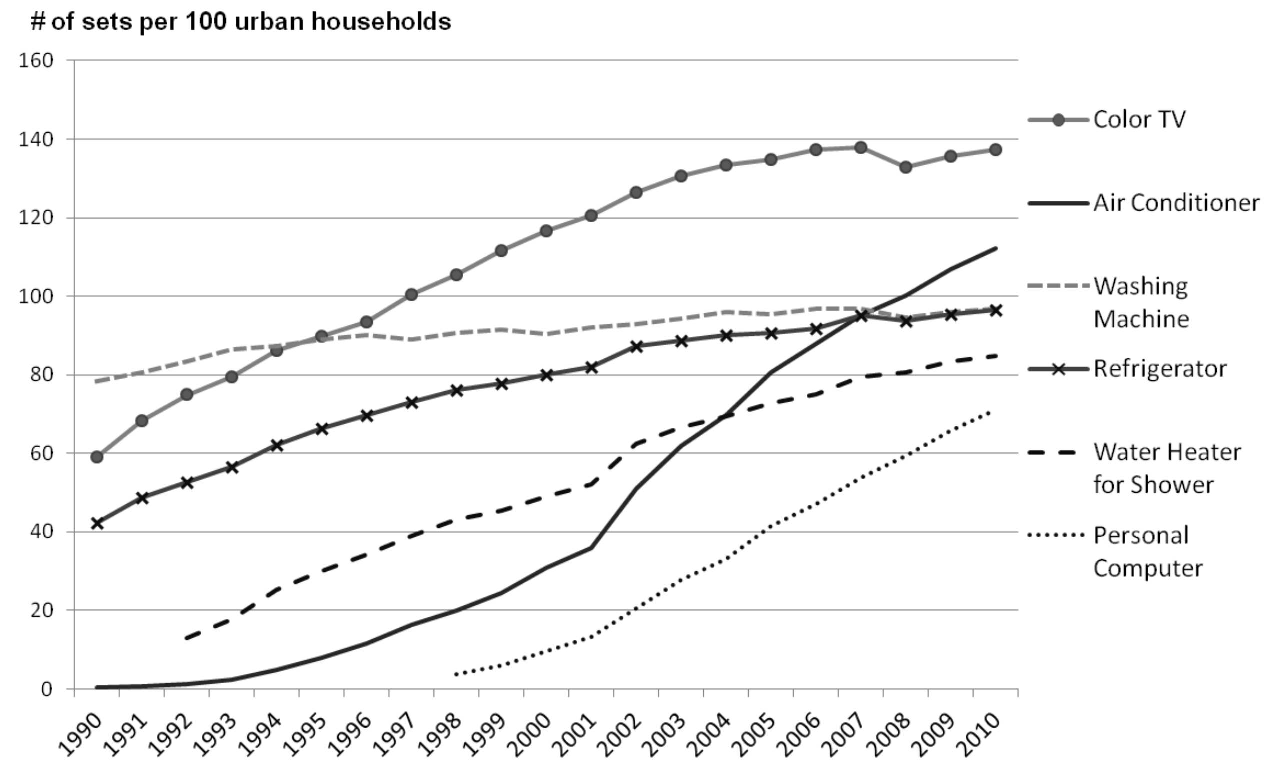


Figure 1.6 Household Appliance Ownership of Urban Households in China

Source: author's calculation based on China Statistical Year Book 1991-2011

Chinese people say that daily life is nothing but "clothing, food, residence, and travel." For a typical urban household in China, a home and a motorized vehicle are the two most expensive durable goods it normally purchases, reflecting two important aspects of lifestyle the household chooses. Households make decisions on whether to buy a home, where to live (neighborhood), and what kind of unit to occupy, decisions which condition the type and quantity of home appliances (centralized heating, air conditioning, etc.) and, in turn, in-home energy use. These first-order residential choices a household makes (hereafter I use the term "residence" or "residential choice" to include all aspects of these choices) are considered at the same level/order of decision as the household's vehicle ownership choice, i.e. how many and what types of vehicles to own. Household vehicle ownership is the base for household mobility, conditioning the mode choice of household members, and in turn transportation expenditures and energy consumption for personal travel. Personal mobility and residential location are also intertwined. On one hand, households select residential locations at least partly "based on their travel abilities, needs and preferences" (Litman, 2005); on the other hand, where a household resides potentially influences its accessibilities, travel demand and therefore vehicle needs. Both residential choice and vehicle ownership choice are constrained by households' resources (e.g. income) and influenced by households' lifestyle preferences. The existence of the "self-selection" issue in the built environment and travel behavior literature (see Cao and Handy, 2009 for a complete review) essentially shows the same point, that there are unobserved factors (attitudes, or lifestyle preferences) that influence both people's residential location choice and travel behavior—households choose ("self-select") to live, at least partly, in a neighborhood that facilitates travel options that fit their preferences. Therefore one important hypothesis I make is that urban households in China consider residence and vehicle ownership together, as they are considering buying into a certain type of lifestyle. I call this the household's "lifestyle bundle" choice.

Ultimately, in this research I am interested in seeing how policies related to neighborhood design might influence how urban households make their lifestyle bundle choice, which conditions both travel energy and in-home energy consumption. To understand how factors influence urban lifestyle and, in turn, households' ownership behavior and energy consuming behavior, I use "lifestyle group" to segment the households with different lifestyle preferences and values. Households belonging to a different "lifestyle group" may therefore have a different sensitivity in response to policies.

In theory, neighborhood design can influence households' lifestyle choice from two perspectives. First, it constrains the lifestyle choice: how a neighborhood is designed influences what alternatives households have, including attributes of residence and accessibility. Second, it shapes the choice-making process: how a neighborhood is designed also influences households' lifestyle preferences and habits. In other words, neighborhood design not only influences the attributes of the "lifestyle bundle", but it also influences which "lifestyle group" households belong to. As neighborhood design dictates some attributes of households' residence (e.g. a nice open space in the middle of an enclave) which makes certain activities or behaviors possible (e.g. people go downstairs and chat with neighbors after dinner), the routine practice of that activity or behavior becomes a pattern, and gets built into people's preference or value system (e.g. interaction with neighbors is important). In other words, it brings lifestyle change. Consider another example: if the existence of a big parking garage and an inconvenient pedestrian circulation system in a neighborhood makes driving much more comfortable than walking, this then reinforces driving behaviors while discouraging walking behaviors. After a period of time, the repeated good experience of driving and bad experience of walking will translate into more vehicle ownership and driving. The notion of "walking is inferior" gets built into the value system too. This proposition can also be explained by sociologist Bourdieu's concept of "habitus"—individuals' routine practices are influenced by the external structure of their physical and social world; these practices, in turn, contribute to the maintenance of that structure (Cockerham et al., 1997)

Empirically, whether and how neighborhood design influences households' lifestyle choice and direct energy consumption are the central research questions this dissertation tries to answer.

1.2 Thesis Organization

After this introduction, Chapter 2 explores the theories concerning lifestyle, neighborhood design, travel energy, residential energy, and their interactions. Literatures are reviewed and summarized to establish a theoretical model to understand these relationships.

Chapter 3 has two parts. The first part introduces the empirical setting: the case city of Jinan and the data available. Then, based on this research context, detailed research methods are discussed, including qualitative methods and quantitative methods.

Chapter 4 analyzes the qualitative results to understand how urban households in Jinan make residential and vehicle portfolio ownership choices. The concept of lifestyle and categories of lifestyle groups are identified from the interviews. Components of the theoretical model are then modified/validated, and three key hypotheses emerging from the interview results are proposed: (1) residential choice and vehicle ownership choice are an interdependent, bundled lifestyle choice; (2) there are four distinct lifestyle groups with different decision-making mechanisms; and (3) neighborhood design influences households' lifestyle choice, and possibly their lifestyle groups.

Based on the theoretical model proposed in Chapter 2, Chapters 5 to 7 utilize quantitative data collected in the case city of Jinan to test the hypotheses raised in Chapter 4 and to estimate the effects of various relevant factors. Chapter 5 explores the vehicle portfolio choice, supporting the hypothesis (1) empirically. Then, residential choice and vehicle portfolio choice is bundled together as the lifestyle bundle, modeled in Chapter 6. Chapter 6 uses different model structures and provides some support for hypothesis (2) using a Latent Class Model. The estimation results from the lifestyle bundle choice in Chapter 6 are then treated as instrumental variables in the energy consumption model in Chapter 7. In order to test the hypothesis (3) and understand the effects of neighborhood design on households' direct energy consumption, Chapter 7 presents estimates from a model for total direct household energy consumption and a model of travel and in-home energy consumption separately. Simulations are utilized to present the estimated effects of each neighborhood design variable.

Chapter 8 concludes the study, and makes policy implications in the context of low-carbon city development prospects in China. Contributions, limitations and future directions are also discussed.

Chapter 2 Theory and Evidence: Lifestyle and Urban Residents' Energy Consumption

As introduced in Chapter 1, this research tries to answer the question of how neighborhood design influences households' direct energy consumption in Chinese cities, examined through the concept of lifestyle and its link to residence and mobility. This chapter reviews relevant literature from various fields in order to build a theoretical model as a framework upon which hypotheses can be developed and tested and describes the general research approach.

2.1 A Review of Theories and Evidence on Lifestyle, Travel and Residential Energy Consumption, and Neighborhood Design

I draw upon five bodies of relevant theoretical, analytical, and empirical literatures: (1) approaches to energy analysis; (2) consumer theory and behavioral models from neoclassical economics, behavioral sciences, psychological studies, and urban economics with a particular focus on household location theory; (3) analyses of factors influencing travel behavior/energy use; (4) analyses of factors influencing residential energy use; and (5) elaborations of the concept of lifestyle.

2.1.1 Lifecycle Energy Analysis

Energy researchers have been paying more and more attention to the impact of consumer behavior or consumer lifestyle on energy consumption. Schipper et al. (1989) conclude that more than half of total energy use is influenced by consumers' activities for personal transportation, personal services, and homes.

Energy analysis was developed in the early 1970s and considers energy consumption throughout the life cycles of products (for overview and methods, see Boustead and Hancock, 1979). Energy analysis can be carried in the technical way, i.e. process analysis; and economic way, i.e. input-output analysis, or the combination of the two, called the hybrid analysis (Noorman and Uiterkamp, 1998). Household energy requirements can be determined by input-output analysis or the hybrid analysis using a simplified life cycle analysis (Wilting and Biesiot, 1998).

Life cycle analysis (LCA) assesses the impact of a product at all stages of its existence, from raw material production, manufacture, distribution, use, to disposal (ISO, 2006). The approach has been widely used by researchers to evaluate the energy consumption and GHG emission impact of residential buildings. A full building LCA includes three phases: construction, usage, and demolition. The usage phase can be divided into operations and maintenance, and essentially all research confirms that operational energy consumption is the most energy-consuming phase in a building's life cycle (Zhang, 2010). LCA is also applied in the transportation field. The LCA of transportation builds on an ad-hoc extension of the "net energy" analysis done in the late 1979s and early 1980s, which uses engineering methods to estimate the energy requirements throughout the fuel cycle, including the production, distribution, and use of fuels (Delucchi, 2004).

Input-output models are usually used to analyze the total energy requirement and impact of consumers' activities on energy consumption and greenhouse gas emissions, examples include

Vringer & Blok (1995) for the Netherlands, Lenzen (1998) for Australia, Weber & Perrels (2000) for West Germany, Netherlands, and France, and Pachauri et al.(2002) for India. Norman et al. (2006) provide an empirical assessment of energy use and greenhouse gas emissions associated with high and low residential development with two case studies from Toronto. An economic input–output life-cycle assessment (EIO-LCA) model is applied to estimate the energy use and GHG emissions associated with the manufacture of construction materials for infrastructure. The results show that low-density suburban development is more energy and GHG intensive (by a factor of 2.0–2.5) than high-density urban core development on a per capita basis.

Some scholars establish a framework to analyze households' energy consumption and lifestyle; among them are Bin & Dowlatabadi (2005)'s Consumer Lifestyle Approach and Weber & Perrels (2000)'s Lifestyle-oriented Energy and Emission Model structure.

Bin & Dowlatabadi (2005)'s Consumer Lifestyle Approach (CLA) and their estimation for the USA reveals that more than 80% of the energy used and the CO_2 emitted in the US are a consequence of consumer demands and the economic activities to support these demands. They define lifestyle as "a way of living that influences and is reflected by one's consumption behavior." The CLA framework has five components: (1) external environmental variables; (2) individual determinants, such as attitudes and beliefs; (3) household characteristics, such as household size, housing type and size, income and location; (4) consumer choices, such as purchases and use of services and equipment; and (5) consequences, such as resource use and related environmental impacts. In their study they only quantify the relationship between consumer choices and consequences at a macro-level. The Environmental Input-Output Life Cycle Analysis (EIO-LCA) model developed at Carnegie Mellon University is used as part of their analysis for indirect energy consumption (Bin & Dowlatabadi, 2005). Wei et al. (2005) employs a framework similar to EIO-LCA and uses national-level data from China. Their estimates show that residents' lifestyle choices and economic activities to support their demand account for 26% of total final energy use in China (in 2002). For urban residents, residence (building) and in-home energy use take the largest shares of the energy use caused by lifestyles (26% and 15%, respectively), while personal travel (only car and motorcycle travel are considered, calculated using national-level vehicle ownership statistics) accounts for a mere 1.5%.

Weber & Perrels (2000) subscribe to the hypothesis that in the context of domestic energy use, lifestyle can be identified by means of expenditure patterns, specifically: household patterns of equipment ownership, expenditures of time and money, and energy use. They establish a comprehensive model structure (Figure 2.1) to model household behavior in detail, accounting for all aspects of energy-relevant household consumption in an integrated way. Individual household level data for West Germany, the Netherlands, and France are used and 11 different household types are distinguished (e.g. young singles, young couples, middle-aged families, etc.) to account for the impact of the household's position in the lifecycle on consumption. The study shows that more than half of the total energy consumption induced by household consumption is related to direct household energy use. Using a series of different models (e.g. discrete choice models for electricity use and motor fuels, ad-hoc expert opinion-based penetration curve or reasoned substitution mechanism for new appliance ownership, regression for usage, input-output analysis for indirect energy use), influences of different factors on households' energy use are estimated. For example, the study finds that building insulation standards issued in the past are far less effective than presumed and car use turned out to be influenced mostly by income, although model explanatory power was weak partly due to lack of spatial data. Indirect energy is calculated from household expenditures (Weber & Perrel, 2000).

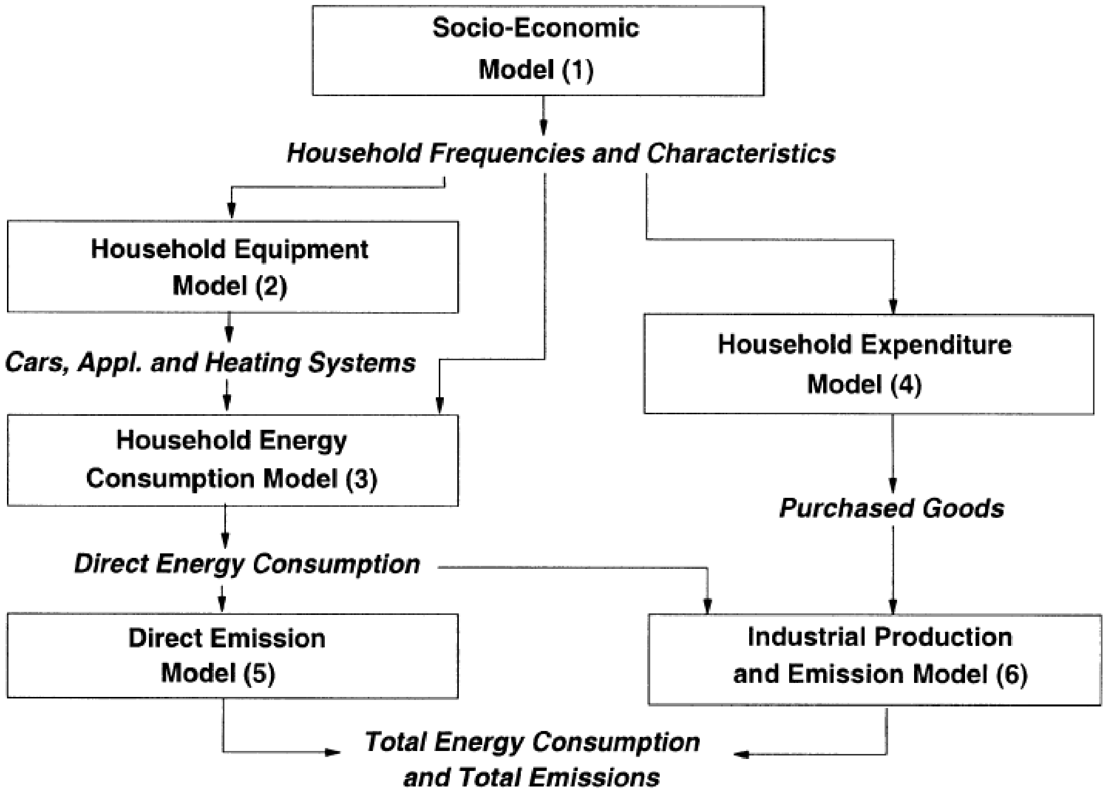


Figure 2.1 "Lifestyle-oriented" Energy and Emission Model Structure

Adopted from Weber & Perrels (2000)

While lifecycle analysis accounts for all energy consumption throughout the lifecycle of products, my research only concerns direct energy consumption, i.e. the energy consumption of end-users (left part of Figure 2.1) including personal travel and in-home energy use, but not the energy used during the production or distribution of products, i.e. the "embodied energy" (right part of Figure 2.1).

2.1.2 Consumer Behavior and Location Choice

In microeconomics, demand functions for consumer goods come from consumer choice theory, based on the assumption of rational decision makers seeking utility maximization within a budget constraint (Marshall, 1920; Hicks & Allen, 1939). Classical consumer choice theory informs us that the choice of a good is influenced by two components: the budget constraint as the objective component, and the utility function (or, consumer's preference) as the subjective component. For the choice made between two goods, certain types of consumers are assumed to have certain shaped indifference curves, representing different levels of utility, or the satisfaction levels the consumer can reach. The budget constraint is represented using a straight line decided by the prices of the two goods. The consumer maximizes utility at the point where the indifference curve is tangential to the budget line, indicating the same marginal utility gain per dollar spent on the two goods. The quantities of the two goods the consumer chooses, or the “best bundle” of the two goods, will change if the budget or the relative price of a good changes, i.e. the income effect, and the substitution effect, respectively.

Traditional household location choice theory builds from this classic microeconomic consumer theory and implies a close connection between residence and mobility. Alonso (1964), drawing from von Thünen’s original model of land rent for agricultural activities, derives the theory of a bid rent function for urban location choices, whereby a utility-maximizing agent chooses among land rent, property size, commuting cost (based on distance to a central business distance (CBD)), and the costs of all other goods and services. Faced with a budget constraint, the agent trades-off rent and property size at different locations for commuting costs. If travel costs go down, the theory predicts movement away from the center, or population decentralization, with a greater effect for higher-income households. From then on, classical static urban economic theory-based models reflect residential location choice as a tradeoff among three basic factors: accessibility (pecuniary and time costs), space (land, size of house), and environmental amenities (scenic views, safety, quality of school), subject to budget and time constraints (Fujita, 1989).

Relevant extensions to the above classical consumer behavior model include the incorporation of non-monetary or non-economic factors that might influence consumer behavior. Lancaster (1971) introduces characteristics space instead of goods space for consumer choice, assuming that consumers derive utility from a product’s attributes. Household production theory (Becker, 1965) assumes that households are producers as well as consumers, with households producing “products” that household members attach value to, using time, a scarce resource, as a production factor. In household production theory, utility maximization becomes profit maximization, and the budget constraint includes both money and time. The unitary model treats the household as a single agent trying to maximize the “family utility function,” while the non-unitary model explicitly supposes that households consist of different members with different preferences (Muellbauer, 1974).

Taking a different theoretical path, with the belief that a boundedly rational consumer makes choices by satisficing instead of optimizing, behavioral economists developed several theoretical procedures (or rules) consumers might use to make decisions: (1) a “satisficing expectancy value rule” whereby a decision maker stops searching if one choice satisfies the pre-set requirements of all aspects; (2) an “additive differences satisficing rule,” by which a decision maker keeps the best option by comparing the most recently investigated options; (3) a “characteristics cut-offs expectancy value rule,” by which a decision maker cuts off the option that does not satisfy the minimum requirements in some aspect; (4) a “simple average rule” by which a consumer rates options in respect of each attribute and adds the scores together; (5) the “polymorphous satisficing rule,” by which the decision maker accepts the option that meets a sufficient number of unordered target characteristics; and, two non-compensatory rules, (6) the “conjunctive rule” in which the decision maker searches and accepts the first option meeting all requirements, and (7) a “characteristic filtering” rule by which the decision maker rules out options in a particular order of priority until only one is left (Earl, 1986).

Other relevant theories and models on consumer behavior include the "Needs-Opportunities-Abilities" (NOA) model from psychological research, to study household consumption and environmental impacts (Figure 2.2). The model presumes that people have certain needs that they can satisfy only when they have the ability and the opportunity to do so (Noorman & Uiterkamp, 1998). By this theory, opportunities (e.g., having the opportunity to buy) can also evoke motivations (e.g., the desire to buy); opportunities also influence people's behavioral controls on consumption. This provides a theoretical basis for the possibility that alternative neighborhood design (as an opportunity provided) influences households' consumption behavior. Although this "NOA" framework shows only one direction – that of the consumer's setting (top box in Figure 2.2) influencing behavior and lifestyle – in reality there is a potential feedback loop that households' consumption behavior and lifestyle also influence their consumer settings by influencing, for example, the place they choose to live, which further influences the NOAs. In addition, people may also opt into particular consumer settings due to desired consumption levels.

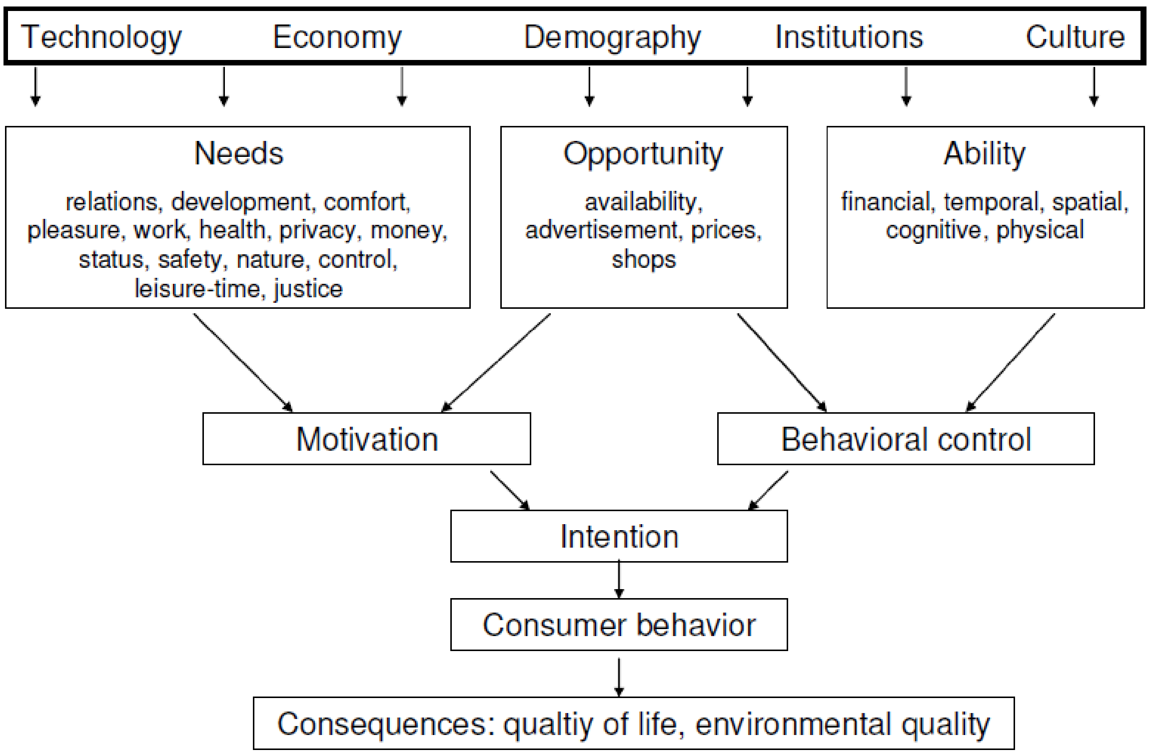


Figure 2.2 The "Needs-Opportunities-Abilities" Model of Consumer Behavior by Vlek et al., 1997

Adopted from Noorman & Uiterkamp, 1998

To sum up, neoclassical consumer choice theory and its extensions provide us with a basic framework to understand the factors influencing consumer behavior and the basic utility maximization framework to model it. Classical household location choice theory in urban economics suggests a strong link between residential choice and mobility choice via: (1) accessibility; (2) property size and other location-related amenities; (3) rents; and (4) budget and time constraints. Consumer theory in behavioral sciences reveals additional possible mechanisms behind consumer behaviors. The psychological model of consumer behavior offers the insight of how decisions are made and potential opportunities for change.

2.1.3 Form and Travel

The literature on the links between the built environment/urban form and travel behavior is particularly relevant to this research for two reasons. First, the theoretical basis or causal mechanisms linking urban form to travel behavior could be similar to the one that links neighborhood design to lifestyle bundle and direct energy use. Second, the ongoing empirical investigations into the role of "self-selection" relates directly to the hypothesis that residential choice and travel behavior (including vehicle ownership choice) are interdependent and are possibly made jointly by households. This section will first discuss the theoretical foundations for and empirical results regarding the relationship between form and travel behavior including those in the developing country context, specifically in China, as well as the theoretical ambiguity and empirical challenges due to self-selection and rebound effect.

Behavioral theory from transportation economics says that travel is influenced by the attractiveness of potential destinations and the friction of distance, or costs, by different modes to those destinations (Beinborn, 1979; Lloyd & Dicken, 1977). Since urban form/design affects the geographical distribution of buildings, the mutual location of functions within the building stock (Næss, 2006), and the layout and functionality of transport networks and supply, it could influence both the attractiveness of destinations and the relative costs of travel by different modes; urban form, therefore, may theoretically influence people's travel behavior. Crane (1996) draws directly from microeconomic consumer theory to demonstrate that travel demand can be linked to the built environment by explicitly affecting relative trip costs by different modes, which suggests an ambiguous effect of urban form on travel because it depends on how the consumer responds to changes in costs (an empirical question). Maat et al. (2005) extend from Crane to present a net utility-based theory of travel demand, positing that people maximize net utility (consisting of the utility of the activities realized by traveling and the *dis*-utility implied by the time and money costs of bridging the distance to an activity location). The net utility perspective adds further ambiguity to determining, ex-ante, the net influence of the built form on travel behavior. In short, consistent with consumer choice theory in economics, for a given individual with given resource constraints (e.g. income, time), the utility of a particular travel choice—what mode to take or which destination to choose—is influenced by the attractiveness of the activity at the destination, and travel time, convenience, and other characteristics of available travel alternatives, which are influenced by the built environment.

The theoretical ambiguities implied above are consistent with the "rebound effect" (increased consumption due to increased efficiency or reduced costs) (Herring & Cleveland, 2008), which implies that making travel easier, cheaper, or more convenient (e.g. road condition improvement, public transit expansion, etc.) may induce more travel, if households have some sort of constant "budget" or need in total amount of travel. The controversial Unified Mechanism of Travel (UMOT) model developed by Zahavi (1979) is based on the assumption of a constant household travel budget (both in travel time and money), which is evidenced by some aggregate level data, e.g. Schafer (2000) finds that travel budgets are roughly stable but only broadly on national aggregate levels. The rebound effect is consistent with the idea that people will, on average, spend a constant amount of time and constant share of income on travel. Scholars also point to possible "compensatory mechanisms" –people may travel more frequently if the distance is short or the trip is convenient, and travel less frequently if the destination is far away, i.e., the "distance decay" (Crane, 1996; Maddison et al., 1996). Studies of leisure travel have identified the "escape hypothesis": people who are not satisfied with their living environment (housing unit and neighborhood) might spend more of their leisure time elsewhere (Kaiser, 1993). Theorists consider such compensatory travel as a "phenomenon of deficit," due to the basic psychological needs for contact with nature (Grahn, 1993), or as "surplus phenomenon" which assumes somewhat constant consumption of resources, i.e. money or time, in travel (Vilhelmson, 1990).

Finally, urban form and neighborhood design could also influence people's social activity patterns (Putman, 2000) which might affect the amount of travel indirectly, for example, more locally based circles of acquaintances might reduce the number of social visits (Næss, 2006).

Note, however, that most of the above theoretical explanations focus on the immediate connection between the built environment and travel behavior and do not account for longer term decisions such as residential location (Handy, 2005). It is possible that different causal mechanisms apply in different situations, depending on the combination of the preferences of the individual and the type of environment in which he/she chooses to live (Handy, 2005). Handy (2005) suspects that the built environment might have a less immediate and more indirect effect on travel behavior through its impact on attitudes over time. This last point relates to the lifestyle concept which will be discussed in detail in section 2.1.5.

A reasonably comprehensive review of the empirical work on the relationship between the built environment and travel behavior, primarily in North America, was carried out by Ewing & Cervero (2001). The same authors expanded upon that review, both geographically and analytically, including a meta-analysis of somewhat comparable models (Ewing & Cervero, 2010). In their analysis, Ewing & Cervero (2010) compute estimated elasticities various travel behaviors with respect to built environment indicators, using more than 50 studies. They find that travel behaviors are generally inelastic to individual built environment measurements, with the highest weighted elasticity being 0.39 (for walking trip response to intersection density) and most others much smaller, although the combined effect of multiple variables could be large. The meta-analysis also finds that vehicle miles traveled (VMT) is most strongly associated with destination accessibility and street network design variables; population and job densities are only weakly associated with travel behavior (Ewing & Cervero, 2010).

Relative to the numerous studies using empirical settings in the developed world, examinations in the developing city context are much more limited. Zegras (2010) uses a household vehicle choice model and regression model corrected for selection bias and endogeneity for automobile vehicle kilometers traveled (VKT) on disaggregate data of Santiago de Chile, and finds that income plays the largest role in determining VKT, but only indirectly via the influence on the vehicle ownership decision. Distances to Metro stations and to the CBD have relatively strong associations with vehicle use, and other form indicators such as suburban street layout and plaza density also have moderate effects. Cervero et al. (2009) use a hierarchical nonlinear model and disaggregate survey data in Bogotá, Columbia, and find that, whereas road facility designs (such as street density, connectivity, proximity to Ciclovía lanes) are associated with walking and biking activities, other attributes of the built environment such as density and land-use mix, are not. Cervero et al. (2009) hypothesize that this result may be because most neighborhoods in Bogotá are uniformly compact and mixed with comparable levels of transport accessibility.

Several recent studies use data in the China context. Næss (2007) takes a mixed-method approach to study the influence of residential location on travel behavior in Hangzhou. The qualitative and quantitative results show that distance to the city center has a considerable influence on travel behavior, e.g. center city dwellers travel less, have a lower share of car driving and make more biking and walking trips, particularly due to shorter trip distances for both commuting and non-work purposes (Næss, 2007). Cervero & Day (2008) utilize a current-day and retrospective survey of recent movers to three suburban neighborhoods in Shanghai and find that job accessibility declines and motorized travel increases after the move, although closeness to a metrorail station moderates losses in job accessibility and encourages switches from non-motorized to transit commuting. Pan, et al. (2009) use discrete choice and linear regression models to analyze travel surveys conducted in four neighborhoods in Shanghai, and find that residents travel shorter distances and are less car dependent in pedestrian/cyclist-friendly neighborhoods. Wang & Chai (2009) use a structural equations model (SEM) and disaggregated travel data in Beijing, and the results show that people in *Danwei* (work unit, or employer provided housing) housing have better job-housing balance, shorter commuting trips, and higher usage of non-motorized transport modes than those who live in market-source houses.

Regarding travel compensatory mechanisms, scholars have observed that people living in the dense inner-city travel out of town more than their suburban counterparts (Tillberg, 1998). The qualitative interviews done by Næss (2006) confirmed that certain mechanisms of compensatory weekend travel exist (e.g. inner city dwellers visit summer cottages and natural areas outside the metropolitan area more often than suburban residents and spend less leisure time doing house maintenance or gardening) but to a very limited extent and not statistically significant in the quantitative analysis. After the review and analysis of more than two dozen studies of travel time expenditures, Mokhtarian & Chen (2004) conclude that individuals' travel time expenditures are not constant, but strongly related to individual and household characteristics, attributes of activities at the destination, and characteristics of residential areas. According to a review done by Greening et al., aggregate studies of total travel amount or fuel use consistently show a small direct rebound effect of 10% for the short run (one year), and as much as 20 to 30% in the long-run. The results of disaggregate household level studies also indicate small to moderate sized rebound effects in personal travel (Greening et al., 2000).

Despite these theoretical inquiries and decades of empirical work examining relationships between the built environment and travel behavior, empirically isolating the causal mechanisms has been given relatively limited attention by researchers (Handy et. al., 2005). Boarnet and Crane (2001) attempted to econometrically strengthen the causality argument by operationalizing Crane's (1996) cost-based framework, and more recent relevant empirical work has moved towards discrete choice modeling (e.g. Zhang, 2004). Nonetheless, such analyses remain imperfect approximations of causal mechanisms. An ongoing practical challenge relates to limitations on experimental designs and the problem widely referred to as "self-selection." Basically, if we want to know the effect of the built environment on travel behavior, but can only study people in different built environments, we cannot easily attribute the behavior to the built environment as opposed to particular behavioral predilections correlated with the built environment. In other words, if a household chooses a residential location largely because of the location's transportation options, then they have "self-selected" – the neighborhood did not "create" the behavior, rather the household chose the neighborhood, but would have behaved similarly in any case. Therefore empirical studies that treat residential location as exogenous will not be able to separate the possible "self-selection" effect and as a result, may overestimate (or incorrectly attribute, entirely) the magnitude of the built environment's influence on travel. Still, in some studies where self-selection is not accounted for, scholars argue that land use variables could be very good proxies for attitudinal and lifestyle preferences to using particular travel modes (Kitamura et al., 1997; Boarnet & Crane, 2001; Cervero, 2002).

Handy & Clifton (2001) suggest that the observed associations between travel behavior and neighborhood characteristics are largely explained by the self-selection of residents with certain attitudes into certain kinds of neighborhoods. To deal with the self-selection issue empirically, researchers have used methods such as direct questioning, statistical control, instrumental variables, sample selection models, propensity score matching, joint discrete choice models, structural equations models, longitudinal designs, etc. (Cao at al., 2009; see Chapter 3 for a more detailed review of methods). Hammond (2005) uses a self administered survey on decision sequences with respect to residential choice and commute mode choice, and finds that residential choice is either conditional on, or interacts with, commute mode choice for the majority of respondents. His eight-person focus group also shows that participants incorporated commute mode choice and access to work into their residential choice. Therefore, people selectively locate in a residential neighborhood to realize, at least in part, their travel preferences.

Studies controlling for self-selection generally show less definite conclusions on the links between the built environment and travel behavior. For example, Boarnet & Sarmiento (1998) find no stable link between density and VMT after using instrumental variables to control for the endogeneity of density using US data. Studying the San Francisco Bay area (USA), Bagley & Mokhtarian (2002) use a system of structural equations and conclude that attitudinal and lifestyle variables had the greatest impact on travel demand among all the explanatory variables, while residential location type had little impact, suggesting that neighborhood type has little influence on travel behavior when attitudinal, lifestyle, and socio-demographic variables are controlled for. However, Vance & Hedel (2007) find significant links between commercial density, road density, and walking minutes to public transit and car VMT using similar instruments with German data. Cao et al. (2009) review 38 empirical studies that utilize various methods to account for residential self-selection, and conclude that although the apparent influence of built environment on travel behavior does diminish substantially once self-selection is taken into account, all of the studies reviewed still find statistically significant influence remaining. For example, Handy et al. (2005) show that differences in attitudes largely explained observed differences in travel behavior between suburban and traditional neighborhoods. However, the quasi-longitudinal analysis of changes in travel behavior and changes in the built environment still shows significant associations, even when attitudes have been accounted for, providing support for a causal relationship. Cao et al. (2005) find that characteristics of the built environment influence walking behavior after accounting for a preference for neighborhoods conducive to walking. Bhat & Guo (2007) show that the built environment (measured by street block density, transit availability, and transit access time) has a significant influence (although very small in magnitude) on vehicle ownership. Similarly, Brownstone & Golob (2009) find that residential density does influence VMT and fuel use, though in a very small magnitude, which suggests that feasible changes in residential density will not have any important effect on VMT or fuel use. Fang (2008)'s discrete-continuous analysis of vehicle holding and usage in the U.S. finds residential density reduces households' truck holdings and usage in a statistically significant but economically insignificant way. The meta-analysis by Ewing & Cervero (2010), however, find that controlling for residential self-selection actually increases rather than diminish the magnitude of built environmental influences measured by elasticities – a finding that they suggest indicates that people able to choose into their (behaviorally) preferred neighborhood settings will further undertake the relevant behavior. Næss (2009) uses qualitative interviews in the metropolitan areas of Copenhagen and Hangzhou to show that in both cities, suburban residents make more motorized travel than inner-city residents, with contributions from people's rationales for activity participation, location of activities, travel mode and route choice, regardless of any self-selection effect of neighborhood type choice.

The review of the literature on the link between form/built environment and travel behavior informs my research in three main aspects: (1) form can theoretically influence how people travel through changing the attractiveness and costs of travel by different modes; (2) the widely found "self-selection" effect between residential location and travel behavior implies that the residential and mobility choices households make are both influenced by the same sets of attitudes and preferences; and (3) empirical studies show that the built environment may influence travel behavior. Among different form-related indicators, regional effects (i.e., relative location, accessibility) dominate, and the effects of built environment seem to be relatively small in magnitude. Theory and empirical evidence suggest ambiguous final results, due to: uncertainty about how individuals will respond in the short and long terms (e.g., participate in more activities; move to new locations requiring more travel); a lack of complete empirical data (e.g., to see whether short term daily travel savings are invested into long-term additional travel on weekends, holidays); and a lack of data over time to see how households respond to new conditions.

2.1.4 Form and Residential Energy

Analysis of residential energy consumption has largely been limited to the building scale, typically related to "green" or "sustainable" buildings, focusing on the role of building-level devices and techniques (e.g. highly transparent glasses, coating and shading devices, adjustable lighting, floor-distributed air conditioning, openable windows, rainwater cooling, etc.). Concerned with the affordability of in-home energy use, for example, Wasik (2010) points out the simple reality that the larger and older the home, the higher the energy bills. Ralph Knowles (1975) is among the first few architects who realized that a single building is no longer the relevant increment of urban growth and should not constitute the urban design tools of the future. Knowles' perspective offers us a theoretical basis to understand the role of urban (as opposed to building) design in influencing residential energy use. He developed a framework trying to use building form and location to minimize the "energy cost of maintaining their equilibrium in a natural environment of cyclic forces" (Knowles, 1975). He suggests an energy-conserving approach to urban design derived from the main recurrences of heat, light, wind, and water (Knowles, 1975). Specifically in terms of solar access, Knowles develops the method of "solar design", considering attributes such as street orientation and building configuration, and most importantly, introducing the concept of "solar envelope", which describes the "volumetric limits of building that will not shadow surroundings during critical energy-receiving periods of the day and year" (Knowles, 1985).

This section first discusses how the connection of urban form and residential energy is established from the basic consumer behavior theory framework, followed by empirical evidence as well as empirical challenges.

Drawing from Ewing & Rong (2008), we can observe two major causal pathways between urban form and residential energy. One is indirectly through housing choice of unit size and housing type and the other is through changes in the micro climate (Figure 2.3). Just like travel energy consumption, in-home energy use, per se, is not the objective of consumers when it comes to housing choice and use. Returning again to microeconomic consumer behavior theory, rational decision makers maximize their utility subject to budget constraints, so residential energy is the by-product of households maximizing their utility of comfort, convenience, privacy, and other needs from their residence. While household's characteristics determine the utility function and budget constraint, urban form may affect the relevant physical attributes of housing stock therefore changing consumer's utility and behaviors. For example, different forms mean different building and space configurations, which affect heat gain, solar gain, shading, and ventilation conditions of the individual housing unit, therefore influencing conditions within the housing unit and, in turn, the need for heating and cooling. Form may also influence the cooling demand via the urban heat island effect. Urban form could also affect building types, and thus influence the portion of shared walls, insulation, and prevalence of other building technologies. Most importantly, urban form may influence households' residential/housing choice of how large and what type of housing unit to occupy, what energy sources to use (e.g., gas, fuel oil), and probably what home appliances to own. Urban form might also have effects on people's behaviors, such as how much time to spend at home versus doing out-of-home activities and thereby influence in-home energy consumption.

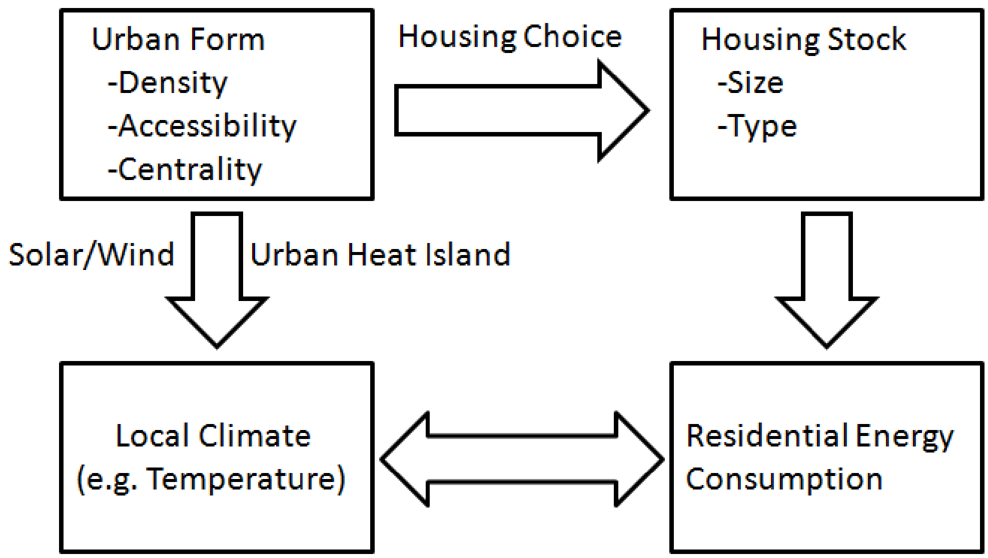


Figure 2.3 Causal Pathways between Urban Form and Residential Energy Consumption

Modified based on Ewing & Rong, 2008

Based on the literature on the urban heat island effect and the physical environment, Stone (2005) identifies three physical planning strategies that could cool cities measurably over a period as short as 10 to 20 years: (1) the use of highly reflective paving and roofing materials; (2) the preservation and re-cultivation of regional forest canopy; and (3) the reduction of waste heat from energy production and consumption. Among these strategies, (1) is at the building level; (2) is primarily regional (although involves neighborhood level green coverage too; e.g. Meier (1991) finds the placement of mature shade trees to the south and west of single-family homes to offset cooling costs by 25 to 80% during the summer months); and (3) implies that the direction of the causal relationship between energy consumption and urban heat island effect seems ambiguous. For example, Stone et al. (2001) find that low density development contributes more radiant heat energy to surface heat island formation than high density development. It is plausible that higher temperature in the summer causes more in-home energy use, and at the same time, more energy use (e.g. more AC use, more motor vehicle travel) also causes the temperature to rise, suggesting a multi-pathway, feedback loop process.

Based on the consumer behavior framework of utility maximization and classical household location choice model in urban economics discussed in Section 2.1.1, various relevant studies and models have been developed to estimate residential energy use and influencing factors, including household income, energy prices, tenure status, building conditions, and urban form. For example, Vringer (2005) find that a 1% increase in income results in a 0.63% increase in household energy use. Leth-Petersen et al. (2001) find that renters use more energy than home-owners if heating is included in rent. Guerra-Santin et al. (2009) summarize the following physical attributes commonly examined in literatures on residential energy use: urbanization rate at the regional level, vintage of building, type of dwelling (e.g. single detached, double, row, flat, etc.), design of dwelling (useful living area, orientation, window-to-wall ratio, roof type, presence of garage, shed, basement, etc.), insulation (ground, window, and roof), heating system (technology, thermal control and efficiency), and energy source type.). Using regression analysis of Dutch household data, they show that occupant characteristics and behavior (e.g. temperature setting) significantly affect energy use, but building characteristics still determine a large part of the energy use in a dwelling, while the effect of occupant characteristics might be larger since these also determine the housing type and other building characteristics (Guerra-Santin et al., 2009). Consistent with the latter, Guerra-Santin & Itard (2010) show that the number of usage hours for the heating system has a stronger effect on energy consumption than temperature setting, and that the main building characteristic determining energy using behavior is the type of temperature control. From comparison and regression studies of U.S. household surveys, Kockelman et al. (2011) summarize that smaller home units, better (thicker) insulation of wall and roof, and shared walls reduce residential energy consumption by reducing the heating and cooling needs of individual units. Particularly, multi-unit building types can potentially reduce unit size, and increase the portion of shared walls.

At the urban form scale, while Ewing & Rong (2008) do not fully explain either the mechanisms linking form and housing stock nor the ones linking housing stock and residential energy consumption, their statistical results do show strong correlations between urban form and housing type and size, which act as mediators for residential energy consumption, as indicated in the previous paragraph. Ewing & Rong (2008) estimate that an average household in compact counties in the USA uses less energy (1.4 million BTU/year) in space heating and cooling than an average household in a sprawling county. However, other studies show no correlation between the two. For example, Kahn (2000) finds no significant difference in residential energy consumption between urban and suburban dwellers.

Simulation techniques have also been used to assess building and neighbourhood-level dimensions related to energy use. For example Depecker et al. (2001) use computer simulation and find that the shape of the building, specifically, the surface-to-volume ratio is positively associated with heating energy consumption in cold weather, but inconclusive in mild or sunny weather. As my research applies empirical techniques, I do not review simulation approaches here.

In the context of China, the effect of urban form on in-home energy use is seldom examined empirically, although there is a body of literature on residential energy use. For example, Xie et al. (2007) use small-size household survey in Changsha to examine in-home energy consumption and find significant effects of household income and household size. Ouyang et al. (2007) utilize household survey data in Hangzhou and suggest a moderate impact of energy saving behaviors on household energy consumption.

Similar to the discussion of form and travel energy consumption in Section 2.1.3, the effect of form on residential energy consumption is theoretically ambiguous and empirical examinations suffer from the challenges of rebound effect and selection bias. The issue of selection bias arises since omitted variables that influence one aspect of housing (e.g. tenure choice) also affect the nature of the demand function for other aspects of housing demand (e.g. housing size). One such variable is the consumer's wealth (not income), typically not available in household survey data (Miron, 2004). Miron (2004) also argues that employment status and strategy, saving plan, and expected income prospects are among the omitted variables that cause the selection bias in housing choice. The fact that some studies find no linear relationship "between energy use for space heating and the physical thermal characteristics of a building, while a linear relationship has been found between energy demand for space heating and indoor temperature" supports the existence of a "rebound effect" of residential energy use (Guerra-Santin et al., 2009). Greening et al. (2000) provide a comprehensive review of rebound effect in residential energy use and conclude that although most econometric analyses of residential end users suffer from issues of omitted variable bias, incomplete specification of behaviors, etc., currently available measurements of the rebound effect for residential energy end uses is between 0 to 50% if energy efficiency doubles (Greening et al., 2000).

The above review of the relationship between urban form and residential energy consumption under the consumer behavior framework implies that form could influence urban households' in-home energy consumption, indirectly via building configuration that changes individual unit thermal conditions and the micro climate and via housing/residential choice, while the actual effect is ambiguous both in theory, due to the rebound effect, and in empirical settings, due to data shortcomings.

2.1.5 The Missing Link: Theory and Practice of Lifestyle Concept

This section first reviews the theoretical development of the concept and measurement of "lifestyle" in sociology, psychology, and market research, followed by a brief introduction of the "lifestyle approach" in sustainable consumption studies. I then discuss applications in three relevant fields: travel behavior and residential location choice, residential energy consumption, and urban design.

The Oxford English Dictionary defines lifestyle as "of or relating to a particular way of living," and it credits the term to Alfred Adler, a psychologist who used it in 1929 to "denote a person's basic character as established early in childhood which governs his reactions and behavior." Nonetheless, however frequently this term has been used in various fields of study, the "lack of consensus on its meaning" is the most notable feature of the literature on lifestyle, with at least 30 definitions being offered (Veal, 1993). Sobel (1981) suggests that a widely accepted definition by sociologists is "a distinctive, hence recognizable, mode of living."

Earlier sociologists considered lifestyle as attribute of a class, that is, a "distinctive style of life of specific status groups" (Featherstone, 1987). Among classical sociological theorists, Max Weber provides the deepest insight into the lifestyle concept and formed the foundation for subsequent lifestyle research (Wrong, 1990). Weber (1968) made two relevant contributions to the understanding of lifestyle: (1) lifestyle represents a pattern of consumption instead of production because consumption of goods and services conveys a social meaning that displays the status and social identity of the consumer; (2) the dialectical interplay between life choices and life chances forms lifestyle. Life choice plays a greater role, while life chances, the socioeconomic constraints, limit people's freedom to choose (Weber, 1968). This idea coincides with the consumer choice model of mainstream economics that people choose their ways of living by comparing the available alternatives under their resource constraints. Bourdieu (1984) builds on Weber's choice and chance framework but emphasizes the role of life chances (structure), indicating that lifestyle choices are not only constrained but also shaped by life chances. Bourdieu operationalizes lifestyle through the introduction of "habitus," a system of schemes generating classifiable practices as well as perceptions and tastes that result in a lifestyle (Cockerham et. al., 1997). In other words, Bourdieu points out that life chances determine lifestyle choice, with habitus creating and reproducing lifestyles. Bourdieu provides the theoretical support for the hypothesis that neighborhood design, or the built environment, can influence life chances and therefore help shape households' lifestyles.

Focusing on the need of self-identity, Giddens gives lifestyles a sociological definition as "utilitarian social practices and ways of living adopted by individuals that reflect personal, group, and socioeconomic identities" (Cockerham et. al., 1997). Giddens (1991) points out that modern society forces individuals to "negotiate lifestyle choices among a diversity of options" , and the "selection or creation of lifestyles is influenced by group pressures and the visibility of role models, as well as by socioeconomic circumstances". The role of group dynamics is pertinent here as, although group interaction is not a necessary feature of lifestyle in general, interactions within family and among neighbors are quite important in shaping urban households' lifestyles. Giddens (1991) also defines "lifestyle sector"—a time-space slice of an individual's activities that is internally cohesive, e.g. in-home energy use and personal travel lifestyle. Giddens notes that once lifestyle is established, it may be quite difficult to break, because it is likely to be integrated with other aspects of a person's behavior, so people feel more comfortable sticking to their established habits, making them less responsive to policies. In terms of theoretical explanations for neighborhood design influencing lifestyle, Giddens (1991) shows that "spatially located activity becomes more and more bound up with the reflexive project of the self," as where a person lives is a matter of choice according to the person's life planning, and "dialectical forms of counter-reaction are possible".

Zukin (1990) builds upon Bourdieu's work, and provides a sociological theory that links residents' lifestyles to place, i.e. the neighborhood they live in, by giving consumption patterns a "spatial embeddedness." Zukin (1990) illustrates how the nature of a complex consumer product (here the neighborhood that a household buys into) not only responds to consumer's desires, but also forces consumers to "adopt new categories of perceptions and judgment", so that elements of lifestyle could be partly shaped by neighborhood design.

Psychologists offer lifestyle analysis at the individual level rather than social level. Some psychologists use George Kelly's 'Personal Construct Theory' (that individuals develop a system of "constructions" against which all actions are judged and evaluated) as a framework for the development of a coherent lifestyle (Veal, 1993).

The marketing and retailing enterprises were the first to recognize the importance of lifestyle in predicting purchasing patterns as social class and income alone became less and less useful predictors (Hakim, 2000). Since first being introduced to the field of marketing by Lazer in 1963, the lifestyle concept has been used for market segmentation and has resulted in an extensive marketing literature on lifestyle (Veal, 1993; Kamakura & Wedel, 1995). Market research uses geographic, demographic, psychographic, and behavioral variables to segment the market. In marketing literature, lifestyle and psychographics are generally used as interchangeable terms but the latter represents the operationalization of the concept for market segmentation (Waddell, 2000). As a principal focus of psychographic study, lifestyle includes three elements: activity, opinion, and interest ("AIOs", Michman, 1991). Activities include work, hobbies, social events, entertainment, shopping, and sports. Interests include family, home, fashion, food, media, and achievements. Opinions run the gamut from social issues, politics, and business to products, the future, and culture (Michman, 1991). Values are the centerpiece determining lifestyle in market research, and serve as a basic integrating framework for consumer attitude development (Michman, 1991). The typical psychographic study asks respondents to indicate their agreement with as many as hundreds of value statements and groups them based on their responses using factor analysis and cluster analysis (Veal, 1993). The most well-known psychographic framework is the VALS (Values and Lifestyles System) and VALS-2 (Values, Attitudes, and Lifestyles System) developed by the Stanford Research Institute (SRI). VALS divides the total population of US consumers into nine lifestyle groups under four big categories: The Need Driven (Survivors, Sustainers); Outer-directed Consumers (Belongers, Emulators, Achievers); Inner-directed Consumers (I-Am-Me's, Experientals, Societally Conscious Individuals); and Integrateds. The VALS-2 identified eight groups as: (1) Actualizers, (2) Fulfillers, (3) Believers, (4) Achievers, (5) Strivers, (6) Experiencers, (7) Makers, and (8) Strugglers (Mitchell, 1985).

Murphy and Staples (1979) developed a family life cycle structure for market segmentation which involves lifestyle changes along different stages of life because of developing experiences, income, and maturity. Geo-demographics, popularized by Weiss (1988), uses geographic variables for market segmentation, based on the assumption that neighbors are likely to be similar in socioeconomic characteristics, lifestyles and consumption behavior (Mitchell, 1995). It works by grouping together small geographic areas (e.g. zipcodes) that have similar demographic profiles (Nelson and Wake, 2009). Famous geo-demographic segmentation systems include Prizm (US), Tapestry (US), CAMEO (UK), ACORN (UK) and MOSAIC (UK). However, lifestyle used for market segmentation is treated as an "exogenous basis for classification", so this body of literature does not answer the question of how individuals and households choose lifestyles, or change them over their lifecycle or in response to changing conditions (Waddell, 2000).

Market research also provides a framework, ultimately useful for understanding household decision-making processes regarding lifestyle bundles, for the customer lifestyle decision-making process that moves up from (1) individual motivations and needs; (2) product usage and purchasing habits; (3) product awareness; (4) demographic influence; to (5) role perceptions (Michman, 1991).

The Institute for Social-Ecological Research (ISOE) has developed a social-ecological lifestyle approach for sustainable consumption studies. This approach analyses three dimensions of lifestyle and their relationships: the social background of households (social situation and household context); lifestyle-relevant orientations (general values, orientations with regard to work, leisure, consumption, the environment, health, etc.; relevant attitudes, emotions, preferences, dislikes, etc.); and, indicators of actual consumption behavior as practiced daily (Reisch and Röpke, 2004). Using this approach, Reisch and Röpke (2004) identified ten lifestyles of consumption (typology of consumption styles) in Germany: "fully-managed eco-families", "childless professionals", "self-interested youngsters", "everyday life artists", "people fed up with consumption", "rural traditionalists", "underprivileged who can't cope", "run-of-themill families", "active seniors", and "status-oriented privileged families". The identified lifestyles can then be used as target groups for the development of socially differentiated information, marketing and consumer advice (Empacher et al., 2002).

As seen above, in and among the various fields of study that utilize the concept of lifestyle, the meaning, content, or measurement of lifestyle differs from study to study. We now turn to a review of the use of the lifestyle concept in the three specific areas relevant to this research: (a) studies of travel behavior and residential location choice, (b) studies of residential energy use, and (c) the lifestyle concept in the field of urban design.

(a) Lifestyle in travel behavior and residential location choice studies

Different studies of travel behavior and residential location choice take different approaches to defining the scope of lifestyle and measuring it. Some define lifestyle as merely a pattern of behavior, while others focus on attitudes and preferences.

Salomon & Ben-Akiva (1983) are the first to use the lifestyle concept in travel demand models and they define lifestyle as "a pattern of behavior which conforms to the individual's orientation toward the three major roles of: household member, a worker, and a consumer of leisure, and which conforms to the constrained resources available." Vilhelmson (1994) develops a conceptual model of lifestyle matching the activity-based approach in transportation studies, characterizing lifestyle as the interplay between individual motivations, individual resources, and the structure of the surroundings, combined with the actual actions carried out by the individual. Ben-Akiva et al. (1996) and Waddell (2000) referred to lifestyle in the context of the set of longer-term household choices including residential location, job location, housing type preferences, and other activity participation which condition patterns of daily activity and travel behavior. In a study of residential location and travel behavior in Netherlands, Næss (2006) limits the lifestyle concept only to include a number of attitudinal and preference variables regarding travel modes, transport policy issues, environmental issues, and leisure activities. Walker & Li (2006) see lifestyle as reflected by preferences for the built environment, explicitly modeling lifestyle preferences and attitudes using a latent class choice model structure for residential location choice in Portland, Oregon. The latent class choice model framework enables simultaneous estimation of the parameters of a class membership model and a class-specific choice model; the class membership model provides information as to who is likely to be in each class, whereas the class-specific choice models provide information on how each class behaves. Walker & Li (2006) employ observed household residential location decisions and, without using variables that explicitly indicate lifestyle, they simultaneously identify three heterogeneous lifestyle groups: suburban dwellers, urban dwellers and transit-riders. Their model does not include psychometric indicators that provide direct information on attitudes, perceptions and lifestyles. Similarly using a latent class model structure, but for the choice of vehicle ownership, Chen & Zegras (2009) identified three groups of households in Beijing: "big, young, affluent families with pro-car lifestyle," "traditional core families," and low-income "incomplete and unstable" households.

Chliaoutakis et al. (2005) measure the concept of lifestyle by the frequency of the participation of the respondents in various activities and use principal components analysis (PCA) to identify five lifestyle factors: amusement, religion/tradition, sports, culture, and driving without a predetermined destination. Bagley & Mokhtarian (1999) defined eleven 'lifestyle' dimensions (culture-lover, altruist, nest-builder, relaxer, traveler, adventurer, fun-seeker, homebody, outdoor enthusiast, athlete, and hobbyist) in studying residential neighborhood choice using a series of structural equations on a San Francisco Bay Area household survey.

Ni (2008)'s dissertation on vehicle purchase and use in Shanghai uses 18 questions in a household survey to triangulate six underlying lifestyles, identified via factor analysis, hypothesized to be related to vehicle purchase: "status-seeking," "bandwagon," "happiness as the first priority," "freedom and control of life,""environmental concern," and "family-oriented." These lifestyle variables are then used as explanatory variables in the "most expensive vehicle" ownership choice model, and the result shows "freedom and control of life" is significantly associated with less bicycle and motorcycle ownership.

(b) Lifestyle in residential energy consumption studies

The concept of lifestyle is also widely used in studies of residential energy consumption, with the scope and definition ranging from behavior to values, and sometimes mixed with other psychological or cognitive variables such as motivations, needs, perceptions, preferences, and attitudes (e.g. Figure 2.4).

In the theoretical model developed by Van Raaij & Verhallen (1983a), although not specifically defined, lifestyle is a crucial factor influencing household's energy use, discussed together with habits and behavioral routines and linked to a household's characteristics, environment attributes, and attitudes (Figure 2.5). In their empirical work using household survey data in the Netherlands, Van Raaij & Verhallen (1983b) define five patterns of energy behavior in relation to the use of heating systems and ventilation habits: conservers, spenders, cool, warm, and average. They use principal component analysis and multivariate regression to conclude that household lifestyle influences energy-related attitudes and behavior, with about 5% of the variation in energy consumption explained by energy-related attitudes.

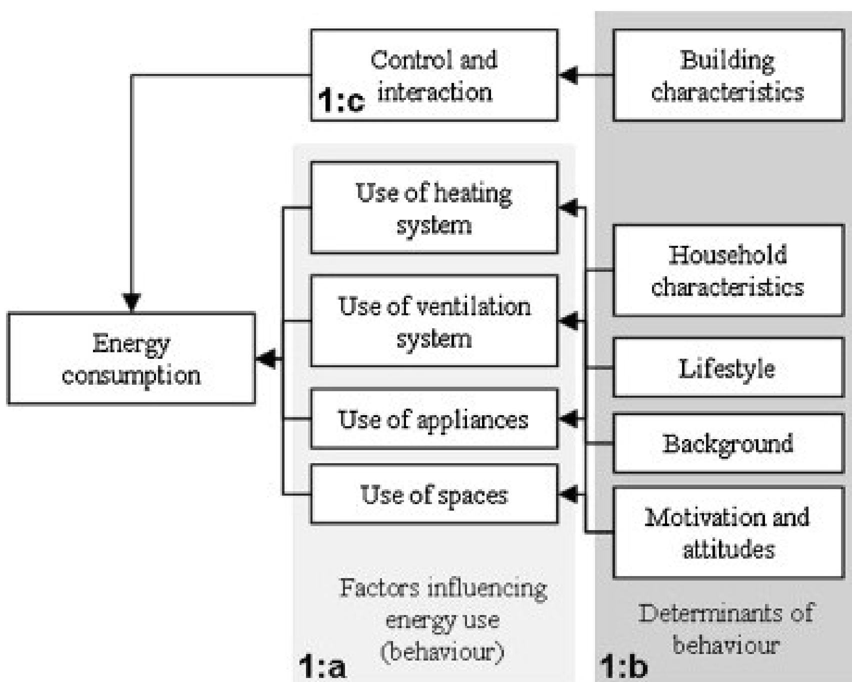


Figure 2.4 Conceptual Framework for Residential Energy Consumption by Guerra-Santin, 2011

Adopted from (Guerra-Santin, 2011)

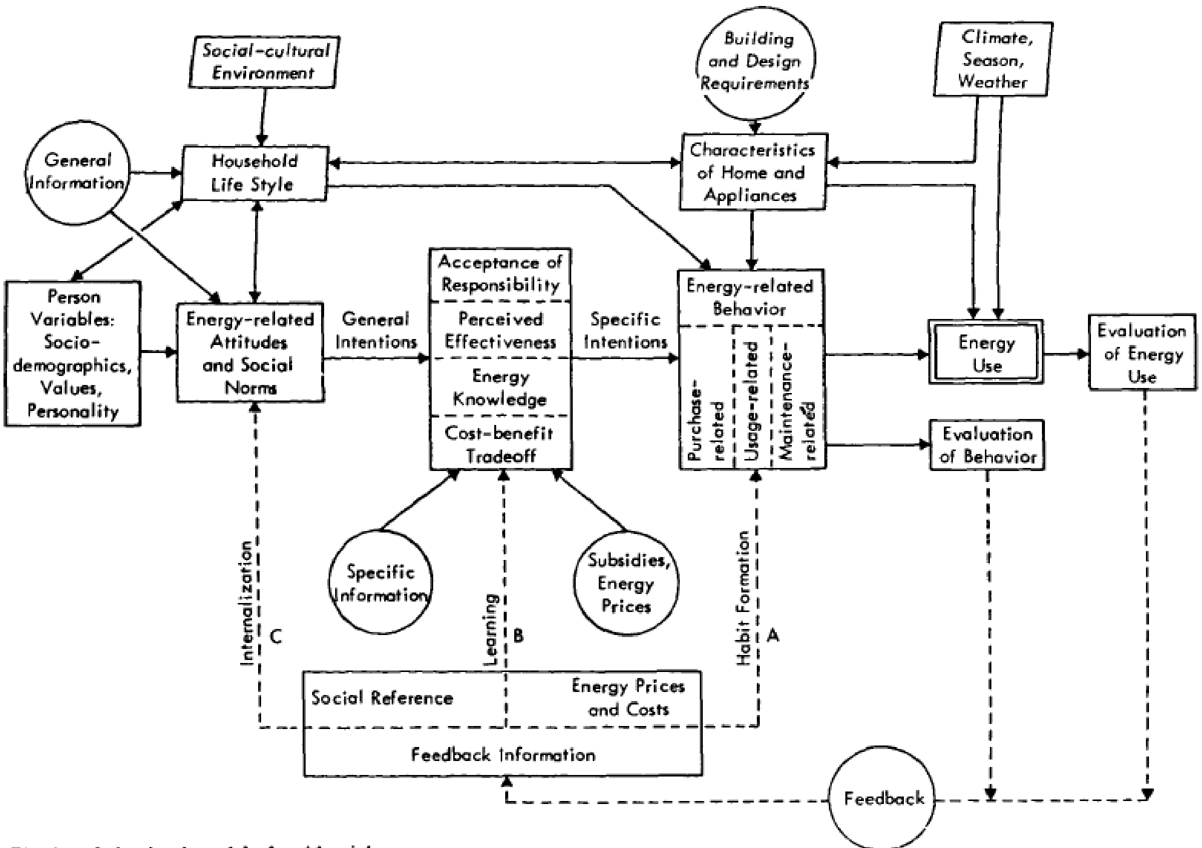


Fig. 1. A behavioral model of residential energy use.

Figure 2.5 Theoretical Model of Residential Energy Use by van Raaij and Verhallen, 1983b

Adopted from (Van Raaij & Verhallen, 1983b)

Vringer et.al (2007) use household survey data in the Netherlands to examine the value patterns and problem perceptions and motivations with regard to climate change and energy and find that families “least motivated to save energy” consume 4% more energy, but otherwise find no significant difference between the energy requirements of households with different value patterns after controlling for socio-demographic variables. Guerra-Satin & Itard (2010) use regression analysis on household survey in the Netherlands and conclude that occupants’ preferences and lifestyle are important contributors to residential energy use.

(c) Lifestyle in urban design

Finally, while urban design influences people’s lives in many aspects, the explicit theoretical connection made between the lifestyle concept and urban design has much to do with the “place branding” in marketing strategies (Blitchfeldt, 2005), and “experience economy” in leisure studies (Venturi et al. 1972). Examples in practice include “lifestyle villages” or “lifestyle centers”, aiming to give shoppers a slow-and-relaxed shopping experience and a traditional urban living experience with outdoor dining, strolling, and people-watching (Rybczynski, 2010).

In terms of the characteristics of physical design, “lifestyle villages” or “lifestyle centers” are typically a mixed retail-residential form, “modeled after main street, U.S.A.” (Scholl & Williams, 2005). While early lifestyle centers of the 1980s and 1990s were simply restyled malls

(Hamilton 2002), since 2000, developers, inspired by the success of New Urbanist developments, have begun to use the age-old mixed-use building type: the apartment above the store (Lonsway, 2009). Design tries to use urban images such as the well-occupied sidewalk to promote a way of living (i.e. lifestyle) that incorporates fashion, desire, style, and culture, built around the consumption patterns of a select group of individuals (Lonsway, 2009). For example, Santana Row in San Jose (CA, USA) seeks to attract an elite clientele both to shop and live and who fit a particular financial and aesthetic demographic (Lonsway, 2009). The pricy apartments and condos and the luxury stores target a small affluent population, who, in turn, are expected to serve as a kind of advertisement for the village and its commercial tenants (Lonsway, 2009).

Steve Guttman, former CEO of Santana Row's developer, said: "the parks are for people who don't necessarily shop at all. Just come and play chess, play checkers in our park with your family. Enjoy the fountains. We want people to come and get married here."(Vu, 2002) The physical design elements are surrounded by the idea of a pedestrian-friendly urban living experience: outdoor shopping streets with storefronts facing the street, restaurants spilling out onto broad sidewalks; small parks and squares further enlivening the streetscape; and cars parked on the street, in garages, and in discretely hidden lots (Rybczynski, 2010). Santana Row has neo-traditional style for its architecture and urban spaces, even in the detailed control over the public face of residences (Lonsway, 2009). For example, in certain buildings, the ground-level merchants are given the right to dress the residents' window above their stores, either for advertising or simply to control environmental context (Hamilton, 2002). Another example, Victory Park in Dallas, has a more modern architecture style, with four thousand residential units, office space, hotel, and a professional basketball arena (Rybczynski, 2010). Although the intention of these lifestyle centers is commercial, just like normal shopping malls, in practice, these "lifestyle-oriented" designs promote densification, infill development, mixed use, first-floor retails, well-designed public amenities, and a diversity of visitors and residents, but without heated or air-conditioned public spaces, superblocks, high-rise, or islands of concentrated poverty (Rybczynski, 2010)

From the literature on the theories and practice of lifestyle we can learn the following: (1) lifestyle reflects patterns of consumption, the interplay between choice and chance, and it changes slowly; (2) the definition, scope, and measurement of lifestyle vary depending on the type and purpose of study; (3) lifestyle segments can be identified in travel behavior and residential energy use behavior; (4) lifestyle influences travel and may influence residential energy use; (5) lifestyle could possibly be shaped by neighborhood design.

2.2 Initial Theoretical Model and Mixed-Method Approach

Based on existing theories and the general context of Chinese cities, I propose the initial theoretical model for urban household's direct energy consumption shown in Figure 2.6. The model has an ownership component and a usage component. The ownership component includes residential choice and vehicle ownership portfolio. This ownership component represents a medium- to long-term decision that households make, therefore it has a possible "lock-in" effect on energy use. The usage component is conditioned on the ownership component, and focuses on personal travel and in-home energy using behaviors of households. Arrows show potential causal relationships or impacts.

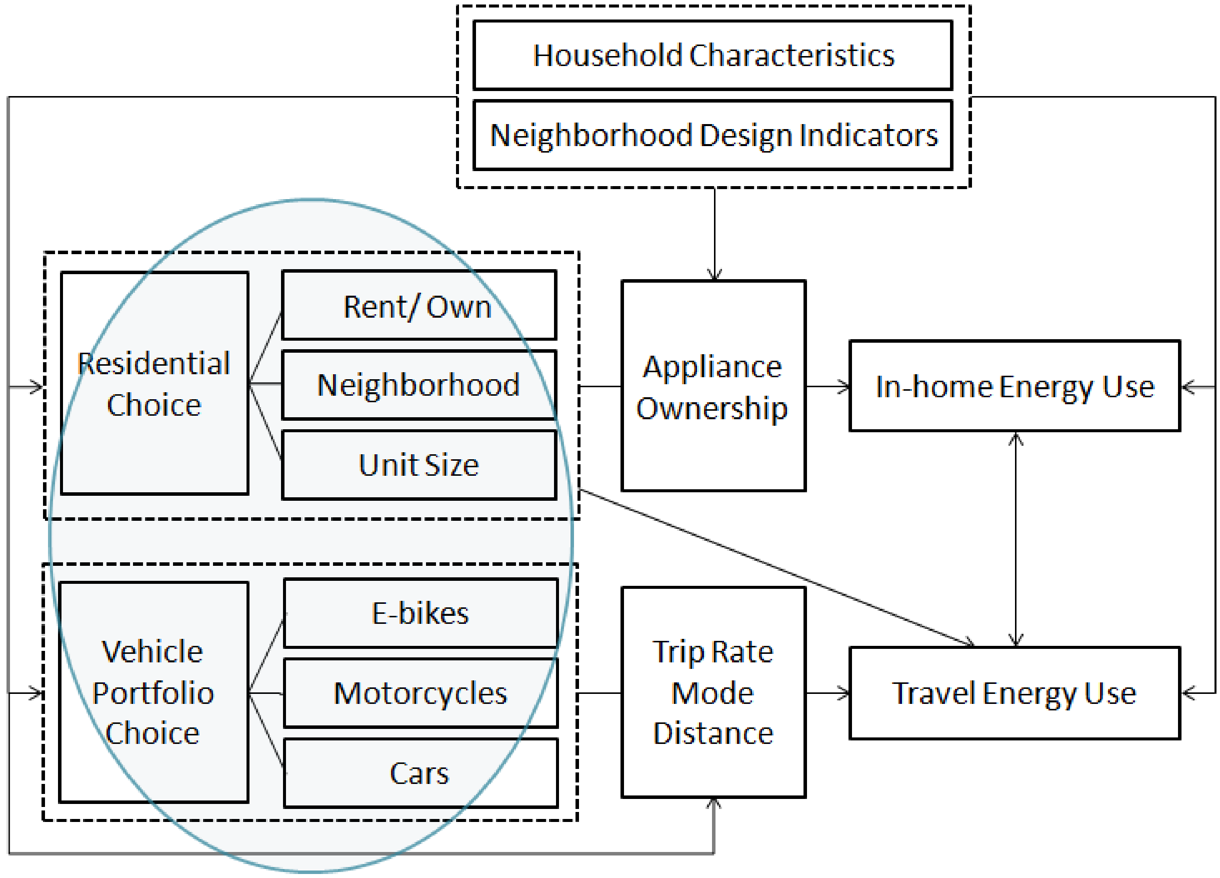


Figure 2.6 Initial Theoretical Model of Urban Household's Direct Energy Consumption

Based on the research question and the initial theoretical model, three initial hypotheses emerge:

- Households make residential choice and vehicle portfolio choice together as a bundle (lifestyle bundle as shown by the oval in Figure 2.6);
- Households with different lifestyles have different decision-making mechanisms (i.e. variations of the theoretical model shown in Figure 2.6 in terms of significance and magnitude of impacts);
- Neighborhood design influences household's energy consuming behavior (including ownership and usage).

I test these hypotheses using the City of Jinan in Shandong Province, China, as the case study city. This qualitative-quantitative mixed-method study will contribute to bridging the literatures on consumer behavior, lifestyle, built environment and travel behavior, and energy consumption. It will provide new insights into the interaction of residence and mobility as a lifestyle bundle, and also enrich the empirical evidence in the developing world.

Chapter 3 Research Context and Research Methods

This chapter introduces the research context, the case city of Jinan, the qualitative and quantitative methods used, and the data collected in Jinan upon which the analysis is based.

3.1 The Case City of Jinan

3.1.1 The city of Jinan

The City of Jinan, located in the heart of Shandong province in eastern China, is one of the 15 largest cities in China holding sub-provincial administrative status. The City of Jinan has jurisdiction over six city districts, one county-level city, and three counties, covering 8177 km^2 with a density of 739 persons per km^2. Among a total population of 6.04 million, 3.48 million live in the six city districts.[7]

With two latitudinal natural boundaries—the Mount Tai foothill to the south and the Yellow River Plain to the north, the city primarily expands eastward and westward. The terrain of Jinan slopes down from south to north, which helps the limestone aquifers create many artesian springs; the city is known as "City of Springs." Jinan has a warm temperate zone continental climate, with four well-defined seasons: dry spring, hot and rainy summer, crisp fall, and cold and dry winter (NBS, 2009). The City of Jinan has a long history of civilization. The Neolithic Longshan Culture discovered to the east of Jinan dates to over 4000 years ago, and the name of "Jinan" was recorded over 2000 years ago during the Han Dynasty. The city has had many historical figures and cultural celebrities as well as a large number of places of historical and cultural interest.

With a GDP of 391 billion yuan in 2010, Jinan's economy takes up 9.9% of the total GDP of Shandong Province, or a 1.0% of the total GDP of China, while the population is only 0.45% of the nation's. The GDP per capita reached US $ 9,960 in 2011.[8] The city of Jinan has a long history of being a transportation hub in eastern China, especially due to the railway. The Jing-Hu railway and Jiao-Ji railway intersect in Jinan, with the former connecting two major economic zones, Bohai Economic Rim and Yangzte River Delta, and the latter linking Jinan to the sea ports. The new Jing-Hu high-speed railway, whose first train pulled into Jinan West Railway Station on June 30, 2011, is expected to have a profound influence in Jinan's economic and urban development.[9]

3.1.2 Growth, Urbanization, Motorization, and Lifestyle Change

Like most cities in China, Jinan has gone through a key urbanization phase since the Reform and Opening-up of China's economy in 1978. The non-agricultural portion of the city's population grew from one fifth in 1976 to a majority in less than 30 years (Figure 3.1), which transformed the city physically, socially, and economically. The rapid economic growth induced urbanization and a transformation to industry and service employment. These urban households

---

[7] Land area, population density administrative divisions and population data (2010 registered population) from: Jinan Statistical Yearbook 2011

[8] Conversion uses nominal exchange rate in 2011. From Jinan Statistical Bureau, Jinan Socio-economic Development Statistical Report 2011, published in March 2012

[9] From China Daily, http://www.chinadaily.com.cn/m/shandong/e/2011-07/04/content_12829317.htm

are demanding more products, more living space, faster and more convenient ways to move around; and this demand is being met with larger homes, wider roads, and more public facilities.

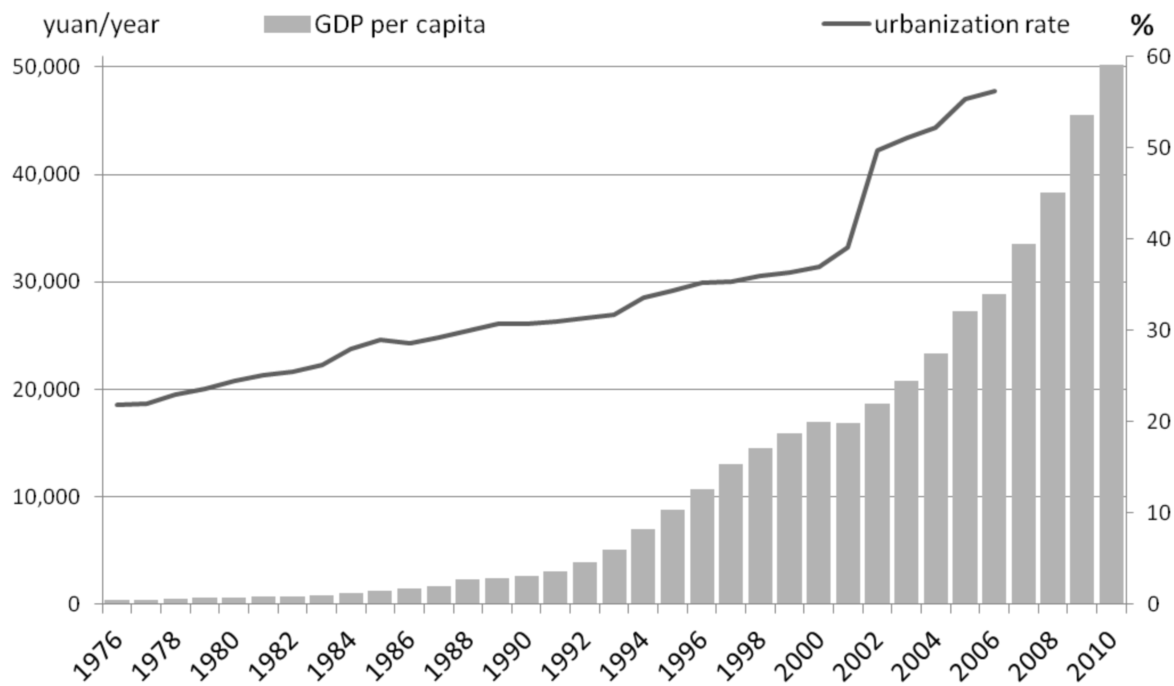


Figure 3.1 Economic Growth and Urbanization in Jinan from 1976 to 2010

Data source: Jinan Statistical Yearbook 2011

Official data reveal a clear pattern of family cars and powered-bicycles taking the place of motorcycles and bicycles as the main mobility tool for Jinan's urban households (Figure 3.2). Car ownership is decreasingly a luxury or status symbol, as one in every four urban households in Jinan now owns a car.

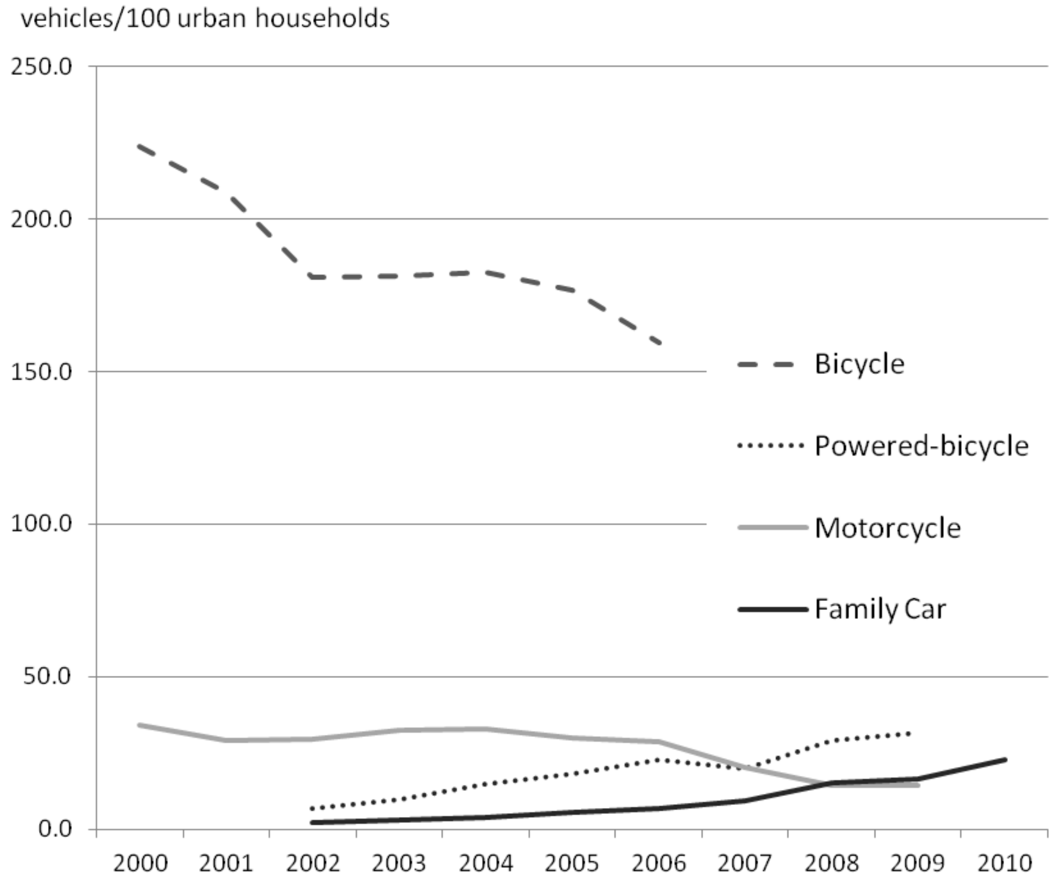


Figure 3.2 Vehicle Portfolio of Urban Household in Jinan from 2000 to 2010

Data source: Jinan Statistical Yearbooks 2001 to 2011

3.1.3 Interaction with the Supply Side

The demand-supply interaction of urban resources links what we observe as economic growth, urbanization, motorization, and urban lifestyle change. While the city government and developers try to meet households' changing demands and expectations, the provision of housing, infrastructure, public facilities, and energy in the city also, in turn, shapes what people desire.

Like most large cities in China, Jinan's real estate development has been thriving over the past decade. Investment in housing is growing almost exponentially. In less than ten years, per capita living space tripled from 10 m^2 to almost 30 m^2 (Figure 3.3). The commercial real estate price is rising roughly in pace with average income growth (Figure 3.4).

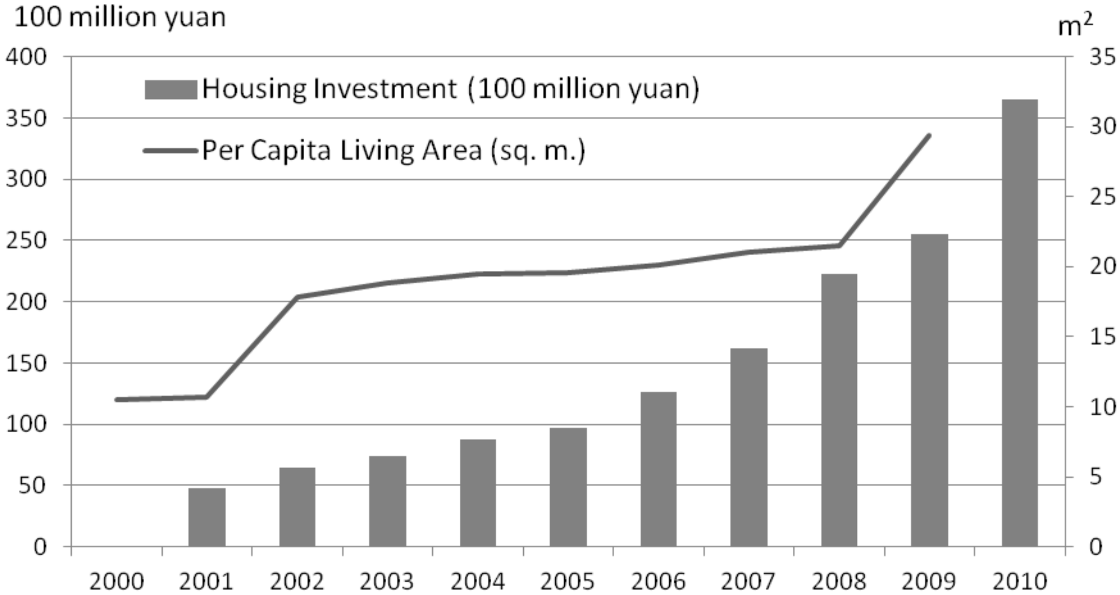


Figure 3.3 Housing Investment and Living Area Per Capita in Jinan from 2000 to 2010

Data source: Jinan Statistical Yearbooks 2001 to 2011

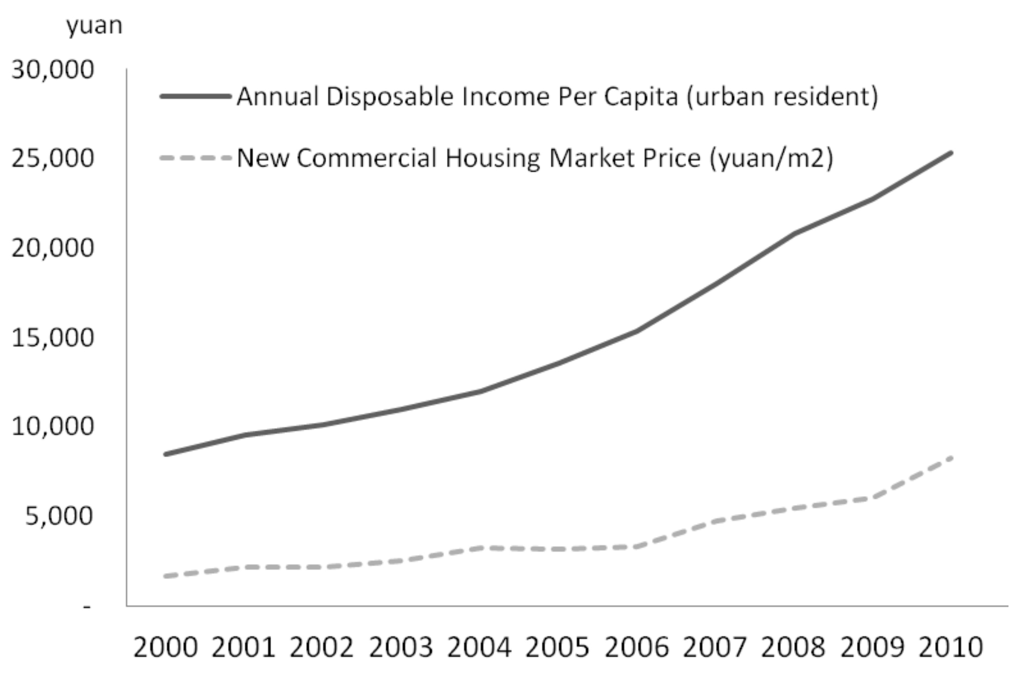


Figure 3.4 Real Estate Market Price and Income Growth Trend in Jinan from 2000 to 2010

Data source: Jinan statistical yearbook and data from Urban-rural Development Commission of Jinan

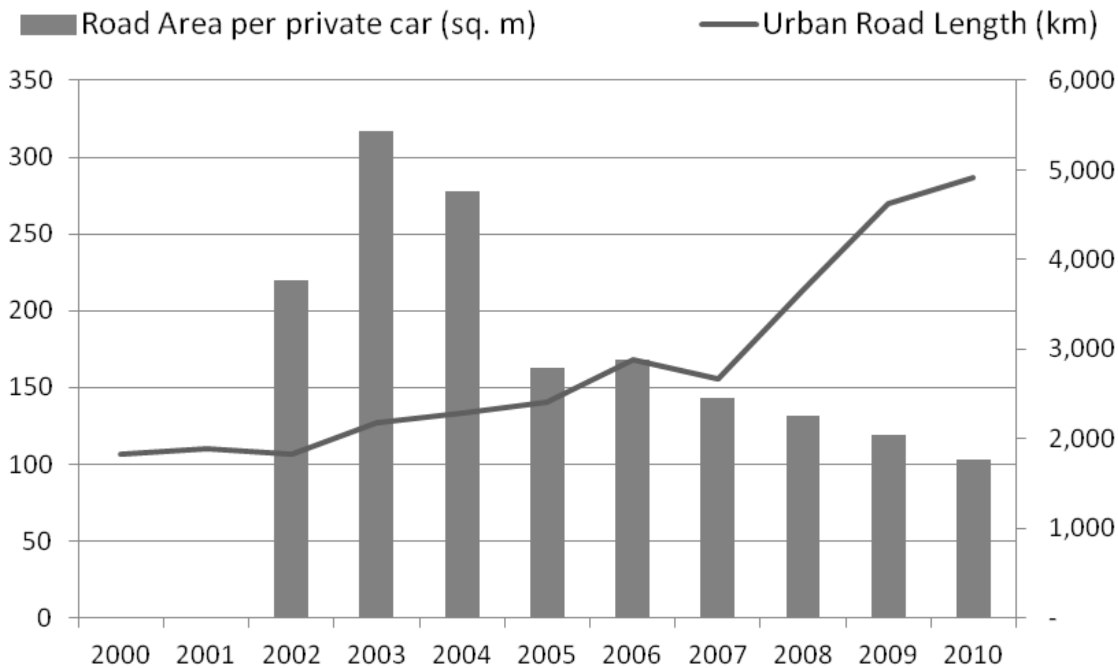


Figure 3.5 Length of Urban Road and Road Area Per Private Car in Jinan

Data source: Jinan Statistical Yearbooks 2001 to 2011

Although the city is building roads faster than ever, the private fleet growth continues to outpace road development. From 2000 to 2010, the total length of urban roads almost tripled (total road area more than tripled), but the average road area per private car dropped to 103 m^2 from 317 m^2 in 2003 (Figure 3.5). This crude measure indicates that congestion levels in the city are likely on the rise.

The bus network and fleet size grew steadily from 2000 to 2008 (Figure 3.6), with the BRT system operating since 2008. Although the number of transit vehicles (including common buses, electric buses, and BRT buses) has not increased since 2008, passenger volumes have—from 681 million annual person trips in 2007 to 1081 million in 2010. As of April 2012, Jinan has six BRT lines in operation with 34.4-kms of designated lanes (Figure 3.6). [10]

On the other hand, taxis, which offer an alternative to private car with somewhat comparable speed and convenience, have only grown modestly in very recent years (Figure 3.7).

Residents' in-home energy consumption (operational energy) depends largely upon the sources available to them. The availability of energy sources has major influence on people's energy-using lifestyle. Figure 3.8 suggests that the city has made steady progress in building infrastructure for neighborhoods so that electricity, centralized heating, and natural gas are available, replacing coal and LPG.

[10] http://www.chinabrt.org/cn/cities/Jinan.aspx

Figure 3.6 Jinan BRT System Map (2012)

Source: map made by www.84ke.com on April 17th, 2012

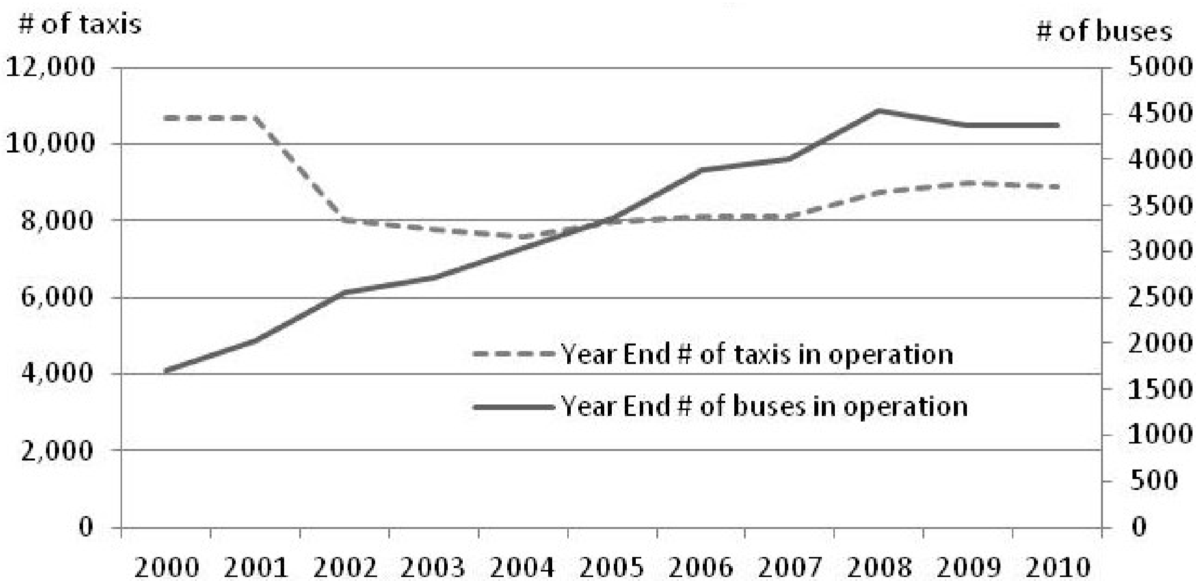


Figure 3.7 Numbers of Buses and Taxis in Jinan

Data source: Jinan Statistical Yearbooks 2001 to 2011

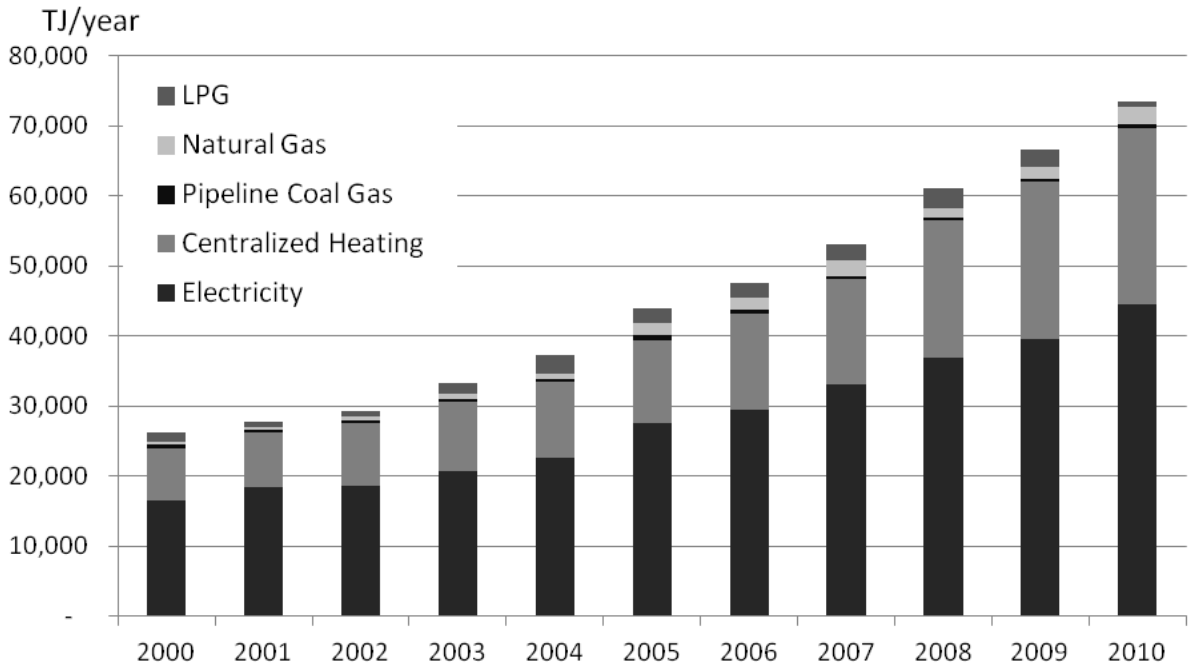


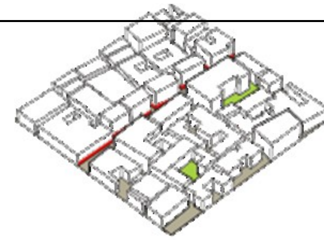
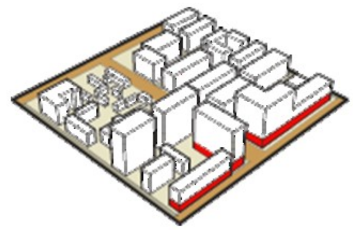
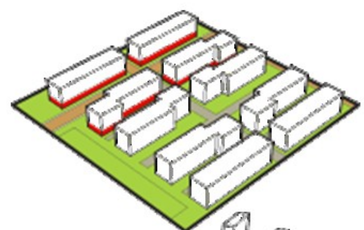
Figure 3.8 Citywide Residents' Energy Consumption in Jinan

Data source: Jinan Statistical Yearbooks 2001 to 2011, all original consumption data are converted to TJ.

3.1.4 Neighborhood typology

As part of field research conducted for the "Making the Clean Energy City in China" project (MIT, 2012), researchers identified four neighborhood typologies: "Traditional," "Grid," "Enclave," and "Superblock." These typologies have distinct form characteristics (Table 3.1), roughly representing patterns of urban development in Jinan during different historic periods (see MIT (2012) for details). These four typologies of neighborhood categorization are used as the sampling frame of households for both the quantitative and the qualitative data collection employed in my research.

Table 3.1 Summary of Form Features across Four Neighborhood Typologies in Jinan

Typology (time of development)	**Building/Street/Function**	**Access/Parking**	**Graphic Representation**
Traditional	1-3 story courtyards; fractal /dendritic fabric off a main shopping street, on-site employment	no cars	
Grid (1920s)	Block structure with different building forms contained within each block, retail on connecting streets	Easy access; cars on-street; some parking lots; no underground parking	
Enclave (1980-1990s)	Linear mid-rise walk-ups; housing integrated with communal facilities (kindergartens, clinic, restaurants, convenience shops, sports facilities, etc.)	Moderately gated (walls, fences and sometimes security guards at entries); scarce surface parking; no underground parking	
Superblocks (-2000s)	Towers in park with relatively homogeneous residential use	Completely gated; sufficient parking (underground, surface, etc.)	

Adopted from MIT, 2012

3.2 Qualitative and Quantitative Analysis Methods

As discussed in Chapter 2, I aim to understand how neighborhood design influences household's direct energy consumption in Chinese cities, through the effects on lifestyle. To answer this question, further theoretical development and empirical testing are needed. I take a mixed methods approach, adopting qualitative and quantitative methods. The qualitative analysis attempts to construct concepts related to lifestyle and to validate the initial theoretical model structure and hypotheses developed in Chapter 2 in the empirical context, while the quantitative analysis will test these validated hypotheses empirically and estimate the size of the effects of variables that are crucial for policy suggestions. This section elaborates the general methods applied in the qualitative and quantitative analyses in the following chapters.

3.2.1 Qualitative Methods

Qualitative research methods include ethnographies, case studies, participant observations, focus groups and interviews, etc. While the transportation behavior field tends to be dominated by quantitative analysis, researchers have argued for interpretative and qualitative approaches to supplement quantitative methods in understanding the experiences, motivations, perceptions, and other causal relationships in the urban transport arena (Røe, 2000).

Qualitative techniques for travel behavior research include focus groups, interviews or participant-observation techniques (Clifton and Handy, 2001). They can improve the design and the interpretation of traditional surveys (e.g., Handy et al., 1998), be used in parallel with quantitative methods (e.g., Jones et al., 1985) or be independent of quantitative approaches (e.g., Gaber and Gaber, 1999; Kurani et al., 1994). For example, Flamm and Agarwal (2012) use focus group discussions to explore the constraints preventing people with environmental concerns from buying "green" vehicles. These constraints included vehicle features, family and work responsibilities, residential choices, and routines and preferences.

Lanzendorf (2003), in a study laying out the theoretical framework for mobility biographies, concludes that retrospective qualitative interviews are the best method to explore the variety of possible interactions and to discover causal relationships between different life domains. Næss (2006), studying the relationship between urban structure and travel behavior in the Netherlands, uses semi-structured interviews of 17 households – focusing on the reasons for activity participation, location of activities, travel mode and routes, and on the opinions about different parts of the metropolitan area as places to visit and to live in – to identify the detailed mechanisms through which urban structure affects travel behavior. Næss (2007) looks at the rationales behind people's travel behaviors (including activity participation, destinations, mode and routes choice) via interview analysis of 28 households in Hangzhou, China, and shows that outer-area residents travel more and use more private cars than those live in the central areas.

As suggested by Røe (2000) that qualitative analysis in urban transportation field should be based on both empirical evidence and prior theoretical framework, I employ qualitative analysis, beginning with semi-structured interviews, coding the interviews with different coding techniques, and conducting content analysis and narrative analysis. These methods are described below.

A key aspect of interview-based qualitative research relates to data analysis, which entails both processing and analysis. One major branch of methods that is entirely inductive for qualitative theory building, the grounded theory approach suggests three ways of coding: open coding, axial coding and selective coding (Strauss and Corbin, 1998). Open coding identifies first level concepts and categories, axial coding makes connections between categories and sub-categories, and selective coding chooses one core category to develop a single storyline so that all other categories can be related around it (Strauss and Corbin, 1998). After several rounds of coding, patterns in the data presumably become apparent, making it possible to generate hypotheses or statements of relationships. The coding effort is not about seeking confirmation of some presumed relationships, but involves looking for variations and contradictions in the data (Strauss and Corbin, 1998). Content analysis is usually used in exploratory qualitative studies to build core constructs from textual data through a systematic method of reduction and analysis (Miles and Huberman, 1994). Text is coded into established categories to support the generation of ideas, and the number of times a similar piece of text is attributed to a category can then be counted. The method is often used in computerized qualitative analysis where large sections of text can be rapidly coded by computer software. Following data reduction, constructs are formulated through a process of interpretation based on the contextual settings from which data were derived (Parahoo 1997). Another method to analyze interview data is narrative analysis, trying to find the “stories” interviewees are telling (Kvale, S., and S. Brinkmann, 2008).

In my research, which entails household interviews (described further below), I utilize these three techniques (open coding and axial coding[11], content analysis, and narrative analysis) to analyze the interview data in order to: construct concepts around lifestyle; explore household decision-making mechanisms related to residential choice and vehicle portfolio choice, considering the dynamics between household members; identify different lifestyle groups and differences in behaviors across these groups; and, understand household attitudes towards policies and the potential effects of hypothetical policies.

3.2.2 Quantitative Modeling Methods

Quantitatively answering the basic research question on household energy use behavior under the behavioral theories elaborated above requires disaggregate household-level data to apply relevant statistical models of end-users. Based on the initial theoretical framework with the ownership component and usage component of household energy consumption developed in Chapter 2, endogeneity is a basic econometric challenge for the quantitative analysis, as the ownership and usage are two interrelated decisions—the usage is conditional on the ownership, but ownership may also be conditional on expected utilization levels (Dubin & McFadden, 1984). This endogeneity problem has two interrelated dimensions: one is the issue of residential self-selection for travel energy consumption (see bottom left part in Figure 3.9) discussed in Chapter 2, Section 2.1.3—“the tendency of people to choose locations based on their travel abilities, needs and preferences” (Litman, 2005); and the other dimension is the discrete-continuous problem of endogeneity possibly existing in both travel and in-home energy consumption (left part in Figure 3.9). At the same time, in order to test the hypothesis of lifestyle heterogeneity, lifestyle segments have to be identified. This section will review relevant previous approaches in the literature dealing with both dimensions of endogeneity, describe methods and variables to identify lifestyle, and introduce the quantitative methods adopted in my research for hypothesis testing.

Regressions are widely use for estimating residential energy consumption (see Mulder, 1996 and Swan & Ugursal, 2008 for comprehensive reviews). For example, Ewing & Rong (2008) develop a hierarchical model to examine the relationships between urban form and housing stock, with the household level nested within the places level. In the hierarchical model, intercepts and coefficients of Level 1 models are regressed on place characteristics in the Level 2 model (Ewing and Rong, 2008). Handy (1996) gives a comprehensive review of the quantitative methods used in modeling the built environment and travel behavior link, including: simulation studies, aggregate analysis, disaggregate analysis, choice models, and activity-based models.

In terms of self-selection, Mokhtarian and Cao (2008) summarize the approaches researchers have used to deal with the issue of residential self-selection. Since panel/longitudinal data are not available for my research, only methods working with cross-sectional data are reviewed here. As residential self-selection arises mainly via attitudes and socio-economic traits,

[11] Coding is done using the qualitative analysis software “dedoose”.

the approach of statistical control measures includes attitudes as observables in the regression model. After controlling for rich socio-demographics, many recent studies with disaggregate data find no impact of self-selection (Brownstone, 2008).

Instrumental variable approaches aim to purge endogeneity in the behavioral models, by first modeling the built environmental characteristics and then using the predicted values as instruments to replace the observed built environment variables. For example, Boarnet & Sarmiento (1998) use instrumental variables to deal with the endogeneity of residential density in regressions explaining vehicle travel, using percentage of black and Hispanic population in the neighborhood and age composition of housing stocks as instruments. The non-transport neighborhood amenities such as school quality, the demographic composition of the surrounding neighborhood and the age of the housing stock in the surrounding neighborhood, are among the "allowable instruments" for residential choice (Boarnet & Sarmiento, 1996).

Among methods that model joint discrete choices, Bhat & Guo (2007) pioneered the theoretical development and empirical application of a joint structure modeling discrete residential choice and ordinal car ownership. Using data from 2,954 households in the 2000 San Francisco Bay Area Travel Survey and a joint mixed multinomial logit-ordered response model, Bhat & Guo's results show that the built environment has a true influence on auto ownership; the lack of a significant common error term in their application failed to support the speculation that attitude-based residential self-selection influences auto ownership choice.

In the context of this research, I utilize the method of statistical control with demographic and socio-economic characteristics as well as a set of attitudes, and the joint discrete choice of residential and vehicle ownership to account for the potential residential self-selection issue (see right part in Figure 3.9).

The discrete-continuous nature of the ownership component and usage component adds complexity to the issue of endogeneity. It requires some form of econometric correction, to account for the endogeneity in the fact that households with a high expectation of using a product might purchase a particular type or number of products (e.g., households preferring cooler housing might purchase more air conditioners and purchasing more air conditioners results in more electricity for cooling use). Dubin & McFadden (1984) formalize theoretically and examine empirically that households' home appliance ownership and appliance use are related decisions, and present a unified modeling approach consistent with utility maximization.

This can be solved in a simultaneous or two-step method. The latter is basically an instrumental variable approach as discussed above. The two-stage instrumental variable model regresses the endogenous ownership variable on instruments that are correlated with the ownership variable but not with the usage variable, then uses the predicted value from the first stage as an explanatory variable in the second stage regression model. For example, Vaage (2000) uses the binominal logit regression to model the discrete choice of heating appliance ownership, and uses linear regression to model the continuous conditional energy demand. Giuliano & Dargay (2006) justify the two-step method by assuming a sequential decision-making process: (a) household car ownership is a medium-term decision given longer-run choices of residential location and (b) individual travel is the outcome of short-term decisions, given household car ownership and residential location; they estimate an ordered probit model of car ownership and then incorporate the ownership likelihood in a second step OLS model for travel. Vance & Hedel

(2007) use instrumental variables in a two-stage model of car use and VMT conditional on car ownership.

Although consistent coefficient estimations can be achieved through the two-stage method, it is not efficient (Train, 1986; Mannering & Winston, 1985). While control function and related approaches can deal with the case of endogenous "explanatory" variables in the context of discrete choice and other non-linear models, efficient estimation (i.e. correct standard errors) is computationally very tedious (Bhat & Guo, 2007). Models that simultaneously estimate the two stages can be potentially consistent and efficient. There are several methods to achieve this. Dubin & McFadden (1984) provide one pathway, where a conditional indirect utility function provides the basis for deriving the continuous demand and the discrete choice. Bhat (2005, 2008) proposes another approach, a multiple discrete-continuous extreme value (MDCEV) model that embeds the continuous usage into discrete ownership choice. For example, vehicle use by each type of vehicle is a choice variable at the upper level and the vehicle type choices are modeled by a multinomial logit component at the lower level (Bhat & Sen, 2006). Fang (2008) develops a new method to solve multivariate discrete-continuous problems: using a Bayesian multivariate ordinal response system, combining the multivariate ordered equations with Tobit equations to jointly estimate vehicle type/usage demand in a reduced form, called a Bayesian Multivariate Ordered Probit & Tobit (BMOPT) model.

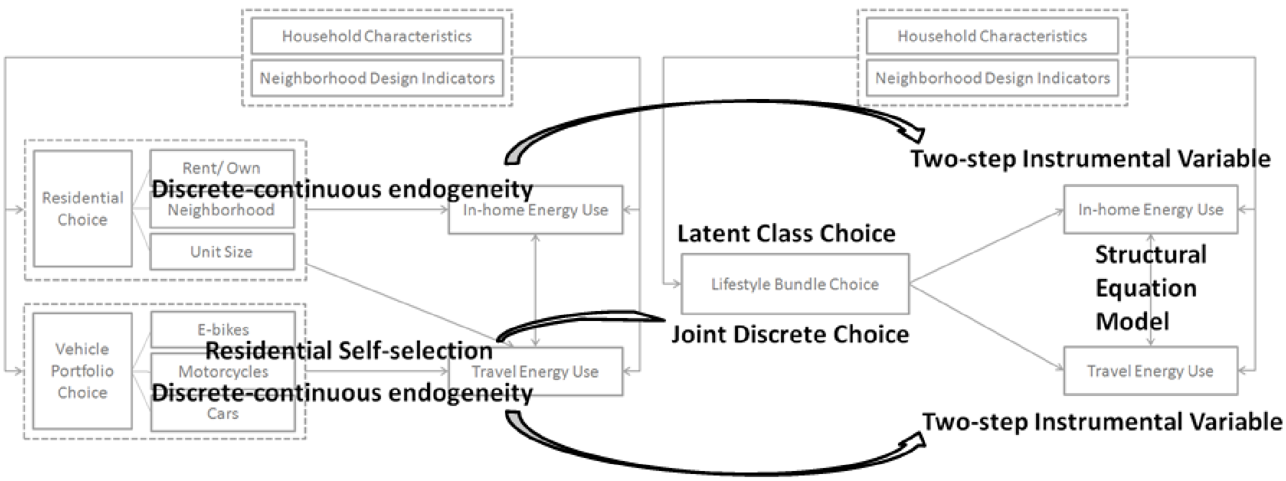


Figure 3.9 Analytical Challenges and Methods Adopted

In this research, I adopt the two-step instrumental variable approach to deal with the discrete-continuous endogeneity issue in the energy consuming behaviors of ownership and usage (right part in Figure 3.9).

In order to test the hypothesis of lifestyle heterogeneity, lifestyles have to be identified. Several relevant quantitative modeling methods have been used in the literature. Part of the endogeneity in the self-selection and discrete-continuous problems comes from the "unobserved" characteristics (e.g., households with a predisposition for walking choose walkable neighborhoods; households with a predisposition for cool air choose more air conditioners) which may be "contained" in the lifestyle. Lifestyle is presumably part of the unobserved characteristics that might be accounting for the interdependence of endogenous variables, i.e. a source of endogeneity. Therefore introducing lifestyle explicitly in the models is, in part, a way to purge the endogeneity problem. Similar to the methods dealing with endogeneity discussed previously (only that lifestyle is latent not observable), there is a distinction between a two-stage and a simultaneous model.

The two-stage models are widely used. Initial efforts, in related fields, to operationalize lifestyle, include using traditional demographic and socioeconomic variables and sometimes attitudinal and personality type variables. Then, factor analysis, cluster analysis, or principal component analysis is used to identify groups or latent variables which might represent lifestyle dimensions. Sometimes these groups or lifestyle dimensions can be used in second stage behavioral models. Among the earliest known examples of quantitatively incorporating lifestyle into behavioral models of transportation, Salomon & Ben-Akiva (1983) use K-means cluster analysis applied to a wide range of observable socio-economic variables to define five lifestyle segments, then at the second stage, estimate separate mode and destination choice models for each lifestyle segment. Krizek & Waddell (2003) use factor analysis and cluster analysis on households revealed travel and location choices (including travel characteristics, activity frequency, car ownership, and urban form at residential location) to identify nine lifestyle clusters. Prevedouros (1992) uses factor analysis from a personality survey to define three personality factors, then applies cluster analysis on the resulting factor scores to define eight personality types, before finally correlating the personality types to residential location and travel behavior. Bagley & Mokhtarian (1999) apply factor analysis on attitudinal surveys to identify ten attitudinal dimensions related to residential location preferences, travel mode preferences, views related to policies, and activity and schedule orientation, then show that the extracted factor scores are significant in a binary logit model of the choice of a suburban versus an urban neighborhood. Lin et al. (2009) propose to use the technique of Support Vector Machine (SVM) to develop classification functions, and identify six lifestyle clusters in suburban Hong Kong. The second stage model can be a structural equation model. For example, in Bagley & Mokhtarian (2002), the endogenous variables at the second stage include residential location type (represented as continuous factor scores measuring the degrees of 'suburbanness' and 'traditionalness' of each neighborhood), attitudinal variables, measures of travel demand, and job location (Walker & Li, 2006).

However, the two-stage models suffer from possible bias in parameter estimates due to measurement errors, as well as inefficiency because the variables of interest are not utilized at the first stage to inform lifestyle segmentation (Walker & Li, 2006). Methods of simultaneously estimating lifestyle and discrete choice include the Latent Class Choice model. Methodologically, latent class choice models provide an important advance in these models, allowing for different utilities to be estimated for each latent segment (McFadden & Train, 2000; Greene & Hensher, 2002). Walker & Li (2006) provide an example of employing a latent class choice model to capture the lifestyle heterogeneity of choosing where to live (residential location), with the latent classes as the lifestyles. Socio-economic characteristics such as income, age, and household structure are indicators for latent class membership and shown to be strong determinants of lifestyle preferences (Walker & Li, 2006). Zhao (2009) also utilizes a latent class choice model to explore the preference heterogeneity in car ownership behavior. Using socioeconomic attributes of households (e.g. income, age, and household structure) as well as residential location (e.g. living in outer city, train access) to predict latent classes, Zhao (2009) find households have heterogeneous sensitivities to "car pride" and "perception of convenience."

This research adopts the latent class choice model and utilizes demographic and socioeconomic characteristics as well as a set of attitudinal indicators for the simultaneous identification of lifestyle group with the first-stage lifestyle bundle choice model (Figure 3.9).

The simultaneous model can also be done rigorously in a full Structural Equations Model (SEM), which achieves consistency and efficiency through simultaneously estimating a series of measurement equations and structural equations (Mokhtarian & Cao, 2008). For example, Bagley and Mokhtarian (2002) use a nine equation structural model system with nine endogenous variables (two measuring residential location type, three measuring travel behavior, three attitudinal, and one job location), and find attitudinal and lifestyle variables have the greatest impact on travel behavior while residential location type has little direct impact. Brownstone & Golob (2008) build a simultaneous equations model of households' choice of residential density, VMT, and vehicle fuel use. Conditional on a rich set of socioeconomic covariates, they find that residential density choice is not determined by VMT or fuel use, but does influence VMT and fuel use.

In light of the quantitative precedents, my research objective and the available data, I chose the following three main model structures for hypothesis testing: (1) a multinomial logit (MNL) model, with a possible nesting structure for vehicle portfolio choice; (2) a joint MNL and latent class choice model for lifestyle bundle choice, consisting of residential choice and vehicle portfolio choice; and (3) structural equations models for travel energy and residential energy consumption, including an approach using the predicted values estimated in (2) as explanatory variables, by which the combination of (2) and (3) is a form of two-stage instrumental variable model.

(1) MNL model

The multinomial logit model is the most basic of the Generalized Extreme Value family of models (Ben-Akiva and Lerman, 1985). The model structure is shown in Figure 3.10. The form can be written as:

$$\boldsymbol{U_{in}} = \boldsymbol{\beta' X_{in}} + \boldsymbol{\varepsilon_{in}} \tag{1}$$

Where:

U_{in} is the utility of household n choosing alternative i;

$\boldsymbol{\beta}$ is a vector of coefficients;

X_{in} is vector of explanatory variables, including household attributes H_n, alternative attributes Z_k, and neighborhood design indicators N_i, as well as their interactions.

ε_{in} is the error term which is assumed to be extreme value i.i.d.[12]

Therefore the probability of household n choosing alternative c is shown as:

$$\Pr(Y_n = c) = \frac{e^{\beta_c X_{in}}}{\sum_{k=1}^{K} e^{\beta_k X_{in}}} \tag{2}$$

For the model to be able to identify, utility for one alternative has to be set as constant. Usually the utility of one alternative is set to zero; this alternative is called the "base alternative" and all the utilities estimated are relative to this base alternative.

[12] Independent and identically distributed.

Since the error term is assumed to be i.i.d., the MNL model also leads to the assumption of independence of irrelevant alternatives (IIA). A straightforward IIA test can confirm whether this assumption is violated; if it is, then another model structure (e.g. nested logit, probit, etc.) should be used instead of MNL.

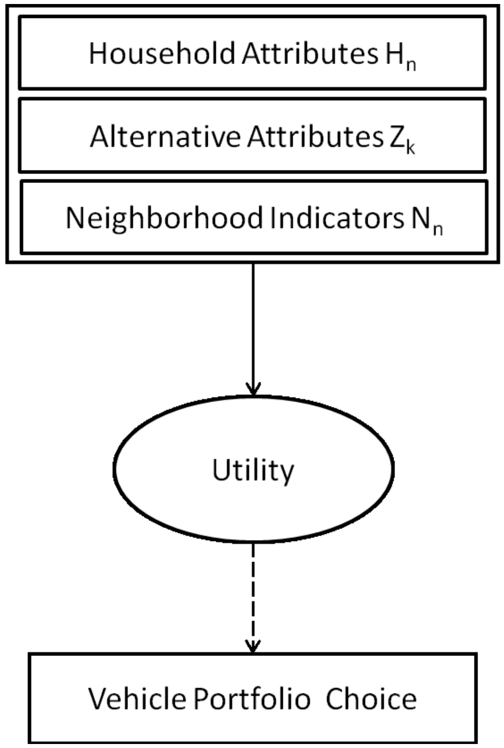


Figure 3.10 MNL Model Structure

In Chapter 5, an MNL model is used to test hypotheses related to vehicle portfolio choice and the interdependence of residential choice and vehicle portfolio choice.

(2) Latent Class Choice model

The latent class choice model is comprised of two component MNL models: a class membership model and a class-specific choice model (Figure 3.11). The class-specific choice model represents the choice behavior of each class and varies across latent classes. In this specific case, the latent classes could be interpreted to represent different lifestyle groups. The class-specific choice probability is written as $P(i \mid X_n, m)$: in this case, the probability of household *n* selecting lifestyle bundle choice alternative *i*, conditional on household attributes, X_n, and conditional on household *n* belonging to latent class (lifestyle group) *m*. The class membership probability is $P(m \mid X_n)$: the probability of household *n* with attributes X_n belonging to latent class (lifestyle group) *m*.

$$P(i \mid X_n) = \sum_{i=1}^{M} P(i \mid X_n, m) P(m \mid X_n) \tag{3}$$

In summary, the approach represented in equation (2) contains a:

(a) Class Membership Model (MNL), with:

- Alternatives: m lifestyle groups (latent classes);
- Explanatory Variables: Household attributes X_n (socio-economic and demographic characteristics, attitudes towards transportation modes, etc.) and other variables that theoretically may be and, through estimation are, determined to be relevant to class membership.

(b) Choice Model (MNL), where for each latent class (lifestyle group) m:

- Alternatives: the relevant choices (in this case, lifestyle bundle choices, consisting of housing unit size and vehicle portfolio combinations);
- Explanatory Variables: Household attributes and other variables that may be determined relevant to the choice.

For my purposes, estimating equation (2) will result in:

- Fitted value of lifestyle bundle choice probabilities: $\hat{P}(i \mid X_n)$,
- Thus, fitted value of housing unit size and vehicle ownership, e.g. $\hat{P}_{large}$, $\hat{P}_{small}$, $\hat{P}_{cars}$

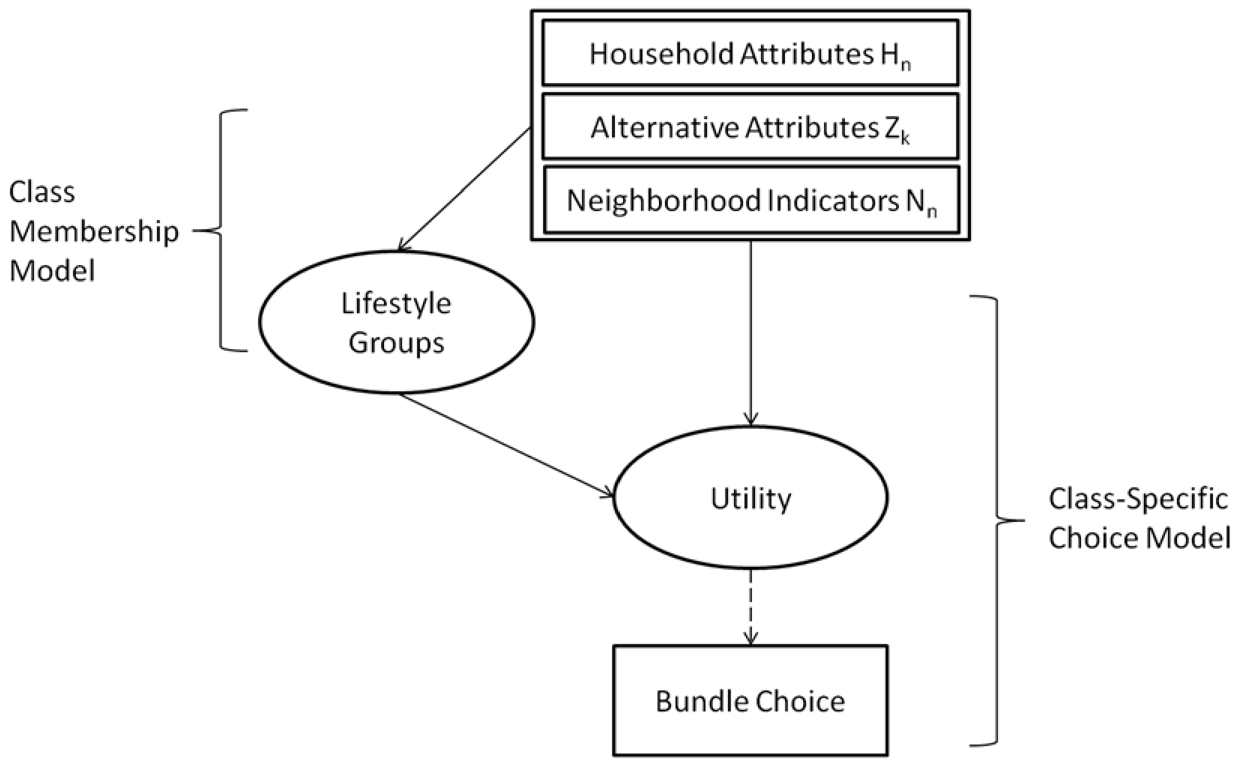


Figure 3.11 Latent Class Choice Model Structure

Revised from Walker and Li (2006)

In Chapter 6 I will use both MNL and latent class choice models to test hypotheses related to lifestyle groups.

(3) Structural Equations Model

To model travel energy and in-home energy, I consider three modeling approaches, represented in Figure 3.12, Figure 3.13, and Figure 3.14. The first approach attempts to use a latent variable representing household's "lifestyle tendency" with endogenous bundle choice and attitudes as indicators. The second approach incorporates the latent variable of "lifestyle tendency" but with bundle choice predicted probabilities from the bundle choice model as Instrumental Variables (IV's) and therefore treated exogenously. The third approach does not have the latent variable of lifestyle tendency, assuming lifestyle tendency is already captured by lifestyle bundle choice, and uses the predicted lifestyle bundle probabilities as IV's.

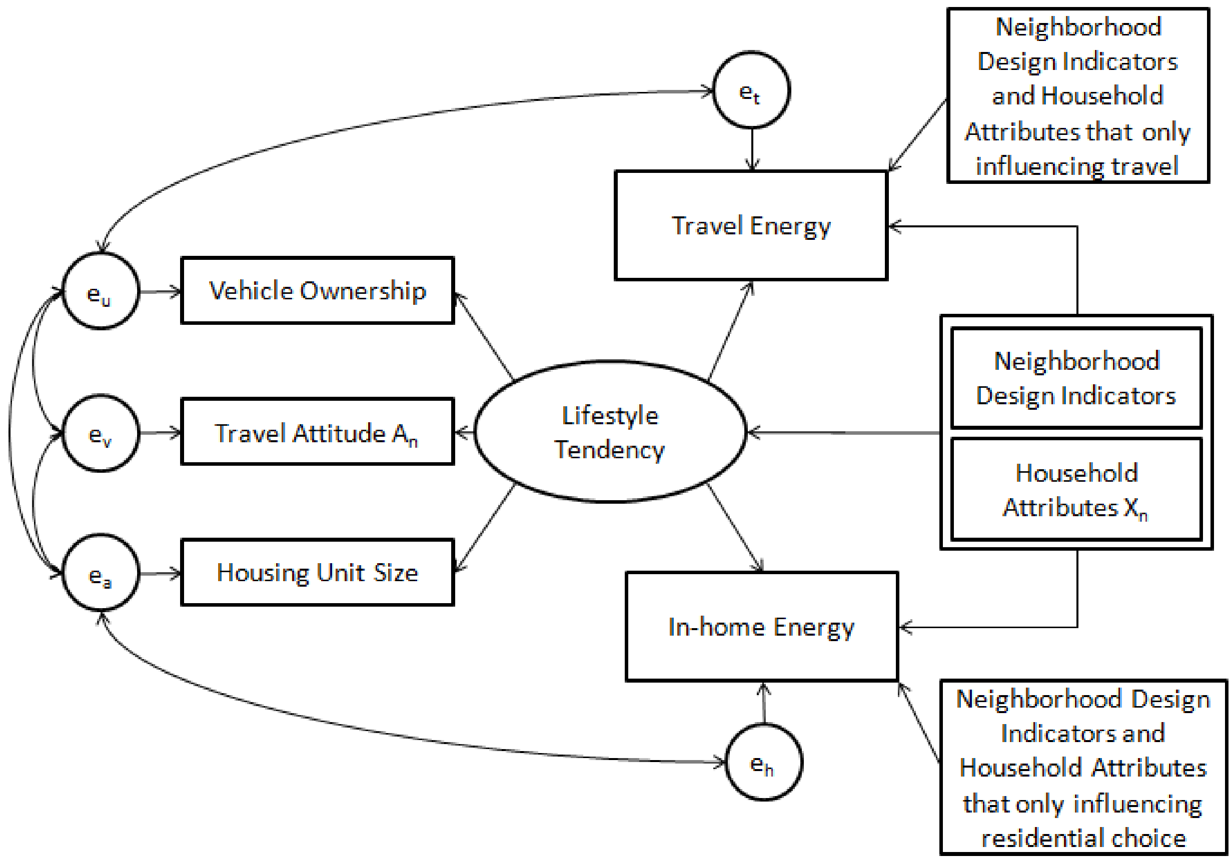


Figure 3.12 Model Structure for SEM Approach (a): with Latent Variable but no IV's

Figure 3.12 shows the SEM structure covering both ownership and usage components, without using predicted values from the bundle choice. The latent variable "lifestyle tendency" is a one-dimensional continuous variable with indicators (including housing unit size, vehicle ownership, and attitudes) as well as travel energy and in-home energy consumption.

There are two main issues with approach (a). First, the meaning and content of the latent variable "lifestyle tendency" is unclear. It has both ownership and usage as indicators, seeming to measure the overall tendency of direct energy consumption, but it is continuous—not reflecting the discrete heterogeneity of different lifestyle groups— and therefore unable to directly test the hypotheses raised. Second, practically, most existing SEM software cannot deal with discrete-nature endogenous variables, and treating vehicle/unit size ownership as well as travel attitudes as continuous might violate the model assumption and result in estimations that do not make sense.

Considering the severity of these two issues, I do not adopt approach (a).

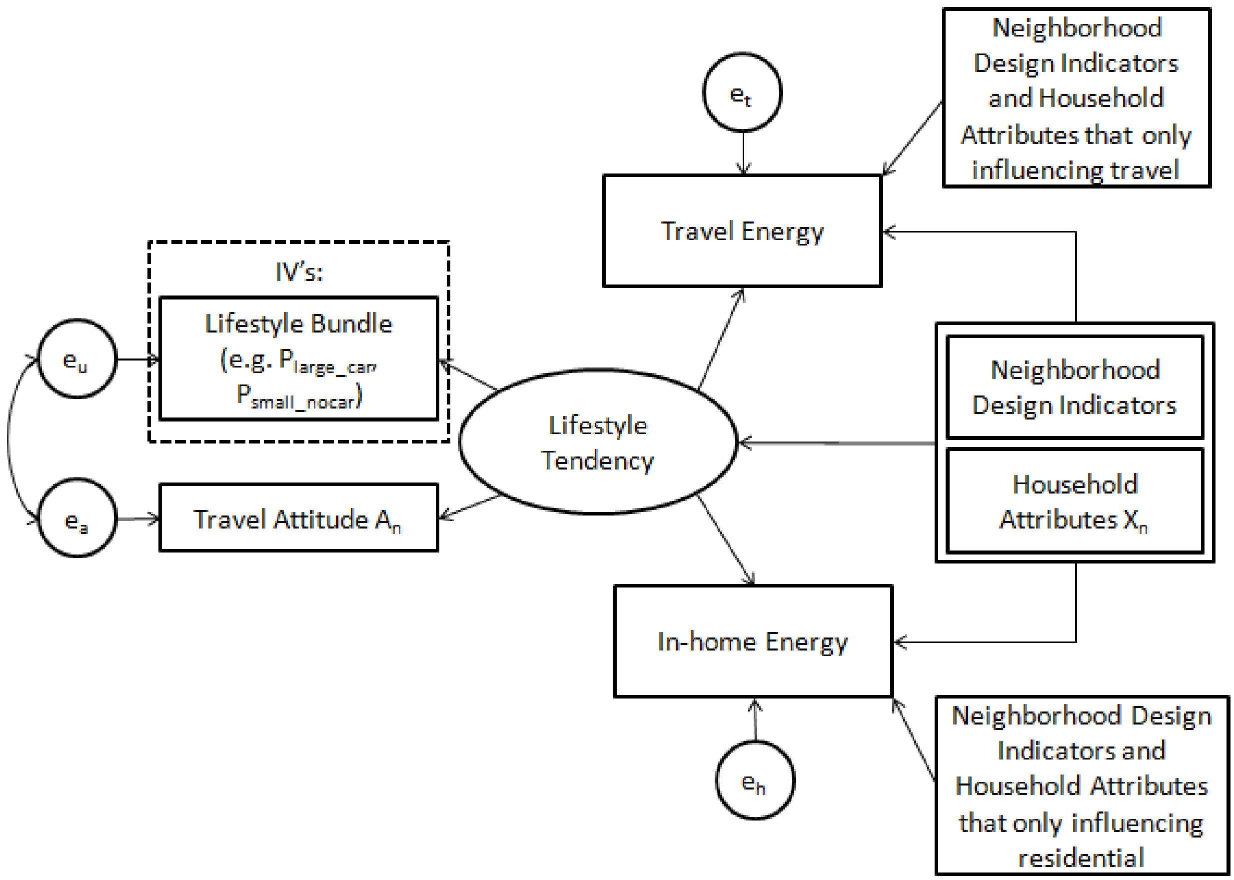


Figure 3.13 Model Structure for SEM Approach (b): with Latent Variable and IV's

Approach (b), shown in Figure 3.13, represents the second stage of a two-stage instrumental variable model. The predicted values calculated from the stage 1 bundle choice model are used as Instrumental Variables (IVs) explaining energy consumption. Possible exogenous variables influencing bundle choice but not energy use directly (instruments in the first stage) include: some attitude questions, underground parking provision, having access to a company car, and regional accessibility measures. For a detailed discussion on valid instruments, please see the model estimation in Chapter 7.

This approach also faces challenges. The objective of approach (b), specifying a latent variable called "lifestyle tendency," is to try to capture the lifestyle difference in the energy usage component (versus the first stage latent class choice model which captures the lifestyle difference in the ownership component). This is theoretically attractive as a household might indeed exhibit different "lifestyles" relating to ownership versus usage behaviors. However, in the context of this research, we do not have enough indicators "directly" measuring this latent variable ("lifestyle tendency" for usage); therefore, lifestyle bundle, attitudes towards travel, as well as travel energy and in-home energy consumption are all used as indicators, which obscures the meaning of "lifestyle tendency." The model results would be difficult to interpret.

Therefore I ultimately do not adopt approach (b) either. The lack of indicators for the lifestyle tendency at usage stage requires a compromise: leaving out this latent variable in the final model.

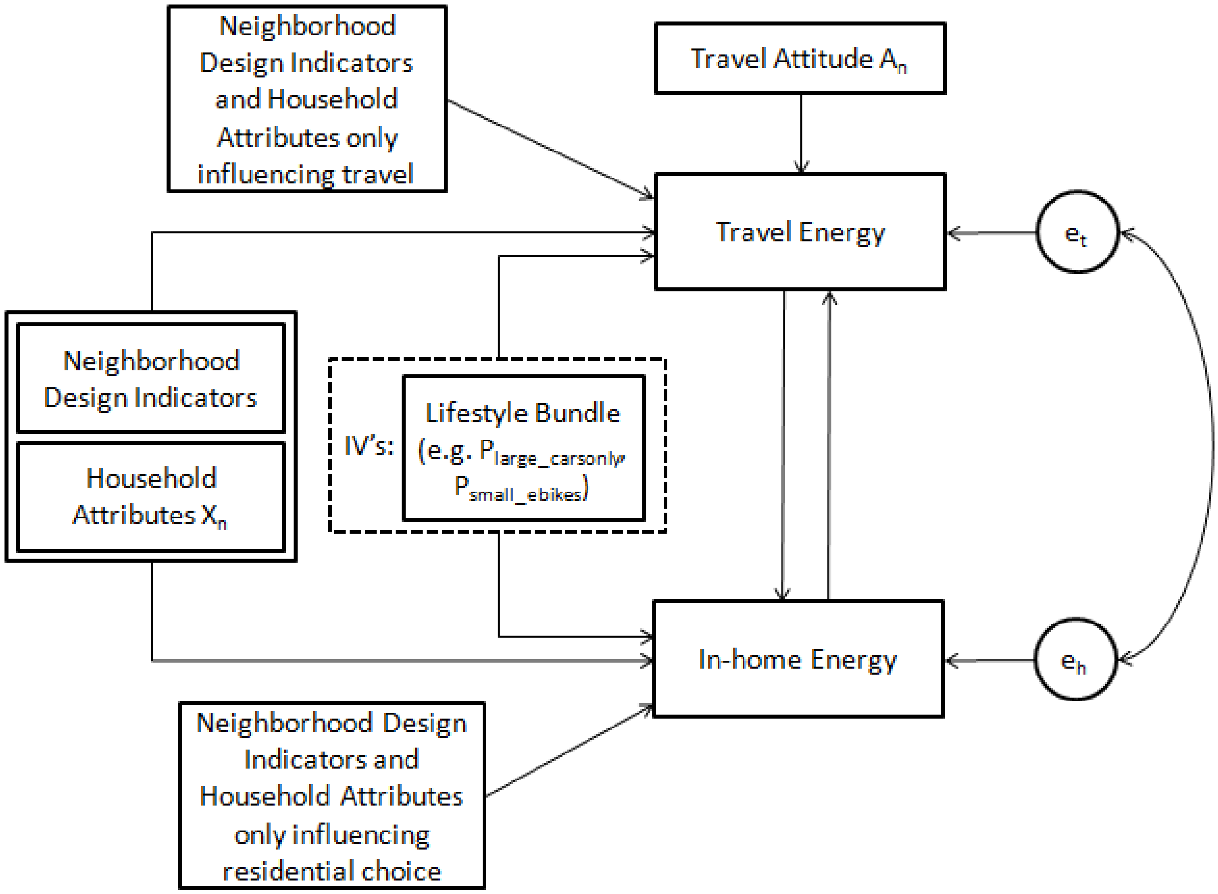


Figure 3.14 Model Structure for SEM Approach (c): with IV's but no Latent Variable

In the end, I adopt approach (c), shown in Figure 3.14. Travel energy use and in-home energy use are the only two endogenous variables, and predicted values from the first stage bundle choice model are used as explanatory variables. There is no latent variable for lifestyle, assuming lifestyle differences are already captured in the first stage bundle choice model. In Chapter 7 I use this model structure to test hypotheses related to energy consumption.

3.2.3 Elasticities and Simulation

Since it is difficult to see the effect of one explanatory variable directly from the estimation results – i.e. the coefficient estimations in the MNL model, the latent class choice model, as well as the two-stage SEM – elasticities and simulations are needed to interpret model results.

Disaggregate elasticities in discrete choice models represent the sensitivity of an individual's choice probability to a change in the value of some attribute (Ben-Akiva and Lerman, 1985). Some scholars use point elasticities at the sample means. For example, Cervero (2002), based on a model of mode choice for journey to work, computes elasticities by increasing one explanatory variable by 1% and applying the model to measure the corresponding percentage change in choice probabilities, setting values for all other variables in the utility function at their statistical means or modes. These point elasticities represent the sensitivity of the dependent variable to the explanatory variable for a "typical" respondent instead of the average individual elasticities (Cervero, 2002). However, as elasticity is usually not constant and the relationship with the explanatory variables is usually nonlinear, it is more appropriate to use average elasticities, instead of point elasticities evaluated at sample means (Train, 2002; Brownstone, 2008).

Elasticities calculated in this research are average elasticities, calculated via sample enumeration: for each respondent in the sample, I calculate the individual elasticity by increasing the examined explanatory variable by 1% and estimating the percentage change in the dependent variable, with all other explanatory variables taking their actual values for the particular observation. Then individual elasticities are averaged over the whole sample.

Since elasticities are usually not constant and the relationship with the explanatory variables is nonlinear in most of the model structures, a single average elasticity does not show the whole picture of effects at different values for the explanatory variable. Thus, I use simulations and produce graphs of the simulated results for the vehicle portfolio choice model, lifestyle bundle choice model, and energy consumption model.

Similar to the elasticity calculations, simulations are also done in a "sample-average," instead of "typical household," approach. The "typical household" simulation takes the mean (or median) values of the sample for all other non-examined explanatory variables, varying only the variable of interest. One issue with the "median household" approach is that the "typical household" is assumed to represent the average characteristics of the total sample, with all characteristics taking the median value of that attribute, which might not even exist in the real world. The more explanatory variables there are, the less likely the combination of median values of all variables exists. For example, the "median household" in the total sample of the Jinan household survey is a family consisting of three household members—two employed and no kids or senior people—living in a neighborhood with mixed attributes of enclaves and superblocks. Especially with dummy variables and neighborhood design variables, it is extremely difficult to find any household that is "typical" or "representative." Furthermore, in latent class choice models, it is challenging (and sometimes arbitrary) to choose one "default" value to set for an explanatory variable that the class membership is very sensitive to (e.g. access to a company car, underground parking provision): a little change in the default value would produce a completely different picture for the simulation. Therefore, all simulations are done as "sample-averages." A description of the simulation procedure follows.

Suppose one explanatory variable (the i^{th}) is selected to be simulated: x_i, e.g. household income. First the simulation range of interest is set, e.g. household income from zero to 1,000 thousand yuan per year; and the interval step size Δx_i is set, e.g. 10 thousand yuan for household income. Iterate x_{in} from the start value until the end value in the set range of interest with interval step size Δx_i, keeping all other explanatory variables at their own actual values. In each iteration, for each individual household in the sample, I compute the dependent variable value according to the model estimation results, getting a simulated Y_n for household n. Then, I average Y_n over all households to get a sample average of Y at each simulated value for X.

For the MNL models of vehicle portfolio choice, the utilities of owning different vehicle portfolio alternatives are calculated and therefore probabilities of a household choosing each vehicle portfolio alternative are obtained: Y = probabilities of a household choosing different vehicle portfolios. Stack graphs are produced to show the probabilities.

For the MNL models of lifestyle bundle choice, the utilities of choosing different lifestyle bundles are calculated and therefore the probabilities of a household choosing each lifestyle bundle alternative are obtained: Y = probabilities of household choosing different lifestyle bundles. However, since the bundle choice is the joint choice of residential and vehicle ownership, the number of alternatives is likely to be large. Therefore the probabilities are aggregated in residential choice and vehicle ownership choice categories to be plotted on stack graphs.

For the latent class choice models of lifestyle bundle choice, the membership choice model is first used to compute the probabilities of a household belonging to each latent class, W_i; then the class-specific choice model is used to compute the choice probability of each alternative P_{ij}, and the membership probabilities are used as weights to get average alternative probabilities: $P_j^w = \sum_{i=1}^{K} W_i \times P_{ij}$, Y = probabilities of household choosing different lifestyle bundles P_j^w. Since the number of alternatives is likely to be large, the probabilities are aggregated in residential choice and vehicle ownership choice categories to be plotted on stack graphs.

Finally, for the SEM of energy consumption, Y (travel energy consumption/ in-home energy consumption/ total direct energy consumption), a similar choice, as identified above, is taken, with energy consumption simulations plotted as line graphs. If the simulated explanatory variable is a dummy variable, there are only two iterations of X_i : 0 and 1. Income is then used as a "background" simulator whose value changes from the starting value to ending value just like the simulation for household income for each of the two iterations of X_i, and line graphs are plotted distinguishing when the examined dummy variable is 0 or 1.

Simulations are implemented by a program written in Perl and graphs are produced using Gnuplot.

3.3 Data

3.3.1 Quantitative Data

1. Household Survey Data

Household surveys in Jinan were carried out by teams from Shandong University, in 2009 and 2010. Each questionnaire required about 15 to 30 minutes to complete, and covered questions on basic demographic and socio-economic information of each household member, housing and vehicle ownership, weekly travel and in-home energy use, and a series of attitudinal questions.[13]

In total, the 2009 survey included 2631 questionnaires from households in 9 neighborhoods and the 2010 survey collected another 1530 questionnaires from households in another 14 neighborhoods.

[13] There were some differences in the questionnaire design between the surveys done in two years. One major difference is in the trip table. In the 2009 survey, the respondents are asked to list all major trips made by household members in weekdays and in weekends, while the surveyor only recorded the trips that are reported; in the 2010 survey, the trip table is broken into commuting trip and non-commuting trip. Other differences include the 2009 survey does not ask about occupancy information for each trip but 2010 does. The attitudinal questions in 2010 expand to more about environmental consciousness and lifestyle, replacing some questions concerning housing and neighborhood asked in 2009. The 2010 questionnaire has an extra part of satisfaction towards the current neighborhood and ranking of factors when choosing neighborhood, which the 2009 questionnaire does not have.

Table 3.2 Summary Statistics of Variables in the Jinan Household Survey

Variables	mean	s.d.	min	max
Household socioeconomic characteristics				
household annual income (1,000 yuan/year)	77.57	61.14	3.6	720
household annual income (US$/year)	12,121	9,553	563	112,500
household size	3.03	1.10	1	10
number of household members currently employed	1.66	0.94	0	8
Housing unit attributes				
unit area (m2)	88.40	50.70	6	960
building height	7.24	4.54	0	33
Household Energy Consumption				
travel energy consumption (MJ/year)	11,424	29,860	0	1,111,591
in-home energy consumption (MJ/year)	64,118	44,251	0	985,611
*Attitudes towards travel**				
driving is a sign of prestige			51.6%	
taking bus is convenient			76.1%	
I like biking			74.1%	
time spent on travel is a waste to me			64.5%	
Housing Tenure				
renting			18.2%	
homeowner without mortgage			67.2%	
homeowner with mortgage			13.5%	
Household Structure				
single			7.1%	
couple			21.3%	
couple with kid			44.5%	
senior household			10.7%	
have kid in the family			48.2%	
have senior people in the family			29.7%	
no household member is currently employed			14.1%	
two household members are currently employed			55.5%	
3 or more household members are currently employed			10.4%	
have more than 4 household members			26.6%	
Living on top floor or first floor				
top floor			14.5%	
first floor			20.7%	
Other resources				
whether have access to a company car			2.5%	
Household vehicle and appliance ownership				
whether own private cars			31.8%	
whether own motorcycles			8.6%	
whether own e-bikes			37.9%	
whether own bikes			55.8%	
no air conditioner			21.3%	
one air conditioner			37.5%	
two or more air conditioners			41.2%	

*Percentage of households agreeing with the attitudinal statement (scores of 3 or more are counted as agreement)

Appendix A2 provides detail on how the information from the survey was used to calculate travel and in-home energy. Table 3.2 summarizes variables ultimately used in the analysis. Dummy variables are shown in percentages.

2. Neighborhood Design Indicators

The School of Geography and Remote Sensing of Beijing Normal University assembled a team which led the effort to collect data on the physical attributes of the 23 neighborhoods comprising the sampling frame.

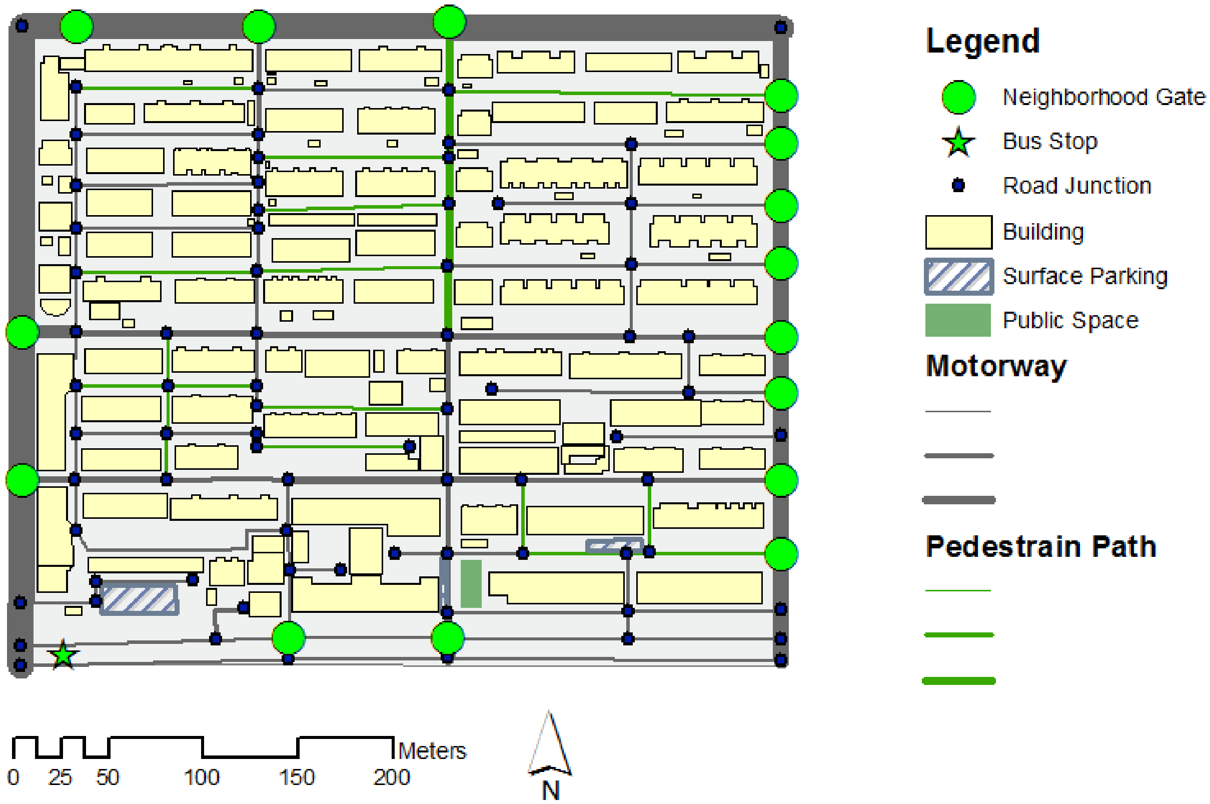


Figure 3.15 GIS information Collected in a Sample Neighborhood in Jinan

For example, Figure 3.15 shows the basic GIS information collected for each of the 23 neighborhoods (e.g. E02). The building layer does not only have the shape of building footprint, but also contains the height (number of floors) of each building, and function/use (residential, commercial, public facility, etc.) of each floor. Besides the road junctions, the information collected for each road segment includes width, length, whether the road segment has tree canopy, and, for motorways, whether it has sidewalk. Designated surface parking and public space (including green space and open space such as public squares, playgrounds, etc.) are marked. Neighborhood gates (entries) through which people can enter or exit are located by points, as are bus stops with route number information.

In addition to the neighborhood-level design and form related variables, each neighborhood was assigned relative location characteristics, calculated using city-wide data including land use, road network, public transit network, as well as city-level attraction points in six categories (i.e. factory, office, school, hospital, shopping, and public space).

Table 3.3 Summary Statistics of Neighborhood Design, Form and Location Indicators

Variables	mean	s.d.	min	max
Neighborhood size (m^2)	245,238	137,593	25,572	537,517
Residential density (# of hh's per acre of land)	67	17	26	104
F.A.R.	1.80	0.50	0.78	3.16
building coverage	0.32	0.11	0.07	0.54
average building height (# of floors)	6.81	3.77	1.88	18.40
building height standard deviation (# of floors)	3.87	5.20	0.30	41.00
Green coverage	0.15	0.12	0.00	0.38
Average building footprint area (m^2)	529	256	48	1179
Entry interval distance (m)	332	291	81	1178
Building function mix	0.22	0.17	0.01	0.58
land use mix within 500m radius	0.65	0.07	0.51	0.81
Underground parking space per hh (sapce/hh)	0.17	0.27	0.00	0.80
Surface parking space per hh (m^2/hh)	1.99	2.25	0.00	11.19
% of roads with trees	0.45	0.31	0.00	1.00
% of residential buildings with street-level shops	0.14	0.12	0.00	0.39
% of roads with walking facilities	0.51	0.30	0.00	1.00
Road density (km/km^2)	30.31	10.04	10.16	56.72
Intersection density (# of intersections per km of road)	9.94	3.44	3.51	17.56
% of cul-de-sacs in all intersections	0.23	0.18	0.00	0.73
Average width of motorway	8.09	4.46	3.17	31.09
Bus routes with stops within 500m radius	12.03	5.49	4.00	24.00
BRT routes with stops within 500m radius	0.77	0.90	0.00	3.00
Distance to city center (m)	4.00	2.00	0.70	8.70
Continuity of street façade	0.67	0.07	0.55	0.79
*Regional accessibility measures**				
Regional Accessibility (factory)	14.23	7.88	3.75	44.88
Regional Accessibility (hospital)	6.54	5.32	0.76	24.86
Regional Accessibility (office)	13.71	20.67	0.94	82.81
Regional Accessibility (public space)	4.94	5.92	0.69	32.10
Regional Accessibility (school)	10.69	8.96	1.28	34.05
Regional Accessibility (shopping)	79.41	103.09	4.44	426.84
Regional Accessibility (total)	129.53	115.10	20.19	448.56
*Simulation based solar/wind indices**				
summer solar gain index	0.30	0.12	0.07	0.56
winter solar gain index	0.27	0.08	0.09	0.40
Southern Exposure Index	0.35	0.03	0.27	0.39
Summer Shadow Ratio (Roofs)	0.01	0.01	0.00	0.04
Summer Shadow Ratio (Facades)	0.10	0.07	0.04	0.55
Winter Shadow Ratio (Roofs)	0.06	0.04	0.00	0.17
Winter Shadow Ratio (Facades)	0.29	0.11	0.18	0.88
façade to volume ratio	0.28	0.14	0.16	0.75
Porosity	0.68	0.10	0.46	0.91
height irregularity index	7.45	6.07	0.94	32.36
building wind summer	0.73	0.02	0.68	0.78
building wind winter	0.72	0.04	0.58	0.79
surface to volume ratio	0.40	0.19	0.21	0.94

*Regional accessibility and simulation-based solar/wind indices calculation see Appendix A3 and A4.

Wind and solar indices are calculated using simulation. For detailed calculations of accessibility and simulation-based wind and solar indices, see Appendix A3 and A4. Please see a complete list of neighborhood-level indicators and their descriptive statistics for the 23 neighborhoods in Table 3.3.

3.3.2 Qualitative Data

From January to March in 2011, I conducted semi-structured interviews with 35 households and more than 50 persons. Each interview lasted from a half hour to a half day, with recording lasting from 30 minutes to one hour and 40 minutes. Most of the interviews were completed inside the interviewee's home, with a few exceptions (one in local café, one in neighborhood courtyard, a few in work places, and one on the internet[14]). The majority of interviews conducted at home were with two or more participants—the household head, usually with the spouse, and sometimes with a parent or a kid as participant as well. The interview was semi-structured with questions on residential and vehicle ownership portfolio decisions and energy-using habits, including: lifestyle ideals (peaceful life, adventurous, trendy, westernized, self-fulfilling, etc.); sequence of the purchase decision-making (e.g. whether vehicle ownership or commuting were considered while making residential location decisions); activities household members desire; main purpose/motivation of home buying/renting (e.g. marriage, wife getting pregnant, housing policy, etc.); factors taken into account when moving; main purpose of the vehicle purchase decision (e.g. child, holidy trip, commuting, etc.); factors taken into account when buying vehicles; home and vehicle purchase decisions made at the household level (interactions between household members); attitudes and perceptions towards current trends (such as charging for plastic bags in supermakets, gas price, housing price, etc.), residential space, transportation modes, residence (e.g. size, amenities, etc.), job, money, environmental issues, culture (e.g. whether living with parents), and social status. The interviews also elicited attitudes and comments towards current or hypothesized urban policies such as fuel tax, metro construction, congestion charging, transit-oriented development, etc. (see Appendix A1 for interview protocol). As most interviews were conducted right after the Spring Festival, a "red package" of 50 yuan ($8) representing "good luck of the New Year" was provided to each interviewed household as appreciation.

Potential interviewee households were selected from among the respondents of the Jinan Travel and In-home Energy Use Household Survey (as described in previous section). I stratified the respondents according to their household income and household structure. I got 9 strata: high-, medium-, and low- income, by single of young couple without kids, core family with kids, and senior households. The initial list was constructed by randomly selecting 4-5 households from each stratum. Then I visited the home addresses of the households on my initial list to check their willingness to participate and availability. I conducted the interview right away if they were willing to participate and available at the time of my visit. I made appointments with those who were willing to participate but not available at that time. This round resulted in 18 completed interviews. I then visited more households in neighborhoods less represented in terms of typology (e.g. enclaves) and location (e.g. the southern part of the city), resulting in an additional ten interviews. Finally, I reached out through personal connections, references by interviewees, etc. to identify candidate households in less represented strata (e.g., high-income mid-aged family living in the southern superblock development; and young single who is

[14] Using a Chinese online chatting program "QQ"

renting). At the end of this process, interviews of 35 households were completed, comprised of profiles aiming to be representative of urban households in the city of Jinan.

Among the interviewed households, income ranges from 20,000 yuan (or $3,000) per year to 500,000 yuan (or $80,000) per year. Though interviewees have different interpretation of the question about "annual household income" (some count bonus some do not, some of them deduct tax, insurance premium, social security, and some of them even deduct mortgage payment and other expenses), we can reasonably use 50,000 yuan ((or $8,000) as a benchmark for low-income or "poor", 150,000 yuan (or $24,000) to divide the middle-income and the middle-class ("xiao kang"); and 300,000 yuan (or $48,000) to define high-income or "rich" in Jinan (Figure 3.16). Around half of the interviewed households are "core families" with a kid under 18 years old. One fifth of them are couples, and another fifth are three generations living together. The household heads of the majority (77%) are between 30 and 50 years old. Half of the households own one home, one fifth own more than one home, 30% are still paying mortgage for their first home, and only one interviewed household is still renting. Half of the chosen households do not own a private car, 37% own one, and 14% own two or more private cars.

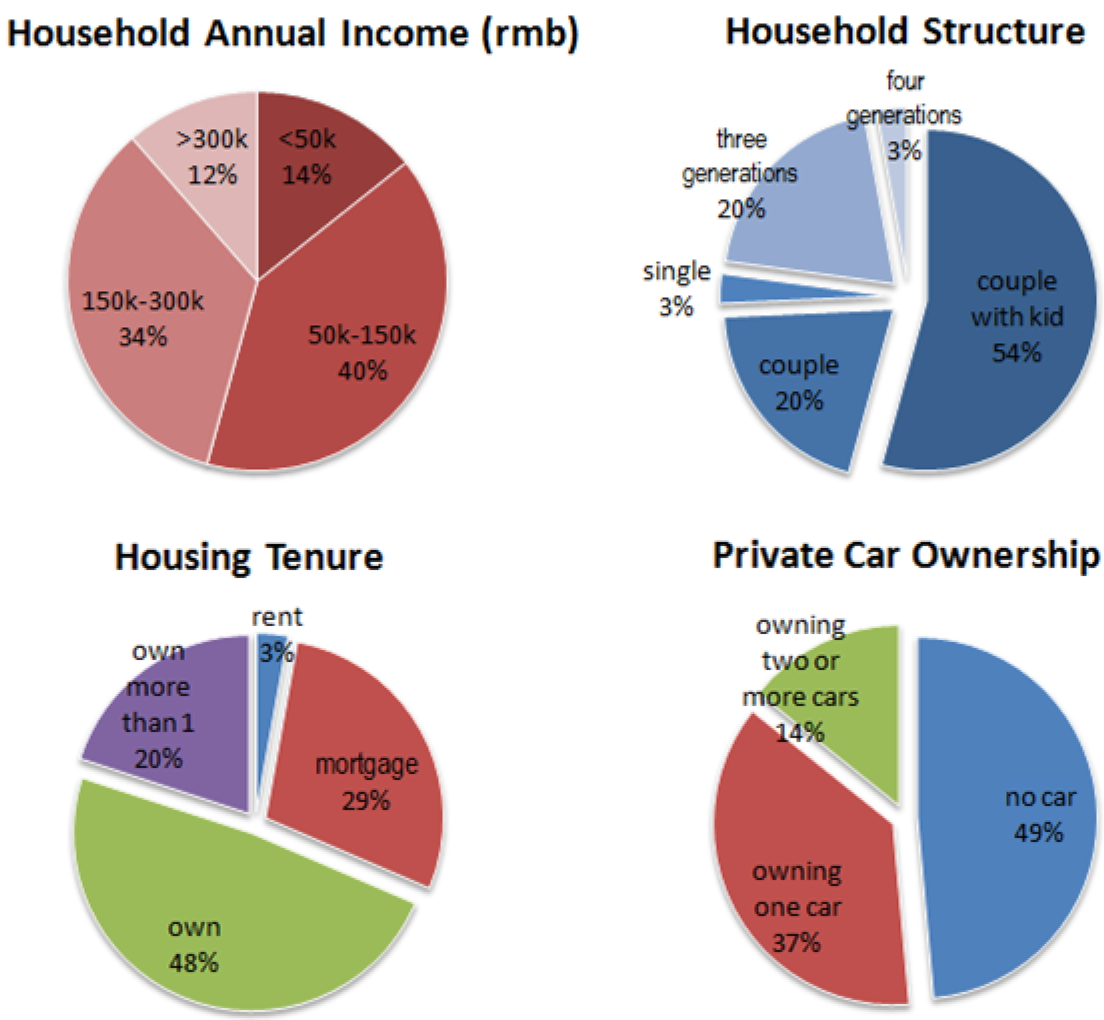


Figure 3.16 Interviewee Household Characteristics

Table 3.4 shows a comparison of a few demographic and socio-economic characteristics of the participants of the interviews, the household survey, and the general population of Jinan's urban residents (from official sources). The sample from the household survey is roughly comparable to the Jinan urban population, while the interview catches more core families (i.e., couple with kid), fewer single-person households, more high-income households, and more car owning households than the city average.

Table 3.4 Comparison of Household Characteristics of Sample and Population

	Interviews	household survey	Jinan urban residents*
sample size (# of households)	35	4,161	1.1 million
household size	3.31**	3.03	3.08
household disposable income (yuan/year)	148,333	77,571	77,989
# of employed household members	1.57	1.66	1.49
# of car per household	0.67	0.36	0.23
unit size (m2)	96.6	88.4	90.6
percentage of single	3%	7%	n.a.
percentage of couple	20%	21%	n.a.
percentage of couple with kid	54%	44%	n.a.

* data from Jinan Statistical Year Book 2011 for 2010 data, italic shows data for 2009

** there is an outlier with 11 household members in the family

After carefully examining the research context of Jinan, reviewing and adopting suitable qualitative and quantitative methods for theory building and hypothesis testing, and summarizing the data collected, this chapter has paved the road for the detailed analysis in the following chapters.

Chapter 4 Urban Lifestyle and Household's Decision-making

This chapter reports on the qualitative analysis of the interviews. I first establish the content and scope of lifestyle, then identify four distinct lifestyle groups in Jinan and characteristics of their decision-making processes, the discussion of the interdependence of residential and mobility choices is followed by mechanisms of lifestyle change. Contents and arguments in this chapter are based on the qualitative evidence in Jinan unless otherwise noted. Some representative quotes are selected from results of the qualitative analysis using open coding, axial coding, content analysis as well as narrative analysis, and the quotes are marked by the interviewee ID (see Appendix A5 for a summary of basic characteristics of the interviewee households).

4.1 The Hierarchy of Lifestyle

In this thesis I define lifestyle as: the way a household consumes direct energy, including personal travel and in-home energy, as derived from attitudes, perceptions, and values. Here the scope of lifestyle concept is more than patterns of energy consuming behaviors—it also includes attitudes, perceptions, preferences, and values (or core beliefs) that can influence behavior. The subject unit is the household instead of individual person. While the behaviors are the sum of ownership and usage behaviors of all household members, attitudes, perceptions, and core beliefs are the ones that influence behaviors, and these attitudes, perception, and values are usually of the key household members.

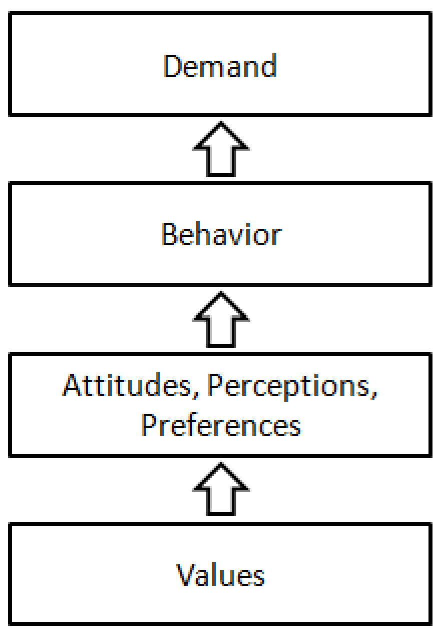


Figure 4.17 Hierarchy of Lifestyle Concept

This concept of lifestyle has four main components as shown in Figure 4.17 with a hierarchy of depth: from top to bottom it gets more deeply held, and takes longer to change. The demand for direct energy is derived from the basic demand of the household for comforts and conveniences residence supplies (e.g. warmth/cool/shelter/entertainment) and mobility. The energy consuming behavior includes purchase behavior of residence and vehicles; and usage behavior, which is the daily activities—travel patterns and in-home energy using habits. Attitudes, perceptions, and preferences are subjective characteristics household members have which influence behavior. Values are the deeply held core beliefs which lay the foundation for all the subjective characteristics.

4.1.1 Housing and Vehicle Demand, Purchase Behaviors

Examples of this hierarchy are abundant in the interviews. The household's demographic and socioeconomic conditions largely determine various kinds of demand for residence and mobility.

Getting married and having a baby are the most often-mentioned life events that make households consider home purchasing. Other reasons include taking care of elderly, investment, income increase, etc. For example, a retired couple mentioned wanting to buy a new residence with elevator because of the trouble getting up and down stairs, especially after the wife broke her leg. (#6) Several households with young children bought or intend to buy homes in good school districts specifically for kids' better education opportunities. However, households have very different demands for residences even with similar objective observable attributes such as lifecycle, income level or household structure. The demand for residence gets much more complicated when more factors are considered: some of these factors are outside the household's current status, including specific life events or some historic information not easily collected. For example:

> *"When we lived in Weihai (another city in Shandong), that dwelling, was around 90 sq.m., and had three bedrooms plus the living room and dining room, but only one bathroom. At that time we lived with my parents, and we had to take care of the kid. I thought at that time, it would be nice if we had two bathrooms. And that dwelling has upstairs and downstairs. ...to tell you the truth, this was something I haven't even told her (my wife). When I was in college and watched those Hong Kong movies, there were a lot of those double-deck units, you know, with stairs inside the room, then I felt, wow, that was so good. I went to Hong Kong last summer and realized Hong Kong people actually live in very small homes—enter the room and immediately you sit on the bed, exit the room and immediately you are on the street. So at that time, I thought this unit was quite nice, and we bought it very fast" (#30)*

Some aspects of familial conditions are also often outside the conditions typically observable in a household survey, including: support from parents, either in-kind (accommodation, childcare, home maintenance, making meals, etc.) or financial (e.g. parents provide down payment); and the support of parents or other relatives (health condition, financial condition, desire to move to the city, build their home, etc.),which can pose a huge burden and influence the household lifestyle decision to a great extent.

For example, planning for future family conditions is important:

> *"It (the previous housing) was too small. For families like us, with parents who live elsewhere, someday you have to live with them. The kid is growing older, and you have to get her a room. ...Yes we paid off the mortgage, but we borrowed from parents. Our current home is two bedroom plus living and dining room, total of 96 sq. m. I think in the future we need at least three or four bedrooms, because*

the elderly will live with us, at least his (husband's) parents. I have an older sister, and my mother said along before that as long as they can walk, they wouldn't live with us. She (my mother) wouldn't have come if not for babysitting! They have a house at home, in the township, the villa-type residence with a yard. Now I think that type of housing is the most luxurious." (#29)

Role of family and friend's financial support (or lack of one) is also evident:

"Our situation might be special. Both of us came from the countryside and neither of our families has any savings. Our parents could not support us, and to tell the truth, a few thousand doesn't help much either. Who wouldn't want to buy good housing in good places? It's not that we couldn't afford the mortgage payment, it's the down payment that we couldn't get. At last we made a hard decision and borrowed money from relatives and friends. Actually relatives and friends could also lend us money for down payment if we chose to pay mortgage, but it would be really hard to pay them back while paying the mortgage at the same time. Now we didn't borrow money from the bank (mortgage) so we just need to pay for one (the personal loan of relatives and friends)." (#7)

In July 1998, the State Council issued a notice calling for the termination of working unit housing allocation (State Council of China, 1998), and Shandong Province stopped the housing allocation as early as the end of 1997. From then on, employees can no longer get housing directly from their employers, but only a housing allowance and/or personal housing fund match. In other words, if the person is younger than 40 years old, he/she probably never got housing allocation from the employer, which makes a big difference in a household's home purchasing process. One transition product is the employer-sponsored housing development, using employer-owned land and funds collected from employees who are willing to buy/join the collective-purchase program. It is usually much cheaper than freely traded market housing, due to no cost of land acquisition. These employer-provided housing benefits differ greatly from one employer to another, and even for the same employer, the details of the policy are time- and position- specific (e.g. sometimes the rank of the employee determines the eligibility). Therefore the home purchase decision is indeed case by case, making generalizations from a household's static socio-economic status to residence demand extremely hard.

The age of the breadwinner in the household, his/her risk-taking tendencies, and industry of employment also make a difference because of the skyrocketing housing prices relative to income since the housing reform. From 1998 to 2010, the earlier one buys home, the more affordable it seems to be—given the average increase in income relative to home prices (see Chapter 3, Section 3.1.3 for statistics). With the same income, households with different risk tendencies make different decisions on home purchase; generally the earlier buyers feel lucky while the later buyers feel regret. Furthermore, the speed of salary increase is highly dependent on the industry and occupation, and the variance is large. Among the households interviewed, while the tobacco industry boomed and employees received salary increases and bonuses which were double, triple, or even ten times of their original income five years ago, workers in the traditional textile industry had been laid off and only get the minimum social security.

"We moved in ten years ago, yes, in 2001. Before that we lived in university allocated housing as well, just a small one, around 30 sq.m. with one bedroom and one living room. The current one is 70ish sq.m. with three bedrooms and one

living room. The housing in the 80s was all this kind of small 3-bedroom. …We used to consider buying our own (home), but not now, too expensive. As new neighborhoods were being built around us, we used to be interested. Then we considered the kid's going to school, and the university's shuttle…now the ones we can afford are too far away. Two years ago there was rumor saying our residences were going to be demolished and renewed, then we dropped the idea of buying home. And now…sometimes, looking at other's new home, I would feel tickled. But the residences are more and more expensive now. The money we have, we could have bought a bigger residence if we bought earlier, now the money is worth less and less, that's how I feel." (#35)

"During the National Games in 2009, (the housing price) rose a lot. At that time we were considering buying. We started looking around from 2008, and watched the housing price rising with our eyes, for at least 2,000 yuan (per sq.m.). But we had a problem. We graduated in 2007, and got married in 2008, and my family renovated their home (in the countryside), and we didn't have high income. Everyone knows you can't lose if you buy residence early, but we just didn't have money. […] We looked at one condo in early 2009, and it cost 420,000, and it was on the 7th floor as well, and location is more to the east, much better than here. You see our home is almost 400,000 including everything. But at that time we didn't have enough money…till we bought this one at the end of 2009, that condo was priced more than 550,000, just less than one year, from March to December…."(#7)

A similar situation applies to car purchase decisions as well. Driving the child is among the most cited reasons to own a private car. However, the timing of the purchase varies a lot even among those who share the same reasons. Some buy the car when the wife gets pregnant; some make the decision when the kid changes school level; for some, a sudden incident becomes the straw that broke the camel's back, such as child getting sick one day making it an awful experience.

Furthermore, where the husband or wife originally comes from also matters; another of the most mentioned reasons for purchasing a car is visiting the home town (in the countryside or nearby townships). If one member of the household came from the rural area, somewhat ironically, a private car seems to be more critical than for those from the cities, since: (1) public transit to more remote rural areas is typically worse; (2) usually the rural area has a more gift-giving culture, so that the visitor has to carry a lot of luggage; (3) rural areas exert greater social pressure, probably due to the smaller size and closer interactions of social life, which means people in the rural area value the "face" (mian zi) more than urban residents, and relatives tend to see a car as a sign of social status. In the latter case, not having a car makes one feel like a loser. A number of interviewed households from the rural area or other parts of the city tell stories with different aspects of the same theme: a private car is much "needed" even for only a few return-home visits each year.

"We seriously considered buying a car half a year ago. Both of our families are in Jinan's countryside. If you have a small car, especially with a kid in the future, then it's extremely convenient for home visit. When we returned home, people at home said, buy a car, like those at your age…[…] Many people don't really need a car, it's just a 'mian-zi'(face) issue. Especially in the villages, actually there are

> *a significant number of people who earn much less than we do…They drive a car to relatives and friends during the New Year, and we ride the motorcycle, you see, right? They look better, and others say: look at these two, like what? Of course, whether you live a good life, nobody else knows." (#7)*

4.1.2 Usage Behaviors, Attitudes, Perceptions, and Preferences

As an important component of lifestyle, subjective attributes of households' attitudes, perceptions, preferences are everywhere and play essential roles in households' decision-making, including towards: different modes of transportation, towards the importance of housing unit and neighborhood attributes, and towards measures of energy efficiency, resource conservation, and environmental protection.

While some interviewees had difficulty pinpointing a reason (e.g., #23 just has a natural aversion to taxis), many attitudes, perceptions, and preferences can be traced back to past experiences of household members, including education, the social environment, previous behavior patterns, the habits of family members, specific incidents, stories from the media, etc. Examples include interviewee #30 (cited above), a middle-aged man who loves large dwellings, especially those double-decked ones with stairs inside the living room, based upon the luxurious depictions from Hong Kong movies which he saw at college. People gain environmental consciousness through television programs, newspapers, the internet, and through their children who learn various knowledge and rules from school. Households living in the older enclave neighborhoods believe it is safer to live in the newly-built gated communities (at least with gates and guards) after they experience the annoying behaviors of neighbor renters or ill-mannered visitors in their own neighborhoods.

Several households expressed strong feelings against mortgages, with one borrowing money from relatives and friends to buy a so-called "partial property" condo built on rural collectively owned land, which does not provide a property certificate or a land certificate.

> *"No we didn't take a mortgage. We think like this: I don't owe the bank one cent, and I don't worry about losing my job. Otherwise, if you owe the bank for 30 years or how many years, you won't have the power to move forward, because you will worry about losing your job every day, and not have the courage to innovate. We just borrowed some money and we are done for one year or two, then we can do anything we want. […] Furthermore, I don't want the bank to rob my money. I hate banks. The China Industrial and Commercial Bank always says its profit is the highest. Where does your profit come from? You rob."(#7)*

Attitudes, perceptions, and preferences also shape households' mobility choices and habits. Some mode or destination being "convenient" or not is the most frequently mentioned reason when talking about mobility choices. However, the word "convenient" is more of a subjective judgment rather than an objective reflection of physical attributes. For example, one household says the neighborhood has convenient transportation because the neighborhood has a number of bus stops nearby with routes connecting to the inner city, while another household says the same thing, but referring to the existence of an elevated highway with an exit nearby. The majority of people do not think driving or owning a car is a sign of social status or prestige; while some do feel that way, to various extents.

"None of those high-rank officials will drive private car…they all have official car, haha…"(#11)

The convenience of the bus also differs in many aspects: some consider walking ten minutes to a bus stop is reasonable, while others are not willing to walk a few steps; people have different definitions of and tolerance for waiting time and crowding; and, people evaluate cleanliness and privacy differently. People with different age and health conditions also see the "convenience" of walking or riding bicycles and electric bicycles differently.

"I used to ride electric bikes, but the air is filthy, and it was not convenient in the winter...plus I had some waist pain." (#12)

People who usually ride bicycle on a clean and safe street have a better evaluation of the bike than those having to ride on dusty and busy main roads.

Almost all of the interviewed people mentioned that it is not "convenient" to call a taxi. According to my own observation and experience, this might be an objective fact, true for most people. Jinan has around seven to eight thousand taxis, and the fleet size is not increasing proportionally to people's travel needs. Also, taxi drivers typically switch shifts at 6 to 7 pm (and 6-7 am as well), exactly when demand is high because of commuting back home and dinner appointments. During the shift switch, most taxi drivers do not take passengers. The situation is even worse when the weather is bad, rainy or snowy. Therefore people's perception of it being "difficult to get a taxi, especially when you need it" gets reinforced over time.

4.1.3 Values

Values are not directly observable, but can be implied from household's behavior, and the attitudes, perceptions, and preferences household members have. The core values of lifestyle involve the normative judgment on or belief in questions like: "what is the meaning of life?" "what is the most important thing in life?" and, "what is a good life?" Relevant values emerging from the interviews include:

- work is the most important thing in life; working is meaningful but enjoyment is not; working is the way to fulfill one's purpose; enjoying life come after one retires;
- a child is the most important thing in the family; responsibility of being a parent is the key to sustaining a family;
- saving the environment for future generations is important; what we do now affects our children in the future; saving is a virtue and wasting is a crime;
- life is about enjoyment, or it will be suffering; life quality is the most important; life is experiencing and exploring; saving is what losers do; The environment should work for humans, not the other way around.

These values or core beliefs are deeply held, and lay the foundation for the upper level attitudes, perceptions, and preferences, with the outside feedback, ultimately shaping people's lifestyle behaviors.

4.2 Lifestyle Groups and Lifestyle Indicators

From the lifestyle hierarchy analysis in the last section, we can see it is imperative to recognize the heterogeneity of households' lifestyle decision-making. To summarize, besides the readily observable objective household characteristics (e.g. demographic, socio-economic condition), we need to differentiate households taking into account differences in:

1. Resources and burdens outside the household scope, e.g. from parents and other relatives;
2. Experiences in the past or expectations for the future:, e.g. resources and responsibilities/burdens not reflected by current income or current expenditure; and,
3. Unobserved attitudes, perceptions, preferences, and deeply held values.

4.2.1 Lifestyle Groups and Indicators

Several themes emerged from the interviews of representative Jinan households. What fundamentally differentiates the lifestyle decision-making mechanisms are the deeply held core values and beliefs. Based on this, I define the concept of *lifestyle group*. A lifestyle group consists of households sharing similar values of life and therefore similar mechanisms of lifestyle decision-making. Households within the same lifestyle group would therefore likely have similar responsiveness to incentives or changes. Based on this definition, four types of households are evident from the interviews, namely: (a) job-oriented; (b) child-oriented; (c) budget-oriented; and (d) amenity-oriented. Certain indicators – from the household's demographic composition, socioeconomic conditions, behavioral patterns, and/or claimed attitudes and preferences – exist, which seem to be similar within a group but varying across groups. I call them the lifestyle indicators.

Let's look at the four lifestyle groups identified from Jinan urban household interviews, exploring each group's characteristics in terms of lifestyle hierarchy, lifestyle indicators, and responsiveness to incentives/changes, with some examples.

(a) job-oriented

This kind of households has at least one key household member who believes that working is the meaning of life/key to self-identity/responsibility for the family/priority of life. They work hard and are devoted to their job. They make residential and mobility choices around their job. Commuting is the top factor they consider when deciding where to live—they like to live close to the working place or at least to the employer's shuttle stop.

> *"If the bus line runs from my home to my working place, I will definitely drop my car…the ideal neighborhood would be that the working unit is underneath my apartment" (#5)*

> *"I used to be the employee of here (Zhong Qi), it (Zhong Qi) started to build housing here, so I bought the housing here…I have always been living in this area, so I wished I can stay in the vicinity. The land was owned by my employer. (Did you have employee discount when buying the house?) No there was no discount. It's just that somehow I have this feeling for this land…plus my child was in elementary school nearby" (#1)*

They first consider and usually always buy the employer-built real estate, and they believe it is more quality-cost effective option than those on the free market. Some of them buy cars or rent temporary places when the employer changes location, and some relocate to another city as the job moves.

> *"At that time I took the company shuttle to work. Later the company moved to a closer place, walking took only 15 minutes. Now (the company moved again) I*

have to drive, it's 8 kilometers…but we carpool. The three of us, each has a car, and go to work together, so we take turns. (purpose of carpool) of course saving gas, and more importantly, we can talk in the car. We were colleague classmates, and we have a lot to talk about."(#16)

They closely bond with their colleagues and are influenced by colleagues' opinions and behaviors when they buy housing and vehicles. For example, they look at homes their colleagues buy or desire, they believe what their colleagues recommend, and they have preference to live in the same neighborhood with colleagues. They go to driving school with colleagues and get driver's license long before they can afford a car. They look at a colleague's car and driving experience which motivate them to buy their own. Sometimes they learn driving for the purpose of their job, and they get their own family vehicle later in life.

"my colleagues' home are getting better so from 2004 I started to think about buying a new home"(#15)

"I don't have a driver's license now, not yet. When I started work, our superior asked us to learn driving, and the expense could be reimbursed. We didn't have time to learn though. In our office only two female colleagues knows driving, and the director knows driving, none of the rest male colleagues knows. So if you have some business to do somewhere, the director cannot drive if he drinks alcohol, and that is not good. (How about taxi?) The problem is we often go to other cities in Shandong. If you go somewhere like Tai'an or Dongying, two or three hours drive. If you go there and meet the client, the director needs to drink. He must think like this, so he told us this." (#26)

Some of them are running their own business, and buy cars even before home purchase, thus becoming accustomed to life with a car.

"That car was just for his (husband) business stuff, I take the company shuttle to go to work. The rest of us take bus. The grandparents take the bus too—they have free senior passes anyways." (#1)

"(Why did you buy the car?) I work in the construction site and I need it. I have to, or I can't do it. It (the site) is so far, and I can't use my two legs to get construction projects. […]The van is for transporting workers to the site. I use the SUV, and they (wife, parents) don't use it—they don't need it, no need for the kid. " (#4)

"I considered this (living in the suburbs) when I bought the car. The inner city will definitely get more and more congested, and the parking is not convenient either. I get a car first, then it doesn't matter if the house is further away. It's convenient—my job is not 9-5 anyway, the working time doesn't matter. (we) haven't considered the inner city at all, it's too crowded. We are not working class with a schedule, it's not necessary (to live in the city)." (#4)

Some objective lifestyle indicators to identify these job-oriented households include: age of household head (ranging from early 20s until retirement, but mainly middle-aged), education level (key household members with higher education tend to be more job-oriented), size of employer (if not self-employed, tend to work in very large enterprises), industry and occupation (tend to be in better-paid industries such as tobacco or real estate, instead of declining old industries), position (tend to be in higher ranking, or management, positions), business owner (a strong positive indicator for job-orientation), salary and other employer-provided amenities such as access to a company car, housing and transport subsidies (the more employer-provided benefits, the more job-oriented the employee).

In terms of potential behavioral change, these job-oriented households seem more responsive to incentives or changes affecting their job and those provided by their employer, such as: making commuting easier or balancing work place and neighborhood location; changing the lines, stops, schedules, or running times of company shuttles; reducing or increasing employer-provided parking at work places; changing policies that affect a company's subsidy for housing (e.g., the termination of housing allocation, employer provided renter units, employer's ability to build their own real estate using employee fund-raising, etc.); changing employer's subsidy to travel (free transit pass, reimbursable gasoline, access to the company car, etc.)

(b) child-oriented

This kind of household has a child less than 18 years old in the family. They believe that: the child is the priority of life; it is important to provide everything the child needs to be a good parent; education is important; and, the responsibility as a parent has an essential value for life. They make lifestyle decisions around the child. The education opportunity is the first factor considered when choosing neighborhoods: they value the school districts, they value the bus stops with routes to school, they hope to live in neighborhoods with good kindergarten, and they move to neighborhoods that potentially have clean, quiet, and more highly educated people because they think the neighbors' quality will influence their child's well-being.

> *"I don't mind the neighborhood environment, I don't care about green coverage or whatever, I only care about the quality of neighbors…the government agencies are located here, so you will have good security and people quality"(#10)*

They are concerned with the quantity and quality of playgrounds and other children's facilities in the neighborhood. They want a bigger home and more rooms to give the kid a perfect environment for sleeping, eating, and studying.

> *"(my ideal house) I like the north part of this neighborhood, there is a little garden at the ground level, then it has two floors, so that the activity and quiet areas can be separated. …(ideal home size) the current size is enough…now the living room and bedrooms are separated, but the activity and quiet areas are not. I cook something or talk here, she (my daughter) can hear it in her study room—I don't know whether it is the material problem or the design problem, it's just not sound proof….it shouldn't be like this" (#1)*

They buy cars for picking up and dropping off their kid at school, for making their kid feel more comfortable when returning home or going to the hospital, and/or for taking their kid out to play or to explore the world on weekends and holidays.

> *"Father: "if we buy a new vehicle, we would buy a car. For picking up and dropping off the child. (But she is living on campus?) Still picking her up and dropping her off. It's too far away. In my family it's me who wants to buy a car, mainly for driving her to school. I don't need car for commuting, my working place is close, and my wife goes to work by bus.*
>
> *Daughter: I want a car because the whole family can go out during vacation or holidays.*

(So in your family you two want a car, your wife?) Father: she doesn't want to buy car. Daughter: My dad wants a car because I do. It is difficult to catch a bus, especially during holidays, when visiting others. It's crowded, and not easy to take buses. Driving is so convenient.

(How about taxi? Doesn't it a cheaper option?)
Father(smiling):….
Daughter: taking a taxi is not convenient either." (#3)

They increase their knowledge about the environment and change their behavior to protect it because they want to set an example for their children.

"I don't buy the plastic bags now—I keep a nylon tote in my purse all the time and take it out when I shop—some people say that I am stingy, I don't think so. I don't even bargain with vegetable sellers for a few dimes. You must have seen the ugly scene where plastic bags are flying all over. My child also learns this environmental protection stuff in school. In the future, the neighborhood should have recycling places for batteries. I don't know where to put my used batteries. I wanted to throw them out, but my child told me not to." (#1)

Some quit their job in order to take better care of their babies, or to home-school their children. Some rent houses near their child's school for better protection or assistance.

Having a child in the family is the most obvious lifestyle indicator for child-oriented household. The child-oriented households are likely to be more responsive to incentives and changes affecting the child's well-being, especially education, for example: nearby school quality and enrollment policy of schools; neighborhood facilities including daycare, public space, and playground; the location of nearby facilities such as university, research institutions, museums, and zoos.

(c) budget-oriented

This kind of household believes that saving is a virtue, and wasting is a crime, with saving for the future more important than the quality of life today; the future is important. Some of them are poor with income constraints on consumption; some of them have extra family burdens; and, some of them just experienced a time when they were poor without enough money to sustain normal life, when they formed the habit of saving, and they remain cautious that hard times may come again.

"Our family has been living here since his (my son's) grandparents' time. Although we live here, we don't have the property right. It's called "self-maintenance, self-living". It's an old house and requires fixing every now and then. The owner doesn't charge us, nor drive us away. I don't have a plan to (buy my own house), because I don't have enough money. Sure I want to buy a new house, of course I want to. This is the old one-storey building, not convenient in every aspect. You know, no bathroom, no…everything, of course I want to a buy new house. […] I have a bicycle. Electric bikes? No, the income of blue-collar family can only sustain a normal life. We can't afford those luxurious things. We don't have electric bikes either, one reason is the economic condition, the other reason is that I am healthy now and riding bicycle can be an exercise." (#2)

"I was afraid that if I don't have any income in the future, I won't be able to pay for the property management fee, then they would stop the elevator…so I did not dare to choose a higher floor."(#33)

"The youngsters use running water for shower and sometimes take one hour—they just love that luxury"(#20)

They usually have a budget, and calculate the costs comprehensively and rationally. They have different ways to save water, electricity, natural gas, and gasoline. They consider the price or total costs before any purchase. Price is the more important factor when they buy house, and they usually buy small units with an area "just enough to live in." They save money because they consider their future needs, and they sometimes choose second-hand housing. Sometimes they rent and some buy housing with limited property rights.

"We wanted to buy one under 400,000 so we couldn't afford a mid-rise building with elevators, so we need to find a first floor or second floor second hand apartment, for the convenience of the old"(#23)

They take little risk. Vehicles are also bought after careful calculation—even when they buy a car, they buy the cheapest one, often a Chinese brand, and/or small one with good fuel economy. Again, they usually take into account the full costs, including registration, insurance, maintenance, parking, road tolls, and gas.

"We are considering buying a car of around 70,000 to 80,000 yuan, at most 100,000 yuan. It has to be a small horse-power one, and a practical one. But this year I am a little hesitant when I discovered that, for us, if you are not running business, the car is not of much use. We calculated that for a year, you have to spend more than 10,000 yuan even if you don't drive it. If really for return-home visit, taxi costs only a thousand yuan a year. The car stays there, it will lose value and depreciates."(#7)

They use second-hand products, and have the habit of recycling. They either think luxury is out of reach, or that luxury itself is bad because it has little practical utility. Some of them are very environmentally conscious. They care about the future (i.e., they have a low discount rate).

"We use the monthly pass but we calculate. We have both the monthly pass and the normal bus card. We calculate if we have to take more buses, then we buy the monthly pass, if not, we swipe the bus card. That saves us money.[…]I calculated those expenses. We use 6 cubic meter of water each month, 3.10 or 3.15 per cubic meter, then total 20 yuan. The gas is 2.70 per cubic meter, on average we spend one yuan per day. The electricity use is small. Our energy-saving light bulbs use very little…plus laptops, around half kwh per day. Normally if we don't use the air conditioner, one kwh per day is more than enough. When using air conditioner in the summer time, 3 yuan per day. And we have solar panel for water heater. […] when we buy electric appliances, for those we use for a long time, like refrigerator and TV set, we'd rather spend more money and get an energy-efficient one. Energy efficiency is the priority for long-term usage, even if it's more expensive. The rest doesn't matter. We have a lot of good habits, you might think funny. In the winter, when we use water, we first get tap water in a bucket. The tap water is cold, but the bucket is warm. After a while, the water in

the bucket gets to around 20 degrees, because of the room temperature, then we save the heat to boil the water. I also calculated the water boiling; actually, using electricity is cheaper, but it's slower to use electric burner, and the bottom get burnt easily, and there's radiation problem that needs to be considered. We cook simple too, two persons just one dish. […]One habit of our washing dishes is that we collect all the dishes together to wash, which saves water, and we let the water flow very tiny. When we were renting, the toilet was broken. So we saved the water from clothes and food washing to flush the toilet and we saved quite a bit. The bathroom is the water gulper. You push the button to flush, three cents are gone. I wonder whether the toilet flushing can be connected with the sink. Beijing does a good thing: they flush the toilet using recycled water. Our toilet was the 'water-saving' model. And in order to save money, most of our furniture was the exhibition sample, it's much cheaper, more than half price, cheap and good. […]Another thing is the clothes washing, we wash clothes together. We take showers in a pattern: tonight we take showers both of us take showers, so that the clothes can be washed together. The washer is a water gulper too. The two of us just have strong environmental protection senses, to be frank the most important reason is cost control, but we are also truly doing this for the future generations, to leave them something. […]Education is really influencing people's living habits and personality. She (wife) used to keep books for a year and a half, and it makes huge difference whether you save or not, like a few thousand yuan. For daily expenses, water and electricity can save a few hundred yuan per year. Another thing is dining out, and buying unnecessary things. […]We have no other way. It might have some relationship with the fact that we were from the rural area, and we know how hard our parents made money."(#7)

Some objective lifestyle indicators of this group include income level (budget-oriented households tend to be poorer), the presence of old people in the household, or being a senior-headed household. Besides the obvious difference in leisure demand between old people and young people, the older generation tends to have experienced the hard times of the past when the living standard was low and making money was difficult. Also the floating population, and those who originally came from the rural areas, tends to be budget-oriented. They have lived the hard life. They usually don't have financial or in-kind support from parents and other relatives like their local urban peers do, and some of them carry a heavy burden to care for their parents and relatives because of the poor economic conditions back in their hometown.

Budget-oriented households are most sensitive to price. Therefore changes in purchase price of housing and vehicles, as well as increases or decreases of usage costs, including price (e.g. water, heating, electricity, parking, insurance, gasoline, etc.) and efficiency (e.g. appliances, vehicles), will likely have a relatively large influence on their lifestyle decision-making. The application of renewable energy devices, e.g. the solar hot water heater, is also attractive to budget-oriented households, as they tend to have long-term considerations for cost saving.

(d) amenity-oriented

In contrast to the budge-oriented household, the amenity-oriented household believes that enjoyment is the meaning of life, the future is never as important as the present, life is about enjoying and exploring, life quality is important, and saving is losing. They value the present much more than the future and therefore have very high discount rate. Most of them have relatively high income, and some of them have extra support and resources from their family, e.g. a home or down payment provided by parents, or a job offer made possible because of a relative being a high ranking official. They usually come from urban families, with urban household registration, and have not been through major economic difficulties in the past. They do not have family burdens since their parents and relatives have their own housing and social welfare (e.g. health insurance). They buy bigger houses and cars when funds are available. They buy houses in the more up-scale neighborhoods and in more desirable locations (the east and the south). They value the amenities of the housing unit and neighborhood, and are willing to pay more for some key amenities. They value clean air, green coverage, and open space. They sometimes buy bigger cars, brand-name cars, and luxury cars, and they buy two or more cars for convenience.

> *"We are not willing to live in a crowded place with difficult transportation. We can live in a place with better environment after the retirement. [...]Of course we will upgrade to a second house. [...]And we surely will consider those with enough parking, nowadays every family has more than one car. Of course we plan to buy a second car. I plan to buy it very soon. Not just for commuting…ah, the modern family doesn't spare a car, just buy one more for fun. You can just put it there…now the Chinese are rich, who wouldn't buy one car? It's more convenient as we have two people. One would have a car to drive when one wants, even when the other person needs car for emergency. Otherwise when two of us both have emergency…now a car is not a big expense for an average family. Now I drive her (wife) to work, I'd rather buy a car and let her drive herself, right? It saves me a roundtrip, and that car costs less than my energy. (How will gas price increase or gasoline tax influence your decision?) Since they buy the car, no matter how much you increase it, as long as the family considers it, plans it, and wants it, then they will buy it. If not, then not. (Have you considered the gas price?) I don't care."(#5)*

> *"Those 3-bedroom apartments are so small, they look like a small tofu block. [...] I'd rather not drive than driving an old car…it's like wearing clothes, I'd rather have a good one instead of many bad ones."(#25)*

> *"I think my husband's way of thinking and values are more apparent in our home. He might value the life quality of the family more, sometimes shown more in details….not really details, just every aspect of life. For example, we choose to buy the organic vegetables in supermarkets rather than farmer's market; we choose to dine out in restaurants with good environment, not the dingy small ones, unless it's really special. Everything, the environment, the car, shows your idea about life. It may not depend on whether you are rich or poor, just someone's...with money, I may use it to improve the life quality, but someone with a lot of money might not emphasize on that. The organic vegetables are national certified, even if it has some sham, but could not be worse than the normal vegetables, therefore better for health. Then I don't mind spend two or three times of its price in exchange for a better possibility of health." (#32)*

They have a higher value of time and they value privacy. They spend the money when their income increases and do not worry too much about the future. They have hobbies in their spare time and don't mind spending more to get more enjoyment and to improve their quality of life, e.g. hiring nannies for babysitting, cooking, and other housework.

"We bought this car first to commute, as the factory I worked for stopped the shuttle service due to worsening business.[...]But now I am retired, and it's now for travelling because I love photography. I have this hobby for years. Driving for travel is very independent, but expensive, so we feel conflicting as our income is not high. In the past working was busy, and travel only happened in the holidays, but now it's different. Having a car is good, at least for taking photos in the remote areas. I used to be an advocate for green travel, but public transit really can't provide this convenience."(#12)

The first obvious lifestyle indicator to identify amenity-oriented households is income level (the richer, the more likely to be amenity-oriented), and age (usually young to middle-aged). Whether the household is urban (with registration) and the occupation of their parents (usually professional, business owner, or civil servant) also matter in deciding whether they are amenity-oriented. Attitudes towards spending and the importance of life quality are the markers of them as well.

Amenity-oriented households are not likely to be as sensitive to price changes, but are more responsive to policies that change the quality of lifestyle elements or that provide more amenities. For example, neighborhood green coverage, the quality of public space, luxurious exterior and interior design, building aesthetics, the details and quality of neighborhood facilities, underground parking provision, and convenient shops, barbers, farmer's market with fresh vegetables, tasty restaurants, etc. might attract amenity-oriented households. Increasing the service quality of public transit – in timeliness, cleanliness, and/or proximity to the neighborhood – could also make a difference in swaying these households away from using their car, as might the difficulty in finding parking and the inconvenience of being stuck in congestion.

One thing to notice is that the fundamental difference among different lifestyle groups is the deeply held core value which shapes their lifestyle decision-making, not the revealed demand, behavior, attitudes, or preferences. For example, amenity-oriented people value enjoyment more (also in relative terms), but which amenity brings more enjoyment is subjective; even the definition of amenity is subject to the individual household's judgment, and varies a lot. For example, most think that a larger housing unit is better, while some value the number of rooms, or the functional layout of the unit as more important. Some may trade the extra space for the convenience of walking the dog:

"The year before last year we sold our bigger house, which was a top flour plus a penthouse style, totaling 180 sq.m. But because we had a dog, and we had to go up and downstairs to walk the dog, and that was inconvenient, and we got tired and sold it, just to get rid of the hassle of climbing stairs. And this one is only 100 sq.m., we feel it's not large enough. You look at this, I'd say it lacks a dining room. That room used to be the dining place, I made it into a study room as I have a lot of books. Yes we changed a big house to a small house because of the dog, the old one was on the sixth floor, no elevator, it was really tiresome to walk the dog two times a day." (#30)

The amenity-oriented households might also have different attitudes towards the same mode: The wife in (#32) household said she would take the bus when time allows: "*since I have enough time, resting on the bus is not so bad. I can sit on the bus and watch the views in a* *relaxing mood, which is a rare resting time for me. [...] Driving takes effort.*” while the wife in (#25) household likes driving as *“quality time alone.”*

4.2.2 Dynamics between Household Members

Households’ lifestyle decisions are made by key household members – usually the household head and his/her spouse, with the child and the parents sometimes also involved. So a household can be comprised of a job-oriented husband and a child-oriented wife as well as a budget-oriented parent, but the “big decisions” of residence and vehicle purchase are generally made by all the key members through negotiation. Thus, compromises are sometimes made. Generally, the housing purchase decision is subject to stronger negotiations than the vehicle purchase decision, due to the relative degree of “sharing” of these two assets. Since the above four lifestyle groups are for the household, not the individual household members, these categorizations should be understood as “labels” or “tags” rather than “groupings” or “divisions.” The diversity within the household and interaction among household members could result in some mixture of lifestyle characteristics. For example, a household can be job-oriented, child-oriented, and amenity-oriented. These categories are not exclusive.

The potential for conflict between key household members can exist in all steps of lifestyle decision-making: whether to buy a house or car (the wife is more likely to be influenced by friends and relatives than the husband); which residential location to consider; the acceptable price range (the husband usually has a higher budget while the wife is more conservative and price sensitive); how large a housing unit to buy (usually the husband tends to prefer a larger housing unit than the wife); the floor and layout, neighborhood amenities, etc. Using the lifestyle group “tags” discussed above, within the household, the male members tend to be more “job-oriented” and “amenity-oriented,” while the female members tend to be more “child-oriented” and “budget-oriented.” Key household members argue (or even have fights) about these issues, make compromises, and settle on one decision which affects the lifestyle of all household members, just like the wife in #32 household said: “*the truth is clearer through debate.*”

4.3 Lifestyle Bundle and Decision-making Mechanism

In the lifestyle hierarchy framework discussed above, “behavior” is composed of ownership behavior (or purchase behavior) and usage behavior, and the former conditions the latter. For the ownership (purchase) behavior, the household is making a deliberate decision among several alternatives, i.e. making a *choice*. Hereafter I will use the term “residential choice” or “residence” to include all aspects of the first-order home purchasing behaviors, including homeownership, the choice of neighborhood, and the choice of unit type. Similarly, I define “vehicle portfolio choice” as the process and result of a household deciding how many and what types of vehicles to own. Households make decisions on whether to buy a home, where to live (neighborhood), what kind of unit to occupy, the type and quantity of home appliances (centralized heating, air conditioning, etc.), and, in turn, in-home energy use. Household vehicle portfolio ownership is the foundation for household mobility, conditioning the mode choice of household members, and, in turn, transportation expenditures and energy consumption for personal travel (Figure 4.18).

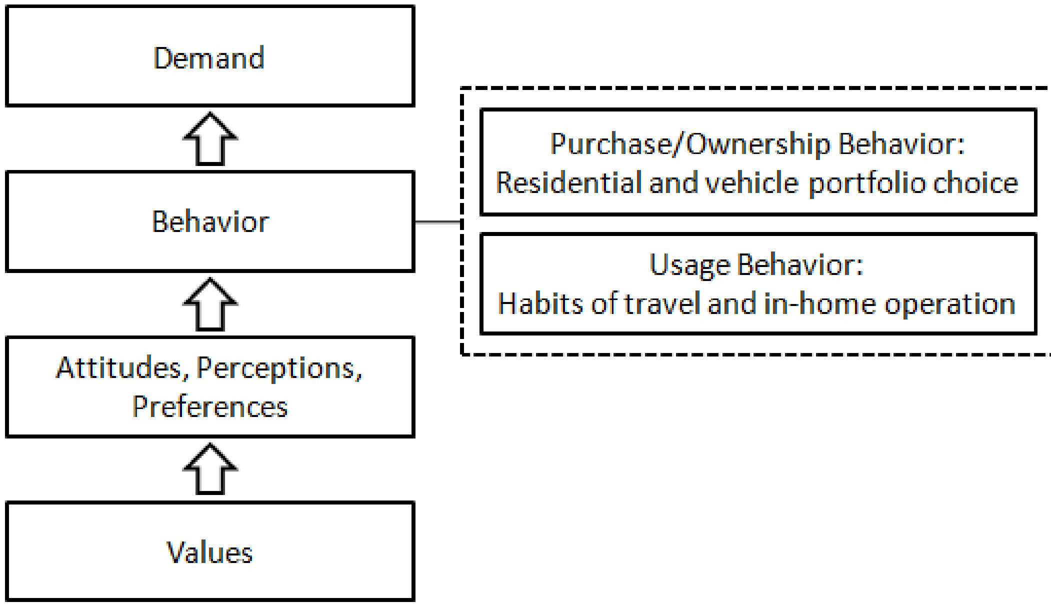


Figure 4.18 Lifestyle Hierarchy of Direct Energy Consumption

The residential choice and the vehicle portfolio choice are interdependent, and both of them are the result of a household making a lifestyle choice. Therefore, I call the combination of the two choices as the "lifestyle bundle".

The fact that residential choice and vehicle portfolio choice are interdependent can be due to two reasons: (1) households make those two choices together; (2) these two choices are determined or influenced by many common factors. The interview results support both sides of the story. On the one hand, households are making their big decisions that can greatly influence their daily life, therefore households are not merely picking a home in a neighborhood just to live in, or selecting a car just to drive, they are choosing what kind of lifestyle all household members are going to live for at least a few years. On the other hand, these two choices are largely determined by the same set of objective and subjective attributes of the household: the demographic and socio-economic conditions and attitudes, perceptions, preferences, and values.

Specifically from the interview results, the "interdependence," or "bundle" structure, between the residential choice and vehicle portfolio choice are evident in three main ways: (a) shared resource constraints; (b) interdependent choices through accessibility and parking; (c) decision-makers' shared attitudes, perceptions, preferences, and values.

(a) Shared resource constraints and different timing

For a typical household in China, a home and a motorized vehicle are the two most expensive durable goods it normally purchases. Housing price in Jinan is about 7000-8000 yuan (US $1,100-1,200) per sq.m. in newly built development, and the per capita living area is around 30 sq.m. (city-wide average, see Chapter 3 section 3.1), that makes more than 200,000 yuan (US $31,000) housing costs per person. Considering the much lower housing price before the real estate boom, and that a significant portion of households received housing allocation from their employer (meaning minimal, if any, actual housing cost) just ten years ago, the average cost of home-owning a decade ago would have been much less than 200,000. Most cars owned by the interviewed households are priced from 100,000 to 200,000 yuan (US $16,000 to US $31,000) today (consistent with prices of the most popular cars sold in other Chinese cities). If we also take into account the higher car prices in the past, and the shorter useful life of a car, we can see that these two costs are somewhat comparable, representing two big chunks of money taking up a large portion of family income (considering the per capita disposable income for Jinan's urban residents is 25,000 yuan (US $3,900) a year). Therefore these two choices are made under a tight resource constraint, i.e. household income, and buying one will certainly affect the decision of the other. What we can observe is that, when income rises, households start to consider between buying a home, a vehicle (especially car), or a second home. In the interviewed households, the first home usually comes before the first car, showing a more primary need for homeownership, attributable to the traditional Chinese value of "settling down" and, noticeably, the skyrocketing housing price which makes people believe that home purchasing is also a good investment. There is exception though, especially when the car purchase is for the purpose of work.

> *"At that time (when we bought the house), we didn't have enough money to (buy the car)…all my saving, and I even borrowed some to be just enough for the down payment."(#14)*

> *"We considered car after we bought the home, because it's already good for us that we can afford a house. After we bought the house, saving every penny last year to find out that we can pay back the money we borrowed this year, then I thought, maybe we should buy a car before the oil runs out—the oil might run out soon if we don't buy a car. […] Then I thought in the future, if we want to have children, and our parents. They have to come living with us, they are getting old in the rural area…plus they will come babysitting. So in the future we have kids and the elderly, two bedrooms are not enough. We have to deal with the second house sooner or later. Then it's better to save the money of car purchase for the down payment for the second house." (#7)*

(b) Interdependent choice through accessibility and parking

When households make decisions on where to buy housing, one frequently mentioned criterion is "transportation convenience." However, how people define this "convenience" (or what I refer to as accessibility of a location) is conditioned upon their current or expected vehicle portfolio ownership. A neighborhood accessible by car could be totally un-accessible by public transit, the same for other modes. Therefore when a private car is available or expected, household evaluate the accessibility of a neighborhood using highway exit proximity and road conditions including congestion. For those who do not have private cars, they value the bus and BRT routes and stops, company shuttle stops, and amenities within walking distance. In the interviews, it seems that accessibility to work and to school are essential, while the accessibility to grocery shopping is not very important as people expect these minor life amenities will come sooner or later. On the other hand, quite obviously, once a household resides in a specific location with the accessibility by different modes relatively fixed for a couple of years, the household will have different incentives to own vehicles. For example, households living in a remote area with a nearby elevated highway and few public transit options are much more likely to buy a car compared to their counterparts in the crowded inner city with abundant bus lines and walkable streets. In other words, household's vehicle portfolio ownership is also dependent on their residential choice—specifically, the location (accessibility) of the neighborhood.

"This neighborhood has very convenient transportation…sure, the elevated highway is nearby. It is convenient to drive." (#5)

"The traffic is getting worse. I bought this house with my own point of view. From here I can go directly to the east and south outer ring road, and straight to the southern mountains, and I don't have to pass through the crowded inner city. […] Of course I knew I would have a car when I bought this house, I just didn't know it would happen this fast – just after one year I bought the car. " (#14)

"This place looks remote, but it is convenient to take the bus to places like Hong Lou. […] There is a bus stop if you walk to the north, and it has two routes. Basically you can go almost anywhere in the inner city. Now distance is not a problem, you just need the transportation convenience." (#7)

"The inner city will surely be more and more congested, and difficult for parking. I bought the car first, then it doesn't matter if we live far away—still convenient. My job is not 9-5 anyway. [..] We didn't consider the inner city at all, too crowded."(#4)

Parking also plays a key role in linking these two choices. Naturally, households with cars (or expecting to have cars) value parking in a neighborhood much more than those without a car. On the other hand, residing in a neighborhood without parking becomes one obstacle for those intending to purchase a car in the future. Therefore, through parking, a household's residential and vehicle choices are also interdependent.

"Because it has underground parking. We thought about parking space as a must. We bought the car after the house…but we thought getting a car would certainly happen, thinking about the future, commuting, the distance, we surely need a car. And the kid, convenient to drive him." (#32)

"There was an economical reason whether to buy (a car) or not, as we just bought the house, right….since we do have loans. [Did you consider buying cars when you bought the house?] Of course we did. We already bought the parking spot." (#9)

(c) Shaped by decision-makers' attitudes, perceptions, preferences, and values

From the discussion of lifestyle groups in the previous section, we know there is heterogeneity in how households make their lifestyle choices. This heterogeneity comes from the deeply held values about life that households have and that influence household's behaviors. It is, therefore, evident that these values about life and household attitudes, perceptions, and preferences influence their lifestyle purchase/ownership behaviors, i.e. both the residential choice and the vehicle portfolio choice. For example, job-oriented households are more influenced by opinions and attitudes from their colleagues, whether in buying housing or vehicles, and commuting is the key criterion upon which both residential location and available vehicles depend. Budget-oriented households pay close attention to prices, whether for housing or vehicle purchases, and the importance of saving figures into both decision-making processes. The following amenity-oriented household borrowed money to buy housing and a car, and this lifestyle tag is the key to understanding this behavior:

"Basically, our life is just 'adequate clothing and food' and money owed. If one feels optimistic about future income, he dares to borrow money and spend money

like this. If he doesn't, he would save the money. Now saving money is losing money, the more you save, the less likely you can afford. He saves money for the down payment. People like that wait until now to realize they can never save enough for the down payment. I made up my mind quickly, and I expect the housing price to rise." (#14)

It is important to understand the interdependence of these two purchase/ownership choices as the central element of lifestyle choice a household makes. It conditions the usage behaviors, which leads to an interdependence of travel and in-home operational energy consumption. The two parts of a household's direct energy consumption are therefore interconnected and any policy or incentive targeting to change one will almost certainly affect the other.

4.4 Lifestyle Change, Neighborhood Design, and Direct Energy Consumption

The reason why we examine the mechanisms of household lifestyle decision-making is to identify ways of changing behaviors—specifically, the direct energy consumption which results from personal travel and in-home energy-using behaviors, i.e. the usage component of behavior in the lifestyle hierarchy. The usage behavior component is conditioned on the purchase/ownership behavior component, i.e. the lifestyle bundle choice which includes residential and vehicle portfolio choice. Both behavioral components are shaped by households' subjective attributes (attitudes, perceptions, preferences, and values), therefore the whole system of lifestyle hierarchy should be considered (Figure 4.19).

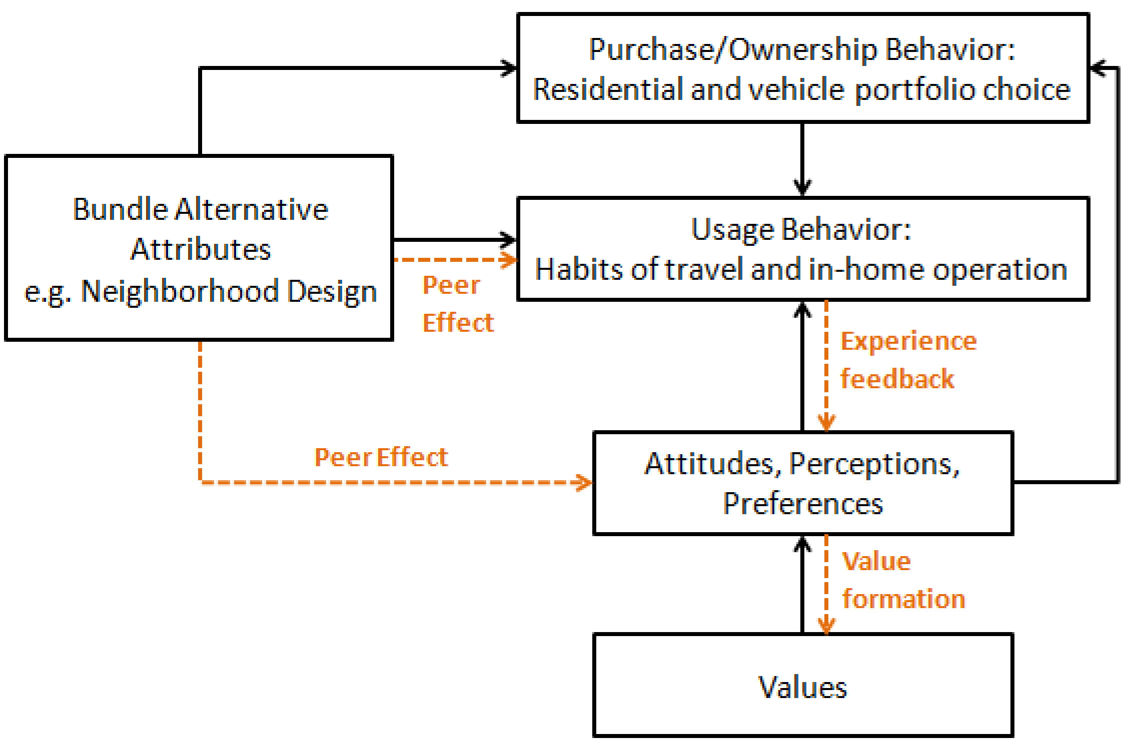


Figure 4.19 Influence of Neighborhood Design on the Lifestyle Hierarchy

Many factors have the power to influence a household's lifestyle behavior, and we are interested in the role of neighborhood design. I found that neighborhood design does not only influence people's purchasing behavior as it is part of the attribute of the lifestyle bundle, but it also influences people's lifestyle group over time.

It is easy to understand how neighborhood design can influence households' lifestyle behaviors (both the purchase and usage components), as it constrains the choice: how a neighborhood is designed influences what alternatives households have, including the attributes of residence and accessibility. A prominent example is parking provision in the neighborhood. More parking, especially more underground parking, makes owning car more attractive, and encourages driving as well. More and better designed open space (including playgrounds) encourages households get out of their home to conduct outdoor activities in the neighborhood, which leads to less time at home, therefore possibly less in-home energy use without adding travel energy consumption. More pedestrian friendly environments give households incentives to walk and bike instead of driving their car, therefore decreasing travel energy consumption.

A clear association emerges between neighborhood type (a combination of neighborhood design attributes) and a certain lifestyle group. Two mechanisms explain the association we observe: (1) sorting effects; and (2) lifestyle change effects.

The mechanism of sorting comes in two ways. First, households with similar characteristics tend to be in the same lifestyle group – sharing similar values, attitudes and preferences – which leads to similar choice behavior, among which is the same type of neighborhood. Second, households like to live with people who are similar to them (see the example below). These "voting with the feet" and "self-selection" mechanisms show that at least part of the association between neighborhood type and household's lifestyle behavior can be explained by the sorting of households' existing lifestyles. That is not evidence that neighborhood design brings lifestyle change.

> *"We still prefer neighbors who are at our quality level. We like it simple, and the neighborhood with not-so-complicated resident composition would be better. The reason why we chose this neighborhood is that, though it is not very upscale, it is a mid- to high- grade neighborhood, and the people here are relatively higher quality. This is one of the reasons we bought it here. […] We interact with very few neighbors, just saying hi to those living in this building entry, except for the neighbor upstairs, with whom we talk more. You communicate better with those who are similar, and you can achieve consensus more easily, such as the sanitation and cleanliness of the building environment, or in the neighborhood, and from parking, you can see the quality of residents. It's also related to the manner when you see each other….so we like to live with similar people." (#32)*

> *"I'm sure there are some higher-level people in our neighborhood, but I feel I still prefer those who are more or less like us. Diverse residents probably lead to more bad people…it was bad when we were renting, like all kinds of people lived there, it made me feel unstable."(#8)*

The interviews suggest that there are mainly two mechanisms through which a neighborhood's physical design changes people's lifestyle. One is through peer effects, and the other is through habits and experience change. Lifestyle change is a process that takes longer time. The first step is the same as we discussed just now: neighborhood design changes the attributes of alternatives for residential choice, or the lifestyle bundle choice (Figure 4.19). The following steps are long-term effects which are shown in dashed arrows in Figure 4.19. Over time, along these two dashed pathways, neighborhood design ultimately changes the lifestyle decision-making mechanism, i.e. the lifestyle group that a household belongs to, which influences their direct energy consumption in a more fundamental way.

One channel for lifestyle change is through peer influence of neighbors (Figure 4.19). This happens through observation and socialization. People observe how their neighbors behave, e.g. what vehicle they own, where they park cars, how they commute, what appliances they buy and how often they use them. By observing, people's ideas of what is "normal", "acceptable", "convenient," and what "looks good" gets influenced by their neighbors. This influence is more widespread and deeper as neighbors socialize. They talk about all kinds of things, exchange ideas, make friends, and even go shopping together.

> *"My lifestyle indeed changed. Living in this kind of neighborhood, we might be assimilated by this so-called high-end community. Like consumption attitudes….things like that. Because you live in this neighborhood, the people you meet, their living standard, their consumption style, and their travel destinations. Yes, you get to know what you didn't know before. Or you don't go to the places you used to go, and you go to places you haven't been to. For example, I don't go grocery shopping at the farmer's market anymore, and I seldom go to Tongyi Yinzuo anymore. Now I often do online shopping. After I have a child, the child has to go to daycare. You have to know what level of daycare the kids in the neighborhood go to. You have to know the consumption level and what clothes they buy, and where they go on weekends, and what kind of pre-education classes they take."(#19)*

While the peer effect is difficult to distinguish from the "sorting effect" discussed previously, the habit/experience change takes a few steps from the physical environment to the deeply held value system, and will be elaborated in more detail as follows.

After neighborhood design changes the lifestyle bundle alternative a household can choose from, it provides an opportunity for some households to experience aspects of life that they previously have not. If the experience is good, the household will have the opportunity to do it again. If the experience is bad, the household will try to avoid it. Repeated activities build into a behavior pattern that we call "habits", activities which people are no longer deliberately choosing, but rather follow without much consideration. Attitudes and perceptions towards related features are formed as early as experiences feedback to our brain, and are reinforced by repeated experiences, and preferences are also formed as habits are. Finally these attitudes, perceptions, and preferences get built into our conscious so deeply that the value towards life is changed.

Figure 4.20 The Experience/habit Channel of Lifestyle Change

For example, a neighborhood design attribute (e.g. a nice open space in the middle of an enclave) makes certain activities or behaviors possible (e.g. people go downstairs and chat with neighbors after dinner). The routine practice of that activity or behavior becomes a pattern, and gets built into people's preference or value system (e.g. interaction with neighbors is important), i.e. brings lifestyle change. Another example could be that the existence of a big parking garage and an inconvenient pedestrian circulation system in a neighborhood makes driving much more comfortable than walking, which therefore reinforces the driving behaviors while discouraging walking behaviors. After a period of time, the repeated good experience of driving and bad experience of walking will translate into more vehicle ownership and usage by residents. The notion of "walking is inferior" gets built into the value system too. This proposition can also be explained by sociologist Bourdieu's concept of "habitus"—how individuals' routine practices are influenced by the external structure of their physical and social world and how these practices, in turn, contribute to the maintenance of that structure (Cockerham et al., 1997)

In the interviews, we can see many examples of pieces of that process: from experience to attitudes, from experience to habits, as well as from habits to attitudes and perceptions.

> *"I don't like gated community. Don't you think our neighborhood is not that high-end? However, one time when I took a taxi , the gate keeper insisted not to open the gate for me. My daughter was sleeping in the cab, but he insisted. How upset I was! Really! She was asleep so I couldn't get off the cab! If she wasn't asleep, I would let her get out of the taxi and walk by herself. But he did not want to open*

the gate! I was so angry I was afraid she would catch a cold. This crappy neighborhood wouldn't open the gate for me!" (#8)

"Some people in the rental house do not have good quality. I feel…they drink all day and get loud. I am tired of that kind of living condition. Therefore I don't want to rent anymore" (#8)

"For example, the parking space. The project I worked on, YongDaYiHe Garden, the entire neighborhood looks empty when you enter. You enter the gate, then through the building entry you can drive to the underground parking, pick a space, park, then take the elevator directly to your home. Our neighborhood only has surface parking, no underground parking. Sure you would want underground parking, once you get to that level…for instance, my car doesn't matter, it's not a good car with a 200,0000 to 300,000 tag, but (those expensive cars) out there under the sun and the wind, you feel sorry. Once you get underground parking, you might also get a closet. You put stuff you buy in the closet, and take a turn to the elevator and you're at home. In the summer you want to grab something, you take the elevator to the closet, very convenient." (#4)

"You've got to have hospital, supermarkets, and schools around the neighborhood. Life, that's a must. Now like us, we have to drive a long way to shop the supermarket, that's tiresome. Our lifestyle changes to some extent since we moved here. […] They are housewives (wife, and mother in law), and they take care of the shopping. They usually take things by themselves. I have to drive them to big supermarkets. […] Those necessities for life have to be nearby. Nobody likes to travel far to get them. We drive but hit the traffic jam, and there's no parking when we get there. You waste a lot of time and save very little money. It is not cheap, and it wastes a majority of your energy and time." (#4)

"Sometimes I drive to work, not in the days when weather is bad. Basically I don't feel like taking the bus since I drive now. [..] (the driving) is more than I expected. Now driving becomes a normal need for me. Because if I want to get up a little bit later, driving is faster, via the elevated highway. It takes me just 20 minutes to drive here. No there is no congestion on the elevated highway. The bus sometimes catches traffic jam and takes 40 to 50 minutes. It is possible that you get up late and it will take an hour by bus. You can even be late for work.[…] (after I moved to the new neighborhood), I drive almost every day, if the weather is good. I can save this time, less time on the road, I can even do some exercise in the office, and I don't want to waste too much time on the road. Someone gave me a bicycle before, for me to exercise. I rode it twice and I don't want to ride it any more. It is a toil. This terrain is like, always upward towards the south, downward towards the north. Ah, it's too bad. When you are struggling up, you are tired to death, when it's down, it slides down so quickly that you don't have to peddle. I haven't bought electric-bikes yet. I am thinking about buying, as a supplement, for the nearby stuff, I can ride electric-bike or walk." (#14)

Now we can put the jigsaw pieces together and see the big picture of the role of neighborhood design in influencing household's lifestyle behavior and group, and therefore household's direct energy consumption. In the short term, neighborhood design influences both the lifestyle bundle decision and usage behavior by changing attributes of alternatives; and in the longer term, neighborhood design could change the lifestyle "tags," or groups, the household is associated with, therefore changing the decision-making mechanism, which leads to a more fundamental change in household's energy consumption behaviors. By altering neighborhood design towards energy efficiency, we could potentially make a household with, for example, an 80% "amenity-oriented" tag into a 40% one, a 50% "budget-oriented" household into a 90% one, and people may choose a smaller unit, fewer private cars, less driving, more walking and biking and bus use, less heating and cooling at home, more energy efficient appliances, and appliances using renewable energy.

4.5 Conclusion

To summarize, we have three main conclusions from the household interviews in Jinan: (1) Households make joint decision of residence and vehicle portfolio, a lifestyle bundle choice. (2) There are various lifestyle groups with distinct value of life and different decision-making mechanisms (summarized in Table 4.1). (3) Neighborhood design influences household's lifestyle behavior and lifestyle group, and therefore household's direct energy consumption, through alternative attributes change, peer effects, and experience/habit effects.

Table 4.1 Lifestyle Group Characteristics and Possible Indicators

	Job-oriented	Child-oriented	Budget-oriented	Amenity-oriented
Lifestyle characteristics	Job is the priority of life; behavior influenced by employer benefits and colleagues	The child especially his/her educational future is the priority of life	Saving for the future is more important than the current quality of life; Have other family burdens or problems to solve	Enjoying most amenities; value time and enjoyment; Do not worry about the future; no family burden
Home-purchasing Criteria	Close to job or company shuttle stops; Company-built real estate; Neighborhoods that colleagues live in; Colleague's recommendations	School district; Daycare; Independent room for kid; Convenient bus for kid's commuting; Quiet, clean; Well-educated neighbors	Price; Future need; Second-hand housing; Renting; Housing with limited property rights	High-end, upscale; desirable location in the city ("South" and "East"); take houses from parents or parents help with down-pay
Vehicle-purchasing Reasons	Car for commuting; Learn driving with colleagues	Car for picking-up kid	Returning home for family reunion in the rural area	Brand-name cars; Taking taxis not convenient
Most sensitive to Policies	Job-housing balance; Employer benefits change (housing provision, parking, gas subsidy, company car access)	School quality/enrollment policy; Daycare and outdoor playground; Location of educational facilities	Car rental program; Pricing; Taxi availability increase; More options (e.g. small home with elevator)	Quality of service increase; Better layout and internal design;
Possible class indicators (demographic, socio-economic)	Access to a company/business car; Business owner; Working for a big enterprise; Stable employment with mid-to-high income	Presence of kid; School district of the residence	Presence of senior people; Senior household head; Floating population	Younger generation with affluent parents; Permanent residence

Chapter 5 Household Vehicle Portfolio Choice

5.1 Introduction

5.1.1 Background

Private motor vehicle ownership is one of the key determinants for long-term mobility, fuel consumption, and emission consequences in cities. With almost 700 million urban residents (NBS, 2012)[15] starting to catch up with the vehicle ownership levels of developed countries, China is at the forefront facing the motorization challenge. Particularly over the past 20 years, Chinese cities are witnessing a dramatic change in motor vehicle ownership. From Figure 5.1 and Figure 5.2 we can see that since the latter half of 1990s, motorcycles are motorizing urban residents in China away from bicycles; then after 2000, powered bicycles (mostly electric bicycles) and family cars are increasingly replacing bicycles as essential mobility stock for urban Chinese households.

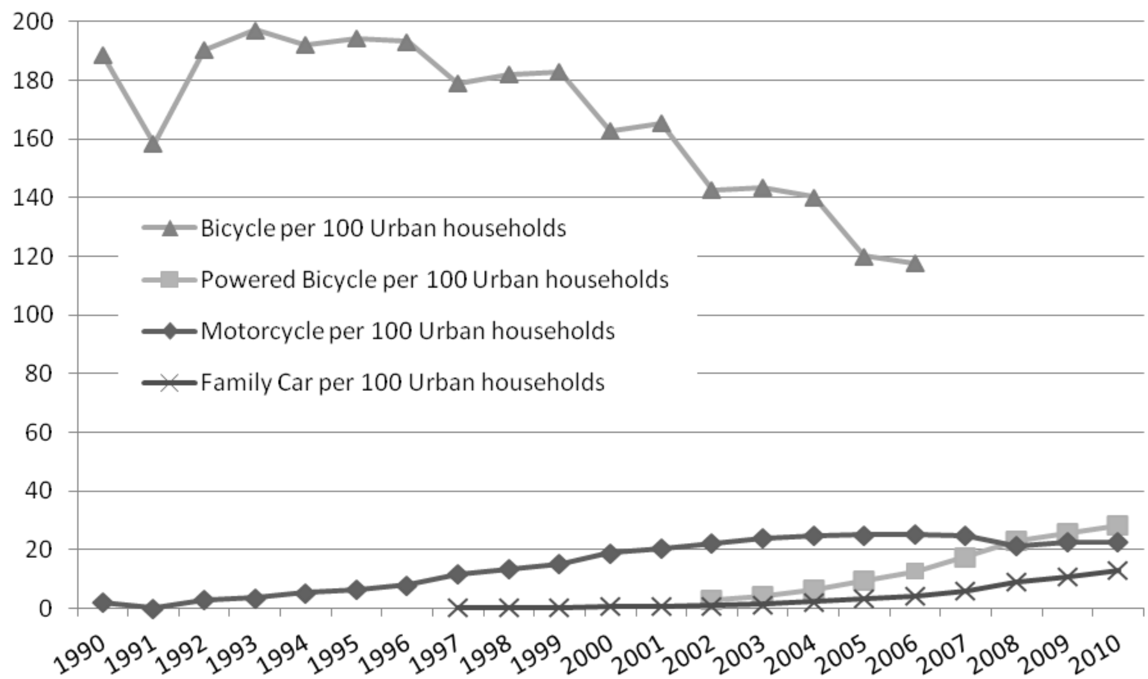


Figure 5.1 Vehicle Ownership of Urban Residents in China from 1990 to 2010

[15] National Bureau of Statistics：China Urban Population Surpassed Rural Population for the First Time --Sina finance. (n.d.). Retrieved March 24, 2012, from http://finance.sina.com.cn/china/20120117/123511222217.shtml

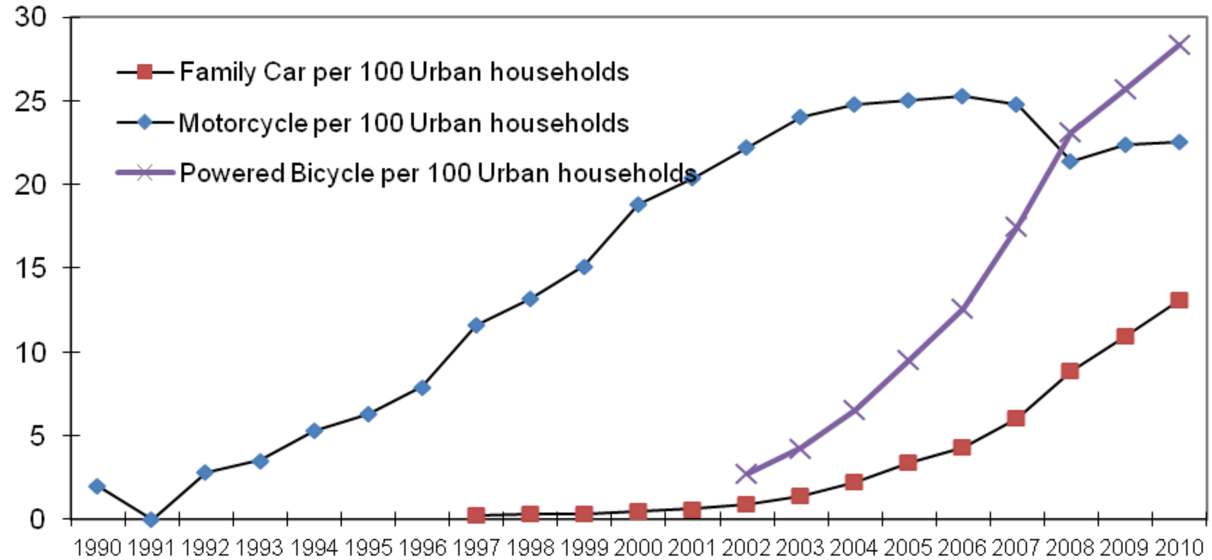


Figure 5.2 China Urban Household Motorized Vehicle Ownership Trend from 1990 to 2010

At the urban level, cities with similar sizes and income levels can have very different motorization rates, in terms of private automobiles (Table 5.1). Chengdu almost doubles Shenyang in terms of private cars per capita, while Beijing more than triples Shanghai, given very similar GDP per capita and public transport facilities. On the other hand, the mix of vehicle ownership of urban households is also very different (rows highlighted in grey in Table 5.1). Despite low automobile ownership, Shanghai has relatively high ownership of electric bicycles while Beijing has very high bicycle ownership. It seems that urban residents in different cities have very different vehicle ownership structures to cope with their mobility needs.

Table 5.1 City Comparisons of Vehicle Ownership (2006 data)

	Chengdu	Shenyang	Beijing	Shanghai
Population (million) [a]	11.03	7.04	15.60	18.15
Population Density of Built-up Areas (persons/km^2)[b]	360	325	1254	2401
Number of Private Cars (million)	0.56	0.19	1.81	0.51
Number of private cars/1000 population	***50.3***	***26.5***	***116.0***	***28.1***
Number of automobiles per 100 urban households	***9.3*** [c]	***3.0***	***18.1***	***4.9***
Number of motorcycles per 100 urban households	***2.8*** [c]	***5.4***	***6.1***	***2.8***
Number of electric bicycles per 100 urban households	***n.a.***	***10.6***	***6.6***	***28.7***
Number of bicycles per 100 urban households	***n.a.***	***139.2***	***191.1***	***123.5***
GDP per capita (yuan)	22,269	35,810	50,467	57,695
Per capita annual disposable income of urban residents (yuan)	12,789	11,651	19,978	20,668
# of public transportation vehicles per 10000 persons	15.41	12.62	22.19 [d]	12.52 [d]
per capita area of roads (sq. m)	12.46	9.77	7.4 [d]	11.84 [d]

Data Source: Sichuan, Liaoning, Beijing and Shanghai Statistical Year Book 2007, all data are for end of 2006
[a] Population: year-end residents who have been living in the city for at least 6 months ("chang zhu ren kou")
[b] data source: China City Statistical Year Book for 2007, data are for end of 2006
[c] data source: China Statistical Year Book for 2007, data are for end of 2006
[d] data source: Chengdu Statistical Year Book for 2007, data are for end of 2006

From the discussion in Chapter 2 we can see that vehicle portfolio ownership, how many and what type of private vehicles a household owns, is one important element of an urban household's lifestyle choice, along with their residential choice of whether to buy a home, how large a housing unit to own, and what kind of neighborhood to live in. Holding different key lifestyle values, households belonging to different lifestyle groups have different vehicle portfolio ownership choice mechanisms, and therefore have different responsiveness to changes. A neighborhood's physical attributes may also influence how households make these decisions. In this chapter, I use data collected in Jinan to test some of these hypotheses, quantitatively. Sections 5.1.2 will briefly go over the literature on vehicle ownership. Section 5.2 will first provide descriptive statistics of the basic characteristics of vehicle portfolio ownership from the Jinan data (5.2.1), then use an MNL model to show the role of household demographic and socio-economic conditions in determining vehicle portfolio ownership in Jinan (5.2.2 base model). Then, residential choice indicators are added into the base model to test if residential choice helps explain vehicle portfolio ownership choice (5.2.3). In Section 5.2.4, neighborhood design attributes are added into the model to test their association with different vehicle portfolio choices. Finally, Section 5.3 uses simulation to illustrate the relative effects of different variables on vehicle portfolio choice.

5.1.2 Vehicle Ownership Literature

Studies on household vehicle ownership can be divided into two basic categories, those using aggregate data and those using disaggregate data. Aggregate analyses model vehicle ownership at zonal, urban, or national levels, and can be used for inputs into travel forecasting models, and/or for intra-city, inter-city, or international comparative efforts, to derive, say, the income elasticity of demand for motor vehicles, and/or develop forecasts of future vehicle fleets. Examples include Beesley & Kain (1964), who use data from 45 U.S. cities in 1960 to predict automobile ownership as a function of median household income and gross city-wide population density; Button et al. (1993), who develop sigmoidal car ownership models using time-series data for a number of low-income countries; and Ingram and Liu (1997), who use aggregate data for an international spectrum of cities. Holtzclaw et al. use aggregate data from three U.S. cities and show the influence of residential density on vehicle ownership (Holtzclaw, 2002). For a more detailed categorization and complete comparison of aggregate models, please see De Jong et al. (2004)

Disaggregate models typically use household level data to examine more detailed behavioral relationships at the decision-maker level. Typically, the implicit or explicit behavioral theory underlying disaggregate models is utility maximization; households or individuals are assumed to choose, from a range of possible alternatives and under income and other constraints, the alternative which provides the greatest utility. This leads to the application of Random Utility Models (RUM) of discrete choice. The "randomness" comes from the inherent stochasticity of the modeled choice processes, captured by random variables representing utilities (M. Bierlaire, 1997) and the discrete nature of the choice comes from the nominal or ordered nature of the outcome of interest (e.g., one car). For most static vehicle ownership models using only cross-sectional data, researchers have used different model structures depending upon the question asked and the characteristics of the dataset, e.g.: Multinomial Logit (MNL), Nested Logit (NL), Ordered Logit (ORL). Most studies reveal that the key factors influencing car ownership include income, cost of car travel, and household structure (e.g., Lerman and Ben-Akiva, 1979; Dargay, 1999). Studies have also examined, in the same basic way, the relationship between vehicle ownership and the physical and functional characteristics of the physical context, such as dwelling unit density or relative levels of transportation service. For example, using an ordered logit model, Cambridge Systematics (1997) find significant effects of population density on household vehicle availability in Philadelphia. In a binary logit sub-model of car ownership, Giuliano & Dargay (2006) find density has a negative impact on car ownership in both the U.S. and U.K., while access to transit has negative impact on car ownership in the U.S. Examining the case of rapidly developing Santiago de Chile, Zegras (2010) finds that, while household income dominates the choice to own the first automobile, the decision to own additional vehicles is increasingly influenced by dwelling unit density, proximity to the central business district, and improved bus levels of service relative to the auto.

Despite numerous studies done in the developed countries, very few studies have focused on private car ownership in Chinese cities using disaggregate models, in large part due to lack of data. We might expect the behavioral patterns of private vehicle ownership in countries such as China to be different from that of the wealthier countries. As only a small fraction of households, those with the highest incomes, can afford a private car, most households remain below the vehicle ownership threshold. At the same time, actual and expected income growth, lifestyle changes, etc. mean that many households soon expect to purchase a car – a decision which may carry as much symbolic value related to status, aspirations, and transition to the "modern middle class" (see, e.g., Vasconcellos, 1997) as purely utilitarian mobility value. In other words, owning a private car can have very strong psychological effects or symbolic meanings associated, or as Wu et al. (1999) suggest: the utility of household vehicle ownership consists of a substantive utility and a symbolic utility. Those authors used a survey, including with questions regarding attitudes, of heads of households in Xi'an, China and find that that vehicle ownership attitudes resulting from psychological and sociological factors apparently influence vehicle ownership preference. They also find that a more expensive vehicle offers more symbolic meaning, reflecting the presence of "Veblen effects" – that is, consumers exhibit a willingness to pay a higher price for vehicles that have more symbolic meanings.

5.2 Vehicle Portfolio Choice in Jinan

5.2.1 Household Vehicle Portfolio Ownership Pattern in Jinan

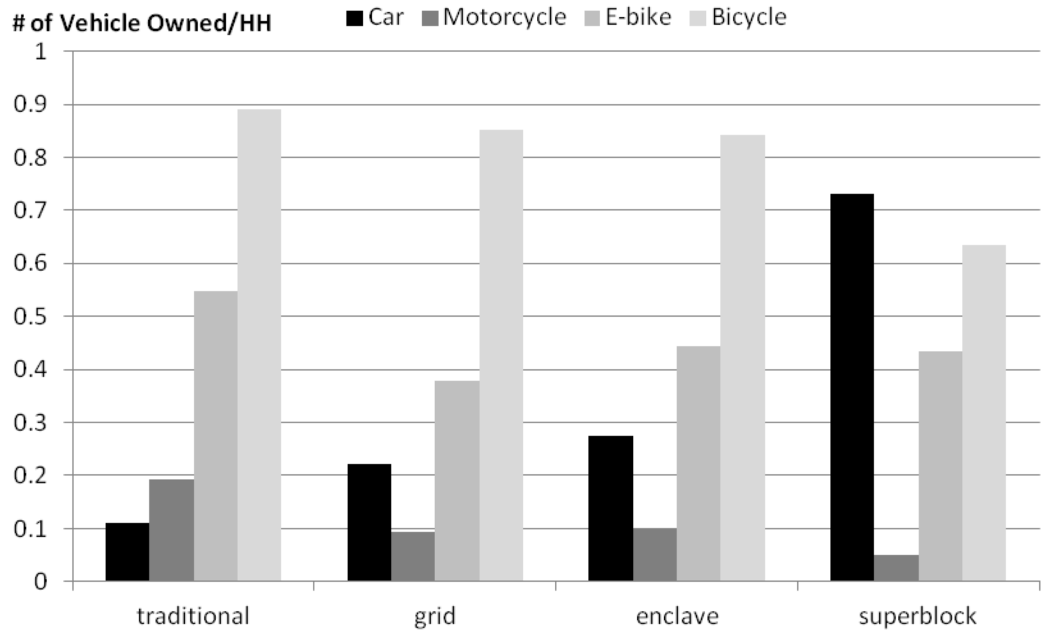


Figure 5.3 Household Vehicle Ownership in Jinan by Neighborhood Type

Figure 5.3 shows a clear pattern that households living in superblock neighborhoods tend to have many more cars than those living in the other three neighborhood types. Urban households in traditional neighborhoods own more electric bicycles and motorcycles. Figure 5.4 gives a clearer picture of household vehicle portfolio combinations across different neighborhood types. We can see that households in grid and enclave neighborhoods have fewer motorized vehicles than even those in traditional neighborhoods. Motorcycles seem to be a much needed vehicle in the traditional neighborhoods. Most distinctly, the majority of those living in superblock neighborhoods have at least one car.

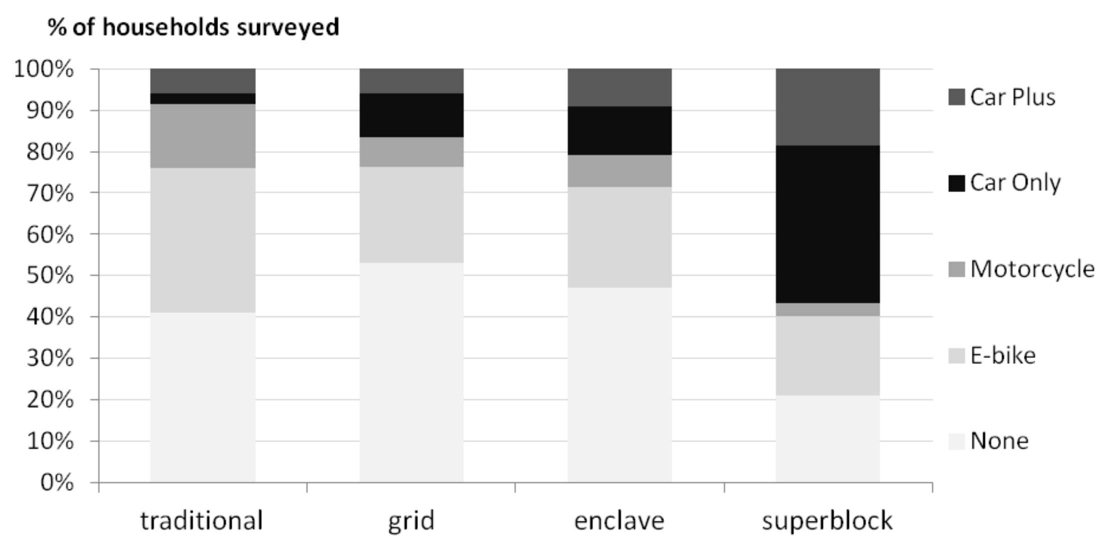


Figure 5.4 Household Vehicle Portfolio Ownership Pattern in Jinan by Neighborhood Type

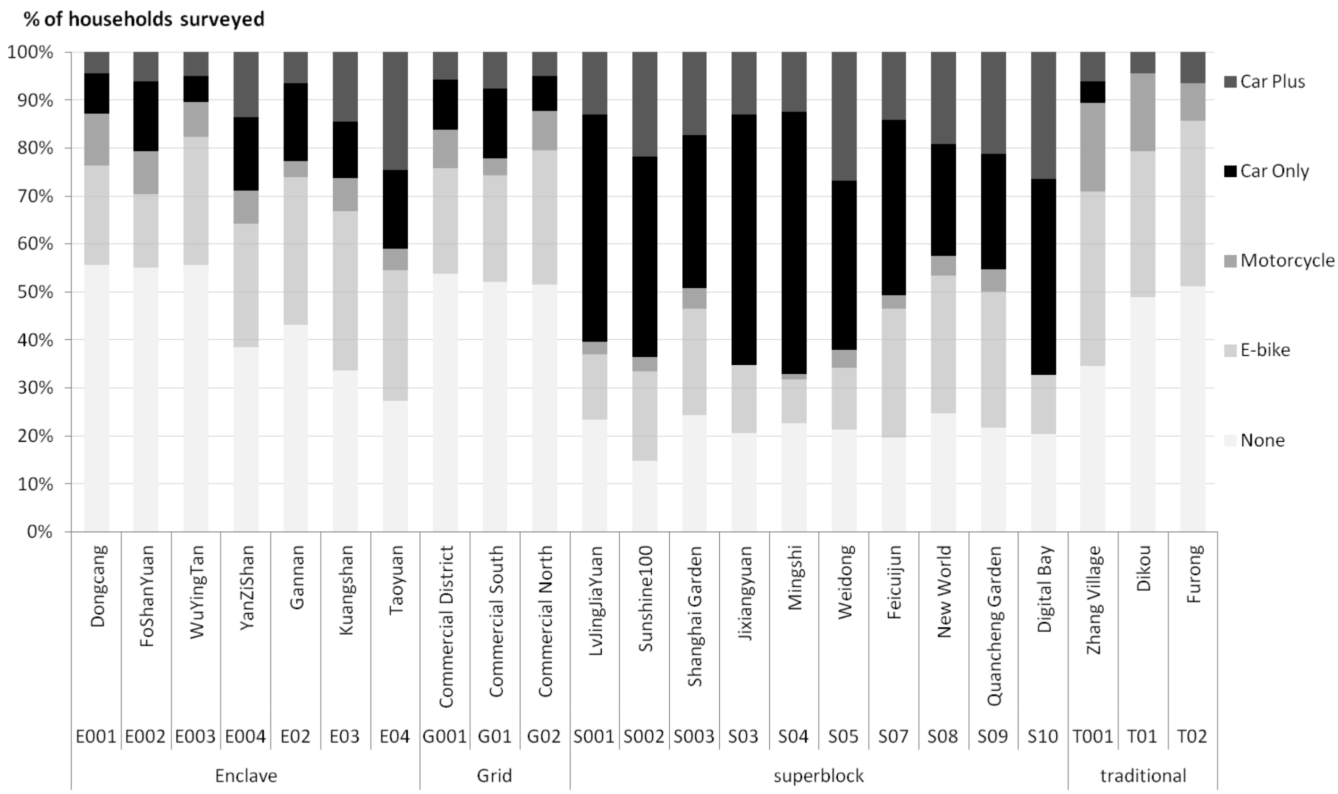


Figure 5.5 Household Vehicle Portfolio Ownership in Surveyed Neighborhoods in Jinan

Nonetheless, household vehicle portfolio ownership by individual neighborhood (Figure 5.5) shows variations even within each neighborhood type. For example, the enclave neighborhood Taoyuan (E04) has similar vehicle portfolio combinations as the superblock neighborhoods New World (S08) and Quancheng Garden (S09), and traditional neighborhood Zhang Village (T001) has almost same level of car ownership as WuYingTan (E003), twice as much as other traditional ones. Thus, accounting for the physical characteristics of specific neighborhoods, as well as the variation of household types within them, will be important in understanding the role of neighborhood design in influencing vehicle ownership levels.

We would expect that the differences in household vehicle ownership might be partially explained by variations in income across the neighborhood types. The boxplot in Figure 5.6 shows that households living in the superblocks are richer than others, while those living in the traditional neighborhoods are poorer. However, we still see overlaps of the income distributions across neighborhood types, allowing for the possibility to control for income variation in modeling the effects of neighborhood physical attributes on household vehicle ownership.

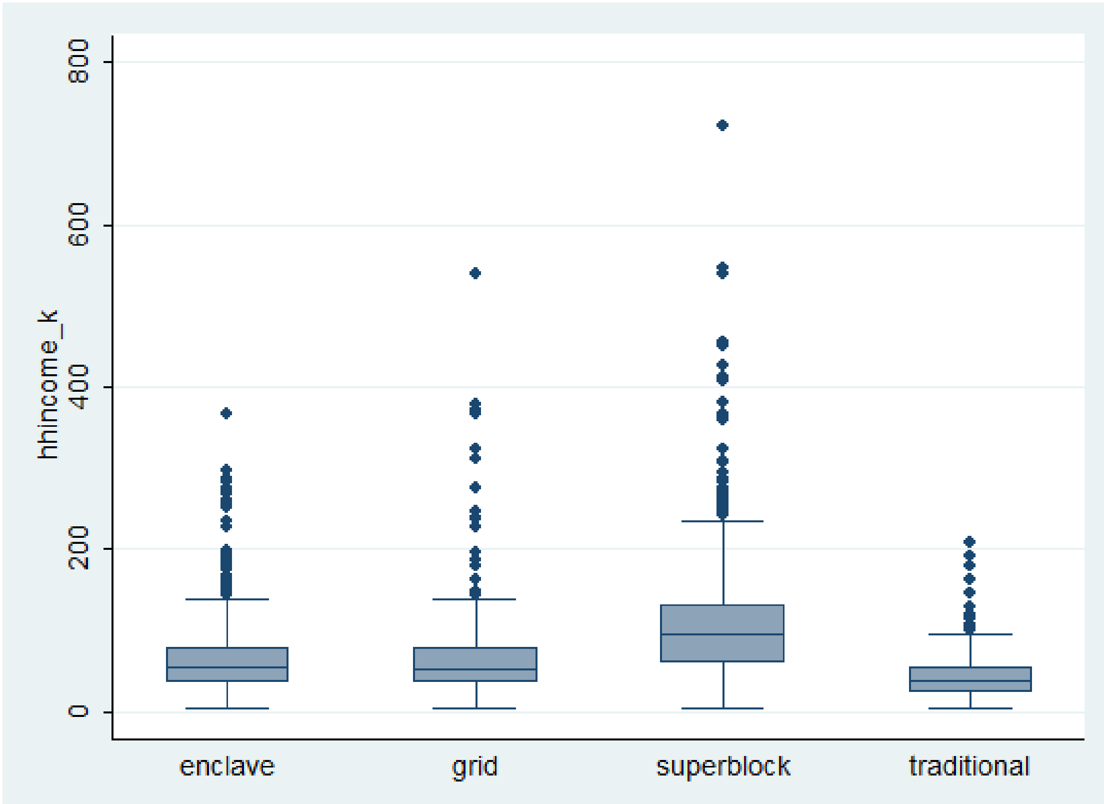


Figure 5.6 Household Income Distribution in Jinan by Neighborhood Type

We also might expect that households with more family members have more incentives to own motorized vehicles because of increased travel demand. The presence of a child in the family, for example, increases certain travel demand, as well as demand for more convenience, speed, safety, and maybe privacy. More employed household members increases work trips and may also then increase demand for motorized vehicles. On the other hand, older adults in a household might lack the ability to operate vehicles and have lower demand for longer distance travel, thus reducomg motor vehicle ownership. Household access to a company car may have countervailing effects. At first, it could reduce the likelihood of owning private motor vehicles because of apparent substitution effects; however, it may also ultimately increase the utility of owning a private car because: 1) people using the company car must obtain a drivers license and learn to drive, thus inducing vehicle ownership propensities; 2) using a company car gives people the experience of owning cars and getting used to a car-owning lifestyle, therefore further increasing the likelihood of car ownership; and/or 3) access to a company car may influence people's sense of "status," such that the company car provides the first taste of the "symbolic utility" of private car ownership.

Attitudes about different modes and vehicles as well as the perceived value of time are the third level of lifestyle hierarchy discussed in Chapter 2, and they may have direct and indirect influences on household's vehicle portfolio ownership choice. Here we used the self-assessed agreement, measured by a five-point Likert scale, on four statements: (1) driving is a sign of prestige; (2) taking bus is convenient; (3) I like biking; and (4) time spent on travel is a waste.

Finally, we expect that several neighborhood physical and transportation system-related characteristics to influence household vehicle ownership. Parking provision, especially underground parking, would likely positively influence owning more cars. A neighborhood's relative regional accessibility may change the characteristics of intra-urban travel demand, thereby changing the propensity of owning motor vehicles. Neighborhood form characteristics – including residential density, building footprint, road network layout, and intersection density – influence the relative attractiveness of different modes and thus influence vehicle ownership choice. The number of bus stops makes public transit more convenient, and other factors that affect the walkability of neighborhood (percentage of street level shops, percentage of roads with walking facilities) can also be associated with different vehicle ownership choice through direct and indirect lifestyle interactions discussed before.

5.2.2 Basic Household Characteristics and Vehicle Portfolio Choice (MNL)

First, let's look at how much variation in household vehicle portfolio ownership can be explained by household demographic and socio-economic characteristics and household members' attitudes only. The model result with the best goodness of fit as determined by the likelihood ratio test is shown in Table 5.2.

Table 5.2 Vehicle Portfolio Ownership Estimation with Household SED Characteristics

VARIABLES	E-bikes Only		Motorcycles (only or plus e-bikes)		Cars Only		Cars and Other Vehicles	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Household Characteristics								
ln_hhincome_k	0.150**	2.33	-		1.430***	16.7	1.319***	12.87
no_employ	-0.630***	-4.05	-0.789***	-2.84	-1.022***	-3.42	-0.604*	-1.68
two_employ	-		-		0.263**	2.07	0.465***	2.63
more_employ	-		-		-0.300	-1.63	0.518**	2.30
single	-0.804***	-4.13	-0.664**	-2.37	-		-0.926**	-2.23
couple	0.187	1.49	-		-0.289*	-1.89	-0.412**	-2.05
fourplus_hh	0.194*	1.91	0.234	1.33	-		0.320**	2.34
have_kid	0.372***	3.63	0.366**	2.55	0.465***	4.16	0.719***	5.16
have_old	-		-0.375*	-1.82	-0.147	-1.22	-0.576***	-3.72
senior_hh	-0.509***	-2.79	-0.642	-1.64	-0.718**	-2.33	-	
Household Resources								
comcar	-0.789***	-2.64	-0.595	-1.27	-		-0.676**	-2.00
Attitudes								
a1_drive_prestige	-		-		-0.103***	-2.71	-0.122***	-2.64
a2_bus_convenient	-0.170***	-4.54	-0.124**	-2.16	-0.287***	-7.01	-0.345***	-7.30
a3_bike_liking	-		-		-0.164***	-4.60	-0.0543	-1.23
a4_travel_time_waste	-		0.0819	1.53	0.108***	2.90	0.137***	3.06
Constant	-0.378	-1.22	-1.307***	-4.34	-5.138***	-11.9	-5.797***	-10.61

N = 3,955; Number of parameters = 44; Log pseudo-likelihood = -5166.53; Adjusted ρ^2 = 0.103;
*** p<0.01, ** p<0.05, * p<0.1
"-" denotes variable not included in respective utility function based on model estimation process.

All coefficients are relative to the base alternative (i.e., owning no motor vehicles). The coefficient estimation confirms that higher income is significantly associated with higher utilities for owning e-bikes, cars only, and cars and other vehicles, and the size of the income effect is much larger for the two alternatives with cars. Income does not seem to have any effect on motorcycle ownership. More household members currently employed also increases the utility of owning more vehicles, especially cars. Having three or more household members currently employed is associated with a higher probability of owning cars and other vehicles. Household size also plays a role in defining the need for owning motor vehicles. A single-person household is more likely to own no motor vehicles, but all else equal, being single does not reduce the likelihood of owning a car; a two-person household is less likely to own cars; and having four or more members in the household increases the utility of owning motor vehicles except "cars only." Having a child in the family increases the utility of owning all kinds of motor vehicles, but the magnitude is larger for owning cars. Having older adults in the household decreases the probability of owning motor vehicles, with a larger decrease if the older adult is the household head. Having access to a company car decreases the utility of owning any of the vehicle portfolios, except cars only.

All four attitude indicators are significantly associated with vehicle ownership choice.[16] The more that people view owning a car as a sign of prestige, the less likely they are to own portfolios with cars, which is consistent with the interview findings. Naturally, people more strongly agreeing that "taking bus is convenient" are less likely to own any motor vehicles, especially cars, less so with e-bikes and motorcycles. This suggests that motorcycle and ebike ownership may be more complementary with public transit use than cars are, although this requires additional study. The more that people claim to like biking, the less likely they are to own cars; while those who more strongly agree with "travel time being a waste of time" are more likely to own cars. Note that these attitudes and perceptions, perhaps more than other household variables, have a potentially two-way relationship with the choice in this model. That is, the attitudes may have preceded the ownership choice (i.e., I find the bus to be convenient, thus I don't need to buy a car) and/or the other way around, the attitudes are formed as adaptation to life conditions (i.e., I cannot afford to buy a car and must take the bus, so I must find the bus convenient).

Note that the coefficient estimates only represent the relationships between the explanatory variables and the utility of that vehicle portfolio ownership alternative relative to the choice of owning no motor vehicles (the "base alternative"). Therefore sometimes it is not so straightforward whether a change in one explanatory variable will increase or decrease the probability of that alternative, as the utilities of other competing alternatives might change with this variable too. Furthermore, the effects of a particular variable on the likelihood of choosing a particular alternative are not constant across the values of the variable (e.g., the income elasticity of demand for the "cars only" alternative is not constant across all income levels). Simulations across a range of variable values (as described Chapter 3 section 3.2.3) can illustrate the effects more clearly. Such simulations, including of relevant household characteristics will be

---

[16] The inclusion of the attitudes in the models as continuous variables could be somewhat controversial, as the Likert scale does not truly adhere to the characteristics of continuous variables. Nonetheless, such an approach is common practice; in this particular case, the model performed better with the Likert values included as opposed to using a simple dummy variable representing agreement with the statement or not (which also has the drawback of losing details on degree of agreement with the statement).

conducted below (Section 5.2.4), using the full model specification, including residence and neighborhood characteristics.

5.2.3 Role of Residential Choice

To test the role of residential choice in determining household vehicle portfolio choice, I add three related variables to the base model: renting, superblock, and unit-size. The results, in Table 5.3, indicate an improvement in the model's explanatory power (better goodness of fit).

Table 5.3 Vehicle Portfolio Ownership Estimation with Residential Choice

VARIABLES	E-bikes Only		Motorcycles (only or plus e-bikes)		Cars Only		Cars and Other Vehicles	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Household Characteristics								
ln_hhincome_k	0.128*	1.83	0.190*	1.82	0.884***	8.12	0.943***	8.36
no_employ	-0.655***	-3.64	-0.735**	-2.40	-1.245***	-3.90	-0.797**	-1.97
two_employ	-0.0670	-0.56	-0.110	-0.63	0.119	0.78	0.335*	1.80
more_employ	-0.273	-1.47	-0.505*	-1.73	-0.399*	-1.79	0.358	1.45
single	-0.864***	-3.97	-1.003***	-3.23	0.0162	0.05	-0.722	-1.56
couple	0.115	0.83	-0.229	-1.08	-0.291*	-1.66	-0.387*	-1.79
fourplus_hh	0.314**	2.40	0.307	1.54	-0.0320	-0.22	0.349**	2.19
have_kid	0.290***	2.66	0.303*	1.86	0.282**	2.29	0.572***	3.98
have_old	-0.152	-1.11	-0.407*	-1.80	-0.193	-1.22	-0.662***	-3.65
senior_hh	-0.406*	-1.86	-0.459	-1.15	-0.847**	-2.47	-0.116	-0.31
Household Resources								
comcar	-0.829**	-2.56	-0.687	-1.41	-0.150	-0.46	-0.771*	-1.94
Attitudes								
a1_drive_prestige	0.0426	1.19	-0.0315	-0.55	-0.0427	-0.99	-0.0840*	-1.67
a2_bus_convenient	-0.162***	-4.24	-0.126**	-2.13	-0.234***	-5.45	-0.311***	-6.35
a3_bike_liking	0.0206	0.58	-0.0112	-0.20	-0.133***	-3.18	-0.0259	-0.52
a4_travel_time_waste	0.0106	0.29	0.116**	2.02	0.0695	1.57	0.117**	2.38
Residential Choices								
superblock	0.324***	2.65	-0.413**	-1.99	0.690***	5.15	0.351**	2.25
renting	-0.122	-0.96	0.484***	2.92	-0.664***	-3.33	-0.613***	-2.67
ln_unit_area	-0.0617	-0.62	-0.0448	-0.30	1.405***	9.22	0.906***	5.09
Constant	-0.213	-0.42	-1.706**	-2.19	-9.424***	-11.55	-8.298***	-9.04

N = 3,924; Number of parameters = 72; Log pseudo-likelihood = -4920.52; Adjusted ρ^2 = 0.143
*** p<0.01, ** p<0.05, * p<0.1
"-" denotes variable not included in respective utility function based on model estimation process

The likelihood ratio test shows that the model with three residential choice variables is significantly better than the base model.[17] This is consistent with the findings from the interviews in Chapter 4, Section 4.3. We might expect that “renting” is significantly associated with a lower likelihood of owning cars mainly because of the shared resource constraint, or more precisely, the current saving constraint to buy housing and cars. Households give more priority to a first-time home, rather than car, purchase, therefore households who have not yet purchased a home will be more likely to save for the one-time down payment on a home instead of buying a car (for various reasons discussed in Chapter 4).

We also expect the variable “superblock” to be associated with a higher likelihood of owning cars, probably due to: (1) the interdependent choice through accessibility and parking, reflecting the fact that superblocks tend to be much more “car friendly” with ample parking, wide roadways, higher speed limits, less pedestrian friendliness, and in more “car dependent” parts of the city (e.g., more peripheral) lacking public transit or pedestrian facilities; and/or (2) shared decision-makers’ attitudes, perceptions, preferences, and values, as explained in Section 4.3, as superblocks might attract a certain type of household that also creates a more auto-oriented *social* community (peer pressure and the like) which may further accelerate vehicle ownership. Lastly, the area of the housing unit is positively associated with a higher likelihood of owning cars, which may be a proxy for the unobserved set of decision-makers’ attitudes, perceptions, preferences, and values (e.g., enjoyment of freedom and privacy) that might influence both desires for larger dwelling unit size and private car ownership.

5.2.4 Neighborhood Design and Vehicle Portfolio Choice

Finally, to test if neighborhood design might influence households’ vehicle portfolio choice, I add variables characterizing neighborhood physical attributes into the model. The neighborhood design indicators provide additional explanatory power over the previous models (the goodness of fit, as measured by the adjusted ρ^2 improves and a likelihood ratio test shows this unrestricted model is significantly better than the model without the neighborhood design indicators[18]). Estimation results of the complete model with neighborhood design indicators are shown in Table 5.4.

---

[17] Likelihood ratio test:
H_0: $\beta^{rc}=0$ (residential choice variables do not have influence on vehicle portfolio choice)
H_1: $\beta^{rc}\neq 0$ (residential choice variables have influence on vehicle portfolio choice)
Degrees of Freedom = (# of parameters in unrestricted model) - (# of parameters in restricted model) = 28
Likelihood Ratio = $-2 * (L_{restricted} - L_{unrestricted}) = -2 * (-5166.53-(-4920.52)) = 492.02 > \chi^2_{0.001,28} = 56.89$,
The test statistic strongly rejects the null hypothesis that residential choice variables do not have influence on vehicle portfolio ownership choice at the 0.1% significance level, and the model with residential choice variables is significantly better in terms of goodness of fit than the base model.

[18] Likelihood ratio test:
H_0: $\beta^{ND}=0$ (neighborhood design indicators do not have influence on vehicle portfolio choice)
H_1: $\beta^{ND}\neq 0$ (neighborhood design indicators have influence on vehicle portfolio choice)
Degrees of Freedom = (# of parameters in unrestricted model) - (# of parameters in restricted model) = 17
Likelihood Ratio = $-2 * (L_{restricted} - L_{unrestricted}) = -2 * (-4920.52-(-4814.93)) = 211.18 > \chi^2_{0.001,17} = 40.79$,
The test statistics strongly rejects the null hypothesis that neighborhood design indicators do not have influences on vehicle portfolio ownership choice at the 0.1% significance level, and the model with neighborhood design indicators is significantly better in terms of goodness of fit than the one without.

The MNL specification passes the IIA test, meaning the preference for each alternative is independent of the inclusion (or exclusion) of other alternatives.[19]

Several neighborhood design indicators have significant associations with the utilities of owning different vehicle portfolios. For example, higher residential density is associated with higher probabilities of owning e-bikes and motorcycles; larger average building footprint size (implying larger volume of buildings) is associated with a higher utility of owning cars only and a lower utility of owning e-bikes and motorcycles. A larger average distance between entries (usually bigger blocks) is associated with an increased utility of owning all motor vehicle types. More underground parking space provision increases the utility of owning cars only, as expected. Denser intersections are associated with a higher probability of owning all kinds of private motor vehicles, especially cars. Residential buildings with more street-level shops and roads with walking facilities decrease all kinds of private motor vehicle ownership, perhaps by increasing walkability. We can also see some neighborhood "amenities" are positively associated with a higher probability of owning cars only, e.g. more roads with trees, more mixed building functions, less surface parking (surface parking is deemed as less aesthetic and less secure feature), and better regional accessibility. This association could be partly due to unobserved attitudes and preferences which contributes to households' lifestyle grouping, which in turn affects the residential choice (neighborhood choice, specifically) and vehicle portfolio choice at the same time.

[19] The IIA test result:

```
**** suest-based Hausman tests of IIA assumption (N=3924)

 Ho: Odds(Outcome-J vs Outcome-K) are independent of other alternatives.
```

Omitted	chi2	df	P>chi2	evidence
1	102.004	93	0.246	for Ho
2	56.817	93	0.999	for Ho
3	68.364	93	0.974	for Ho
4	64.317	93	0.990	for Ho

Table 5.4 Vehicle Portfolio Ownership Choice Model Result with Neighborhood Design Indicators

VARIABLES	E-bikes Only		Motorcycles (only or plus e-bikes)		Cars Only		Cars and Other Vehicles	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Household Characteristics								
ln_hhincome_k	0.113	1.57	0.262**	2.26	0.831***	9.01	0.877***	7.86
no_employ	-0.728***	-4.56	-0.895***	-3.25	-1.362***	-4.51	-0.967***	-2.66
two_employ	-		-		-		0.369**	2.10
more_employ	-		-0.333	-1.38	-0.340**	-2.04	0.591**	2.52
single	-0.892***	-4.48	-1.016***	-3.20	-		-0.790*	-1.80
couple	-		-0.403**	-1.96	-0.292*	-1.86	-0.484**	-2.40
fourplus_hh	0.165	1.64	-		-		0.311**	2.24
have_kid	0.301***	3.10	0.286*	1.75	0.298**	2.48	0.606***	4.21
have_old	-		-0.315*	-1.74	-0.187	-1.46	-0.621***	-3.91
senior_hh	-0.479***	-2.70	-		-0.910***	-2.80	-	
comcar	-0.719**	-2.36	-0.670	-1.39	-		-0.664*	-1.93
Attitudes								
a1_drive_prestige	0.0560*	1.71	-		-		-0.0788*	-1.72
a2_bus_convenient	-0.171***	-4.36	-0.107*	-1.80	-0.258***	-5.82	-0.334***	-6.73
a3_bike_liking	-		-		-0.115***	-3.17	-	
a4_travel_time_waste	-		0.121**	2.23	0.0562	1.42	0.113**	2.45
Residential Choice								
renting	-0.249**	-2.00	0.329*	1.81	-0.790***	-4.30	-0.631***	-2.80
ln_unit_area	-		0.166	1.22	1.321***	8.67	0.853***	5.11
Neighborhood Design								
res_density_hh_acre	0.00635	1.58	0.0081	1.57	-		-	
footprint	-0.0012***	-3.41	-0.00098**	-2.35	0.0013***	3.10	-0.00052	-1.35
entry_m	0.0019***	4.08	0.0018***	2.68	0.00084*	1.92	0.0022***	4.29
functin_mix	1.474**	1.97	-		2.884***	3.43	2.155**	2.46
parking_under_s	-		-1.937**	-2.17	1.119***	3.86	-	
parking_surface	0.084***	2.62	0.0579	1.05	-		0.0930***	3.05
ra_total	0.002***	4.05	-		0.0033***	4.90	0.0034***	4.49
road_trees	-0.642***	-2.93	-0.999***	-3.22	1.069***	3.96	-0.756**	-2.42
street_level_shop	-1.760***	-3.52	-		-2.605***	-4.49	-2.676***	-3.72
walking_facility	-1.358***	-3.58	-		-0.728**	-2.14	-1.751***	-4.29
intersectiondensity	0.127***	5.47	0.0564***	2.85	0.163***	4.60	0.157***	4.68
bus	-0.027*	-1.77	-		-		-0.0278	-1.47
brt	0.280**	2.52	-		0.308***	3.32	0.152	1.19
Constant	-1.346**	-2.09	-3.781***	-4.30	-12.44***	-11.85	-9.073***	-8.65

N = 3,942; Number of parameters = 89; Log pseudo-likelihood = -4814.93; Adjusted ρ^2 = 0.159;
*** p<0.01, ** p<0.05, * p<0.1
"-" denotes variable not included in respective utility function based on model estimation process

5.3 Estimated Relative Effects via Simulation

Using the complete model from the previous section, I now run simulations to demonstrate the relative effects of relevant explanatory variables on a household's predicted probability of owning a particular vehicle portfolio. In the aggregate, these simulations (showing cumulative probabilities) can be interpreted to represent the estimated total share of different vehicle portfolios across Jinan households at: (1) a particular level of the variable of interest (by drawing a vertical line at a particular value of the independent variable); or (2) as the values of the variable of interest change (by moving horizontally along the x-axis). At any given point, the slope of the curve provides the elasticity – the responsiveness of the probability of choice of the different alternatives to a change in the variable of interest – in most cases this elasticity is not constant across different values of the dependent variables analyzed.

5.3.1 Simulated Effects of Household Socioeconomics, Demographics and Housing Conditions

The simulated income effect is shown in Figure 5.7. The probability of owning no motor vehicles decreases dramatically up to the point where income reaches 100,000 yuan (US $15,600), after which it continues to decrease but at a declining rate. The probability of owning electric-bicycles first increases slightly, starts to fall when income passes the point around 50,000 yuan (US $7,800), and then continues to fall gradually. The probability of owning a motorcycle increases slightly then starts to decrease at a slower and slower rate. The probability of owning cars increases quickly at the early stages of higher incomes and continues increasing but at slower rates with continually rising income. The probability of owning the portfolio of cars plus other vehicles has a similar shape. Consider the average annual income of current households in Jinan's superblock neighborhoods, around 100,000 yuan (US $15,600): moving along the x-axis to the right to simulate an income increase, we see a dramatic decline in electric-bicycles and the no vehicle category in exchange for cars; this tendency declines modestly after annual income reaches about 400,000 yuan (US $62,500).

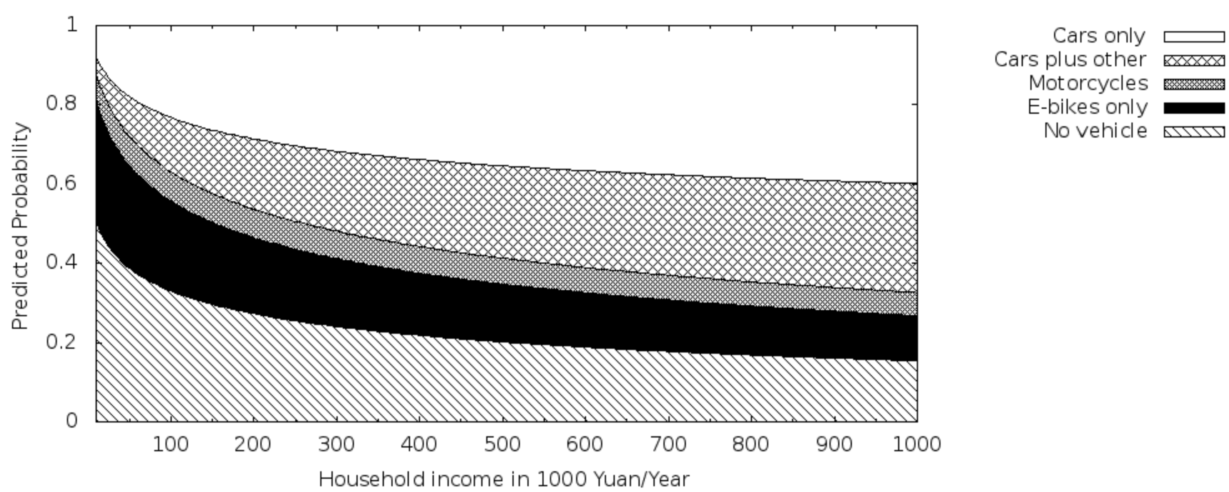


Figure 5.7 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Household Income Level

The effect of having a child in the family is shown in Figure 5.8. The darker (black) lines are the probability curves for households that have a child while the lighter (grey) lines are probability curves for those households without a child. We can see that having a child increases the probability of owning cars, especially when income is high; it also increases the probability of owning e-bikes when income is low (household income below 200,000 yuan (US $31,250) per year). The probability of owning no motor vehicles is lower if the household has a kid.

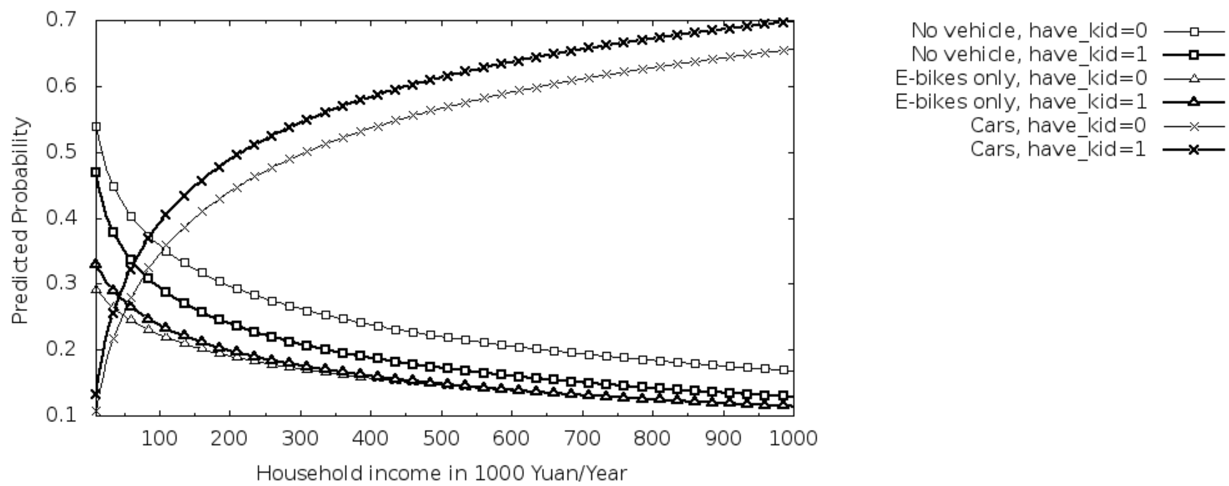


Figure 5.8 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With/Without Child

Note: Curves for "Cars" are the sum of the probabilities for two alternatives with cars: "cars only" and "cars and other vehicles"

A similar simulation can be done to illustrate the effect of having older adults in the household and for households headed by an older adult. Figure 5.9 shows that older adults in the household increase the probability of not owning any motor vehicles, and, as expected, decrease the likelihood of owning cars or electric bicycles.

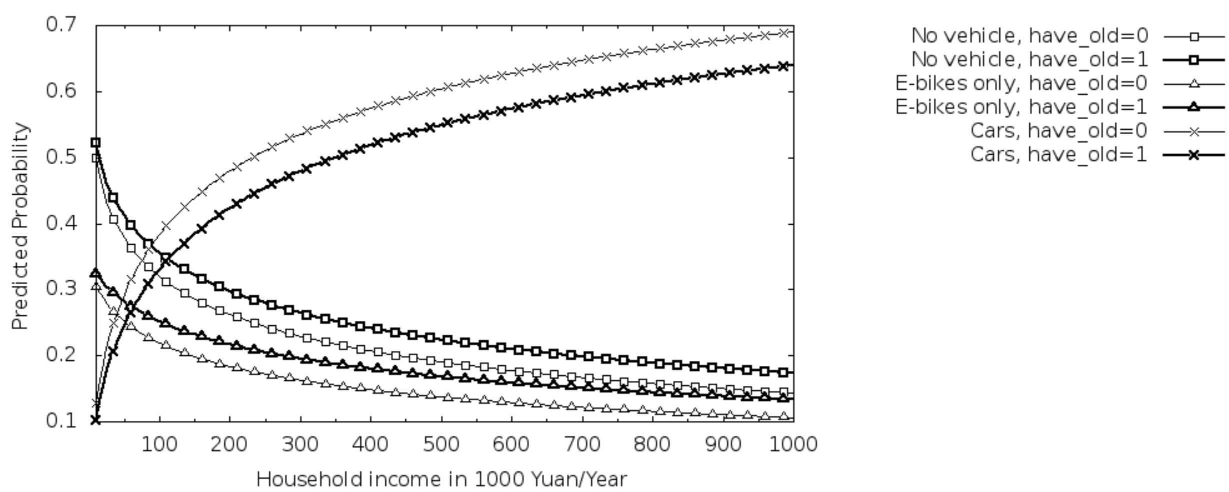


Figure 5.9 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With/Without Older Adult

Note: Curves for "Cars" are the sum of the probabilities for two alternatives with cars: "cars only" and "cars and other vehicles"

As mentioned, the expected effect of having access to a company/business car is ambiguous. In Figure 5.10 a household with access to a company car is shown in black lines while the counterpart is in grey lines. Interestingly, although having access to a company car generally decreases the household's likelihood of owning motor vehicles (as the no vehicle probability increases), this comes mostly from reducing the probability of owning electric-bicycles; the probability of owning cars slightly increases. That is, having access to a company car has a net effect of increasing car ownership.

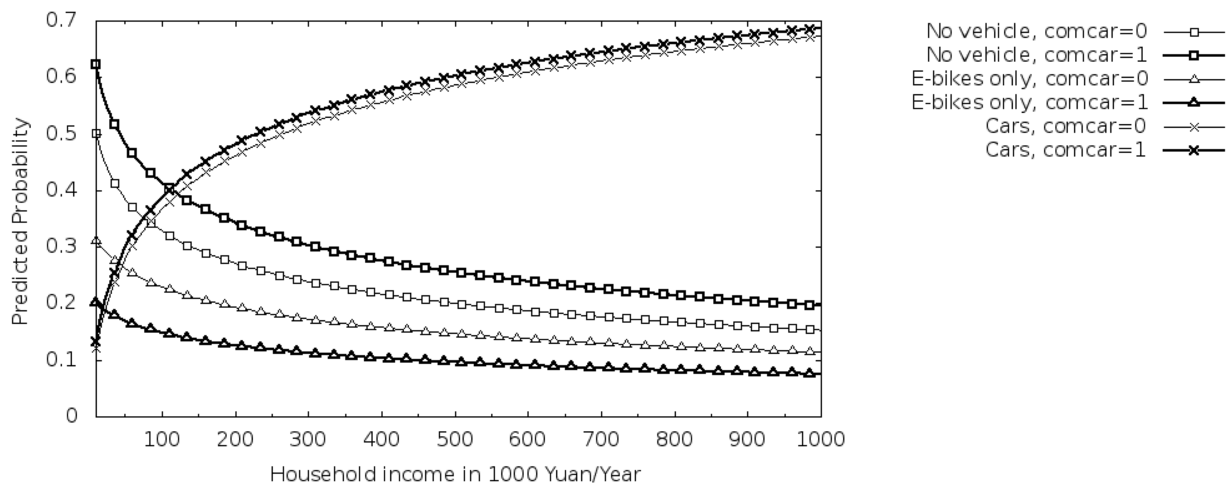


Figure 5.10 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, With Access to Company Car

Note: Curves for "Cars" are the sum of the probabilities for two alternatives with cars: "cars only" and "cars and other vehicles"

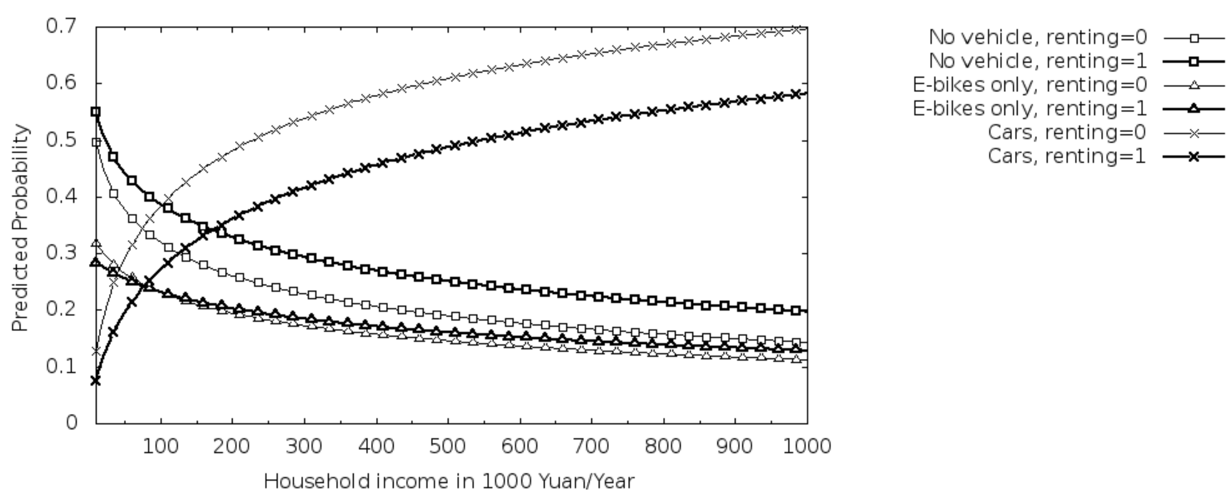


Figure 5.11 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Household Income Level, Renting Home or Not

Note: Curves for "Cars" are the sum of the probabilities for two alternatives with cars: "cars only" and "cars and other vehicles"

Figure 5.11 shows the simulated effect of "renting": the black lines show the probability curves of vehicle portfolio ownership choice with respect to income of households who have already purchased their first home (irrespective of mortgage status) while the grey lines are the probability curves for those who are still renting. We can see that renters have a much higher probability of having no vehicles, a slightly lower likelihood of owning electric bicycles when income is low (less than 50,000 yuan, or US $7,800 per year) but a slightly higher likelihood of owning electric bicycles when household income is higher than 100,000 yuan (US $15,600) per year. The probability of owning cars is much slimmer for renters (an almost 10% reduction in car ownership at higher income levels).

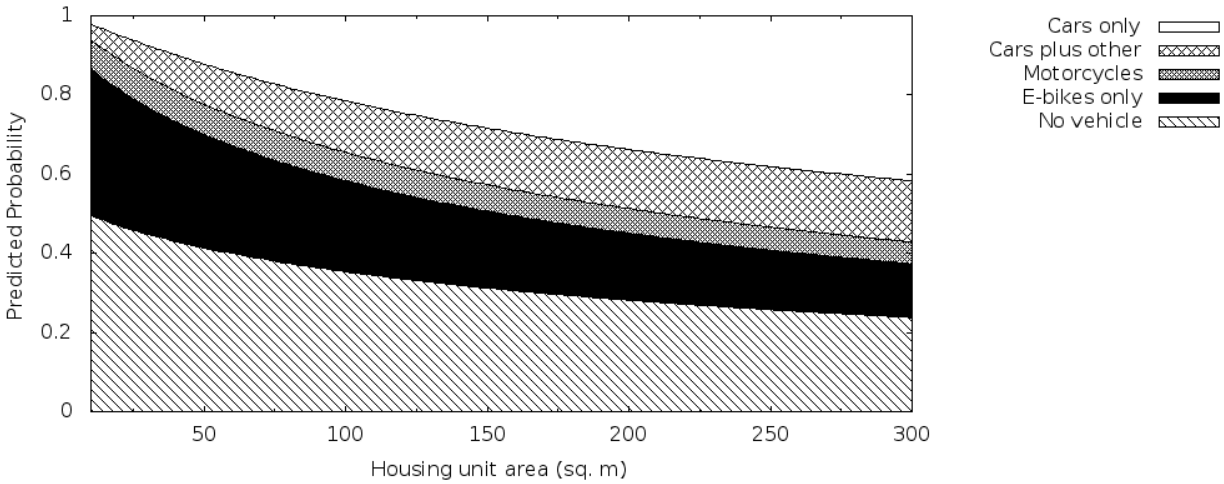


Figure 5.12 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation by Housing Unit Area

Another important residential choice attribute is the size of the housing unit. As Figure 5.12 shows, larger housing unit size is associated with a higher likelihood of car ownership, and lower probabilities of households owning electric bicycles and owning no motorized vehicles.

5.3.2 Simulated Effects of Neighborhood Characteristics

Finally, the effects of neighborhood design indicators are also simulated. Figure 5.13 shows, all else equal, residential density's effect on vehicle portfolio probabilities. Interestingly, as density increases, the share of e-bike owners increases while car owners' and no vehicle owners' shares shrink.

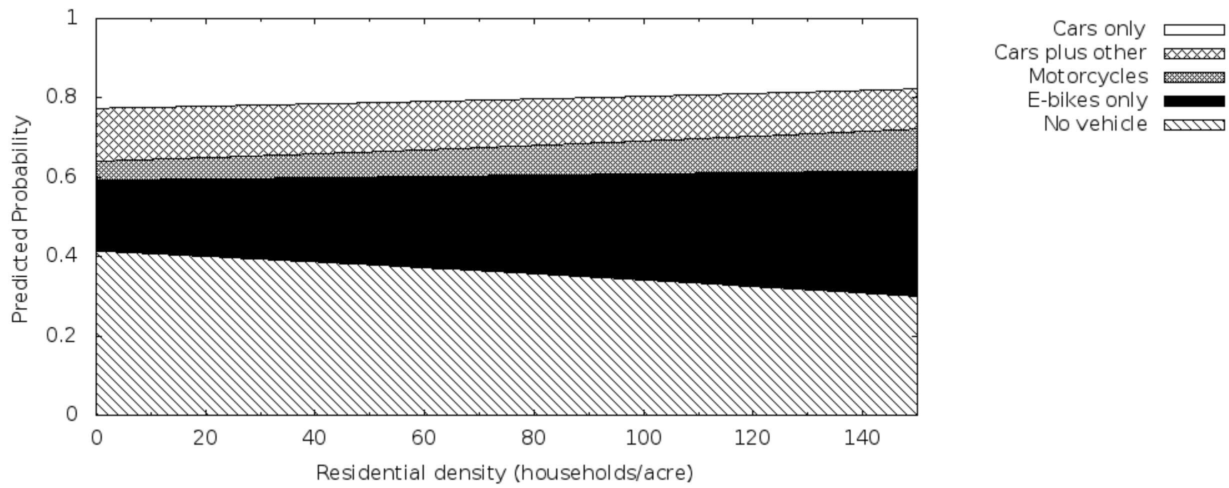


Figure 5.13 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Residential Density

Figure 5.14 shows the relative estimated effect of underground parking. More underground parking space is associated with a higher share of car owners and the decline of e-bike and motorcycle ownership.

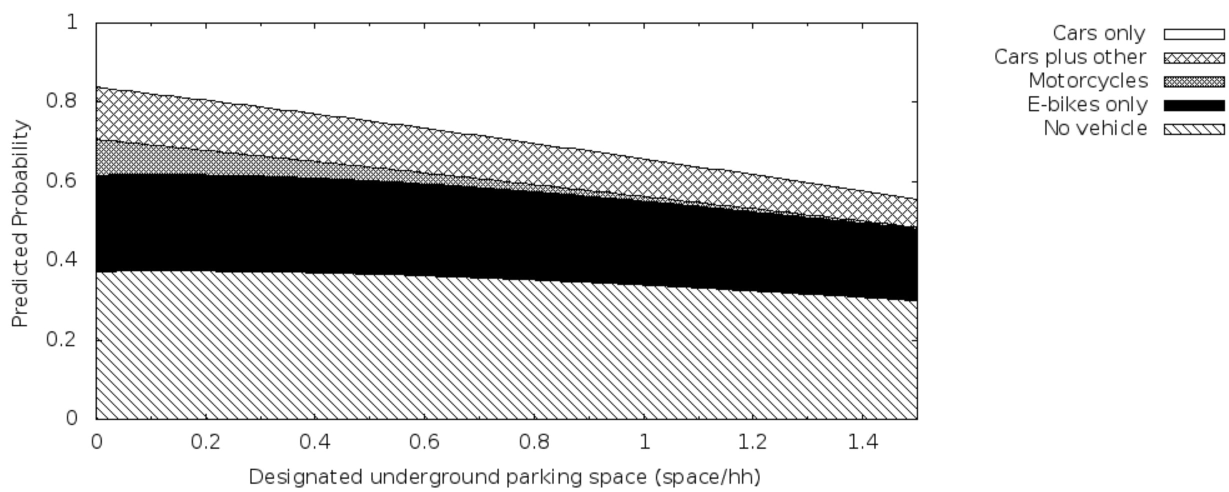


Figure 5.14 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Underground Parking

Surface parking is another story. As Figure 5.15 exhibits, more surface parking is associated with higher e-bike and cars and other vehicles ownership. Its total effect on car ownership ("cars only" + "cars and other vehicles") is almost neutral (the bottom line of "cars plus other" category is almost horizontal). But the proportion of no vehicle owners declines with more surface parking, perhaps because it worsens the walking/biking environment.

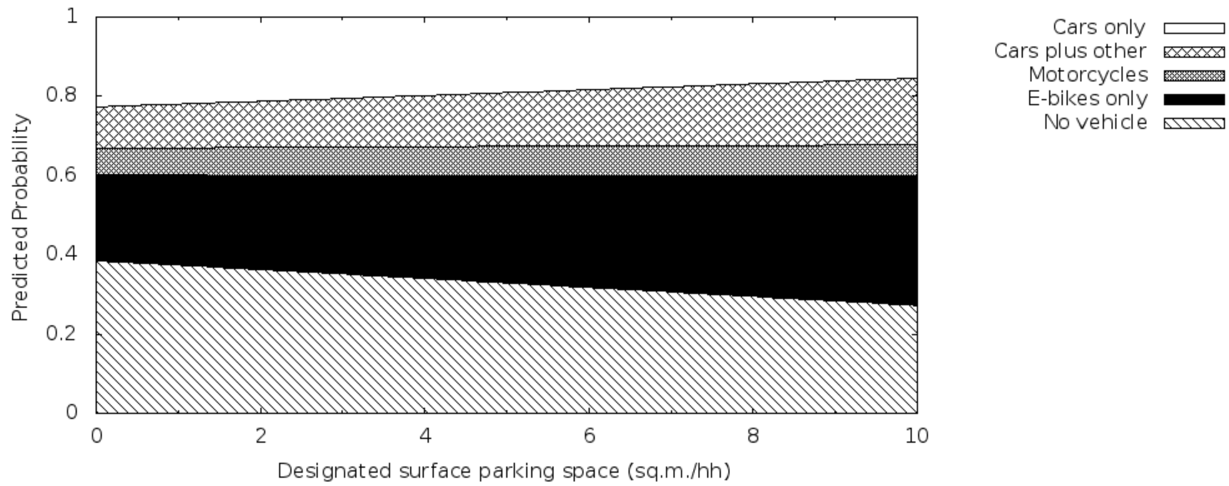


Figure 5.15 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Surface Parking

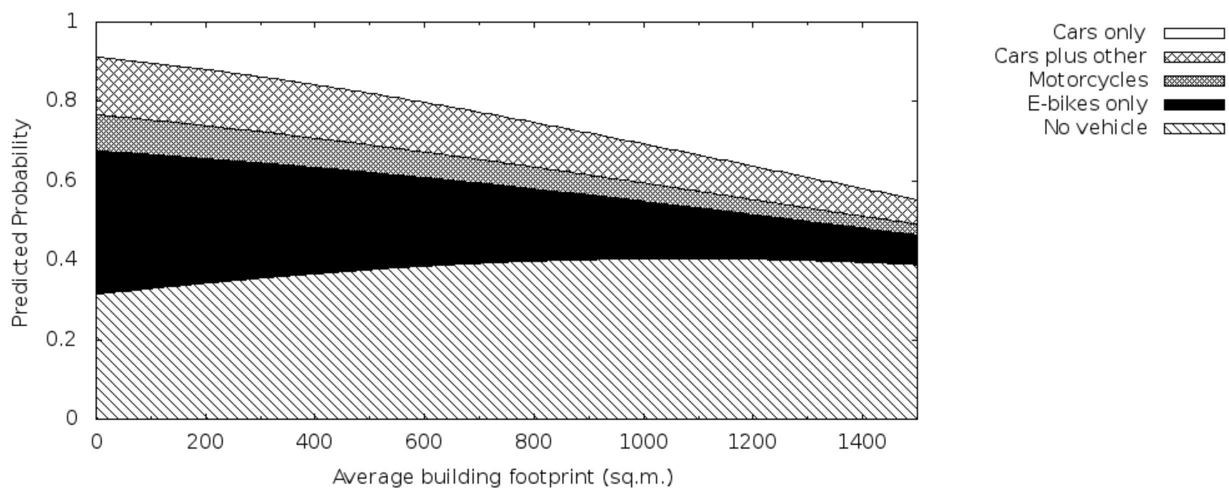


Figure 5.16 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Average Building Footprint

Average building footprint is among the most "influential" neighborhood design indicators with respect to vehicle portfolio ownership likelihood. The larger the buildings (in terms of footprint) in the neighborhood, the more likely that people living in the neighborhood own cars only at the expense of electric bikes and, less so, motorcycles (Figure 5.16).

The average interval distance between neighborhood entries approximates how "closed" the neighborhood is, and the model estimates suggest that more "closed" neighborhoods, with entries further apart, are associated with higher car ownership (higher likelihood of "cars and other" but lower likelihood of "cars only"), much higher e-bike ownership, and a rapid decline in no-vehicle-owning households (Figure 5.17).

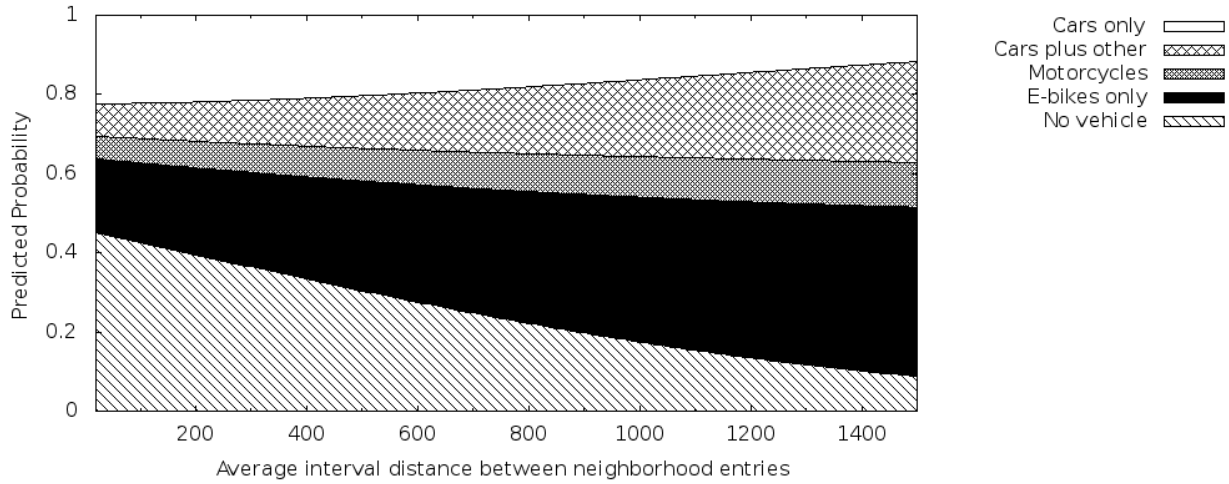


Figure 5.17 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Average Distance between Neighborhood Entries

The percentage of roads covered with trees is one neighborhood amenity that presumably makes walking and biking more enjoyable. Figure 5.18 shows that a higher percentage of roads with trees does slightly increase the probability of owning no vehicles, but is also associated with a larger rise of car owners.

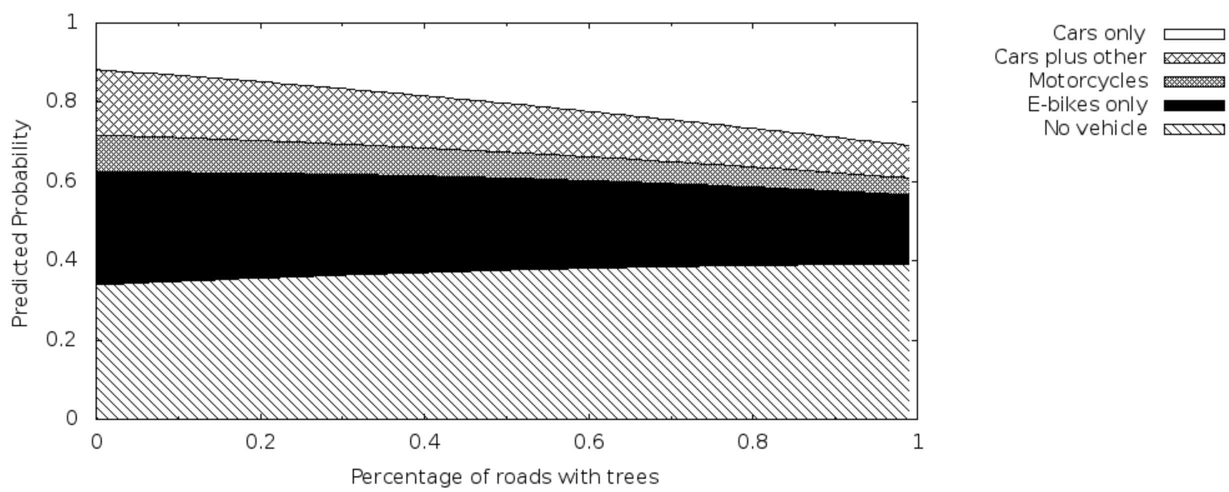


Figure 5.18 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Roads with Trees

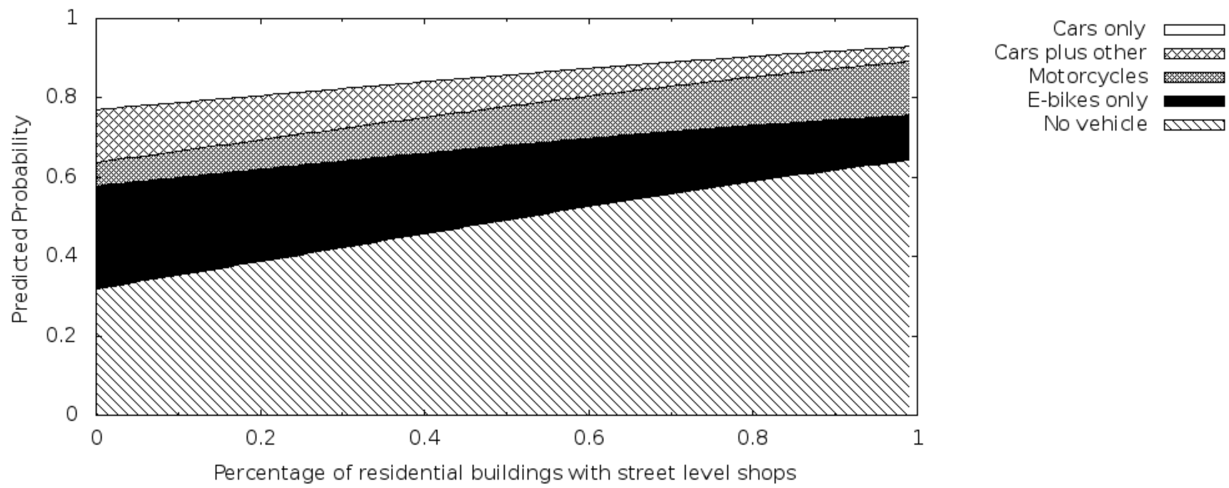


Figure 5.19 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Residential Buildings with Street-level Shops

Residential buildings with street-level shops potentially make motor vehicles less attractive to households by cutting the demand for longer trips. As exhibited in Figure 5.19, more residential buildings with street-level shops is associated with a lower likelihood of car and e-bike ownership, a slightly higher probability of more motorcycles, and much larger probability of not owning any motor vehicles. This is also one of the most "influential" neighborhood design indicators in terms of the magnitude of effects on vehicle portfolio ownership. A similar, albeit more modest, pattern can be observed for the effect of percentage of roads with walking facilities (Figure 5.20).

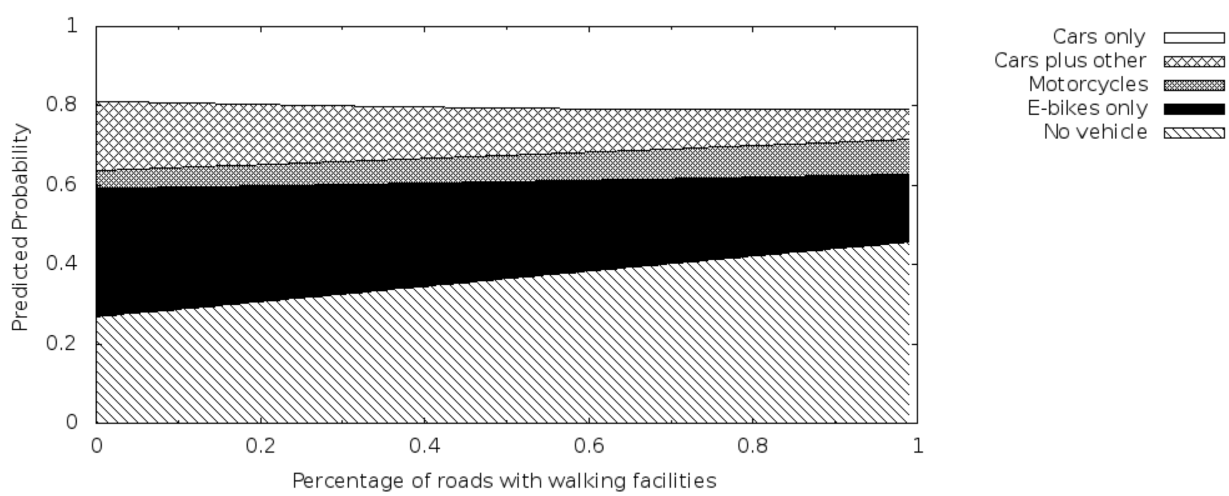


Figure 5.20 Household Vehicle Portfolio Ownership Probabilities: Simulated Variation due to Percentage of Roads with Walking Facilities

5.4 Conclusion

From the above vehicle portfolio ownership choice model developed using Jinan's data, we can conclude that empirical evidence seems to support the hypotheses that: (1) lifestyle group indicators such as attitudes and perceptions also influence vehicle portfolio decision; and (2) neighborhood design indicators are also associated with a household's vehicle portfolio ownership choice.

Specifically in Jinan, average building footprint and percentage of residential buildings with street level shops are among the most "influential" neighborhood design indicators in terms of the magnitude of effects on vehicle portfolio ownership probabilities. People living in a neighborhood with a larger average building footprint are likely to own "cars only," instead of electric bikes or motorcycles. More residential buildings with street-level shops are associated with lower probabilities of car and e-bike ownership, and a much larger probability of not owning any motor vehicles. More underground parking space is associated with more car owners and a more "closed" neighborhood with entries further apart is associated with higher car ownership, much higher e-bike ownership, and many fewer no-vehicle owners.

Nonetheless, the models in this Chapter treat the residential choice variables "renting" and unit size as exogenous, even though based on the theoretical framework and qualitative analysis, residential choices and vehicle ownership choices are interdependent and therefore probably endogenous. The lifestyle bundle choice models in the following Chapter 6 will treat them as joint choice and aim to resolve this possible endogeneity problem.

Chapter 6 Household Lifestyle Bundle Choice of Residence and Vehicle Ownership

6.1 Introduction

6.1.1 Overview

In this chapter I aim to operationalize, econometrically, the concept of lifestyle by examining relatively long term household decisions about residence and vehicle ownership. These represent big decisions that can greatly influence household members' daily lives, therefore households are not merely picking a home in a neighborhood just to live in, or selecting a car just to drive, they are choosing what kind of lifestyle all household members are going to live for at least a few years. These two choices are largely determined by the same set of objective and subjective attributes of the household and its members: demographic and socio-economic conditions, and attitudes, perceptions, preferences, and values. The interdependence, or "bundle" structure, of the residential choice and vehicle portfolio choice is evident in three main ways: (a) shared resource constraint, e.g. income, family support/burden; (b) accessibility and parking; (c) shared decision-makers' attitudes, perceptions, preferences, and values, e.g. driving is a sign of prestige, enjoyment is more important than saving. My research builds from the premise that the interdependence of these two purchase/ownership choices is the central manifestation of a household's lifestyle choice. It conditions household member behaviors, which leads to the linkage of travel and in-home operation energy consumption (Figure 6.1). The two parts of household's direct energy consumption are therefore interconnected and any policy or incentive aiming to change one would affect the other.

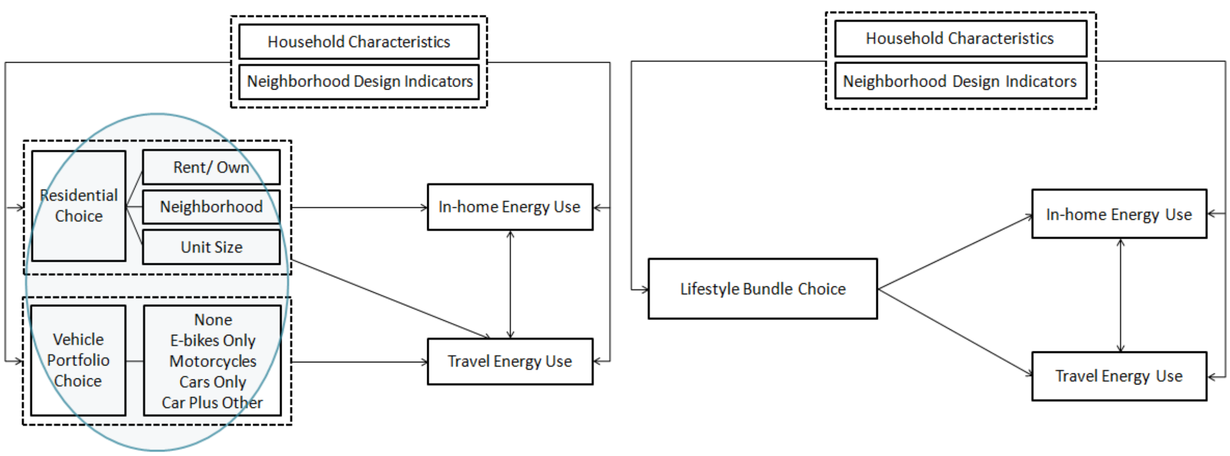


Figure 6.1 "Lifestyle Bundle Structure" in the Theoretical Model

6.1.2 Lifestyle Bundle Structure

The home-purchase stories told by the households interviewed in Jinan (as discussed in Chapter 4) reveal three dimensions of residential choice: homeownership (the choice between buying and renting), neighborhood type (where and what kind of neighborhood to live in), and housing unit size. As the results of the vehicle portfolio ownership model demonstrated in Chapter 5 suggest, these first-level residential choices do have significant associations with vehicle portfolio ownership.

The choice of homeownership (buying or renting) is mostly influenced by life events as summarized in a stylized graph in Figure 6.2.

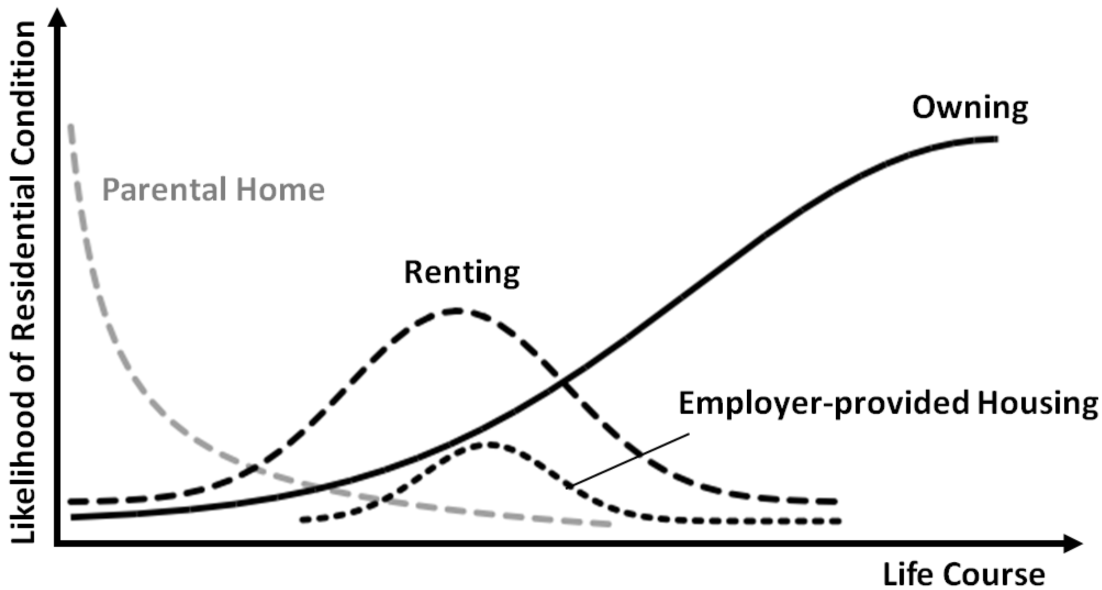


Figure 6.2 Stylized Presentation of Likelihood of Residential Condition over a Household's Life Course

The interviews revealed that the life course of a person can be demarcated by four distinct residential conditions: staying in a parental home, renting, living in employer-provided housing, and buying his/her own home. From the point that an individual moves out of his/her parents' home as an adult, we say that he/she forms a new household. Then, from any time slice of a household's lifecycle, we can observe a certain probability for that particular household to be renting, staying in employer-provided housing, or owning their own home. The highest probability of renting happens around the time people graduate from college and/or are in the early stage of their first job. The likelihood of households today being in employer-provided housing is relatively low, since the policy for "employer-provided housing" was terminated in 1998 when employees already living in employer-provided housing got the option to purchase their housing unit at a low price. Since 1998, even employers with the best benefits only provide shorter-term temporary housing options like hotels or rental subsidies.[20] Therefore we can no longer observe this option. As household members work and accumulate more savings, they start to consider home purchasing, typically triggered by a change in marital status or having a child. We can see that homeownership is more of a stage transition along households' life course, and less of a "choice" that a household makes. To simplify the lifestyle bundle structure in the model, the dimension of homeownership is treated as an exogenous explanatory variable in the bundle choice model.

Where and what type of neighborhood to live in is also an important dimension in a household's first-level residential choice and may also reflect an important lifestyle dimension. However, in order to model neighborhood choice (type or location), a full set of alternatives and their attributes are needed. This information, the attributes of all alternative neighborhoods in the

[20] Summarized from interview results; see Chapter 4.

choice set (available neighborhoods at the time the household makes its location decision), was unavailable for this research. Therefore, neighborhood type and location choice are not included in the lifestyle bundle choice model.

On the residential choice side, then, a household's choice of how large a housing unit to occupy is the dimension reflecting lifestyle bundle. Households make different unit size decisions because:

(1) of a temporal perspective, since whether the housing choice is a long-, medium-, or short-term decision determines how many household members need to be accommodated, the time-frame of financial resources that can be utilized to pay for the housing, and the balance between current vs. future housing needs; and

(2) given the same temporal perspective, different households have different housing needs, resources, and preferences—in other words, different utility functions and underlying variables explaining the choices made.

In this sense, unit size choice at this first-level stage of residential choice is more of a discrete one (e.g., a household decides on whether to occupy a large house that accommodates a child and the older generation, a medium unit for a couple plus a young child for the next ten years, or a small unit just enough for a couple for the next five years) rather than a continuous one (e.g., 130 m^2 vs. 135 m^2). Unlike the discrete unit size choice (large, medium, and small), the specific number of square meters (continuous unit size) depends more on the options that are provided by the neighborhood choice set *after* the household makes the first-level residential choice.

Cluster analysis (k-means) on reported housing unit size from the household survey reveals three different housing unit size categories: large, medium, and small, with an average of about 163, 93, and 46 m^2, respectively (Table 6.1).

Table 6.1 Categories of Housing Unit Size

Unit size (m^2)	housing unit size categories		
	small unit	medium unit	large unit
count	1,462	1,948	713
min	6	69.6	128
max	69	127	960
mean	45.5	93.4	162.5
median	50	92	146

Total n= 4,123

These unit size categories make practical sense, as the average living area for Jinan's urban population is around 30 m^2 per capita (Jinan Statistical yearbook, 2010), very close to the mean of the medium housing unit size. In the interviews, "less than 70 m^2" was mentioned with comments of "quite small" or "just for two persons", while "130 m^2" and "135 m^2" were quoted as "ideal size" or "large enough unit." A histogram of the distribution of housing unit sizes in the sample (Figure 6.3) also shows three concentrations (only unit sizes under 300 m^2 are plotted to show a more detailed distribution). The cut-off values are also marked by the vertical reference lines, both of which are located at the "saddles" between peaks of the distribution.

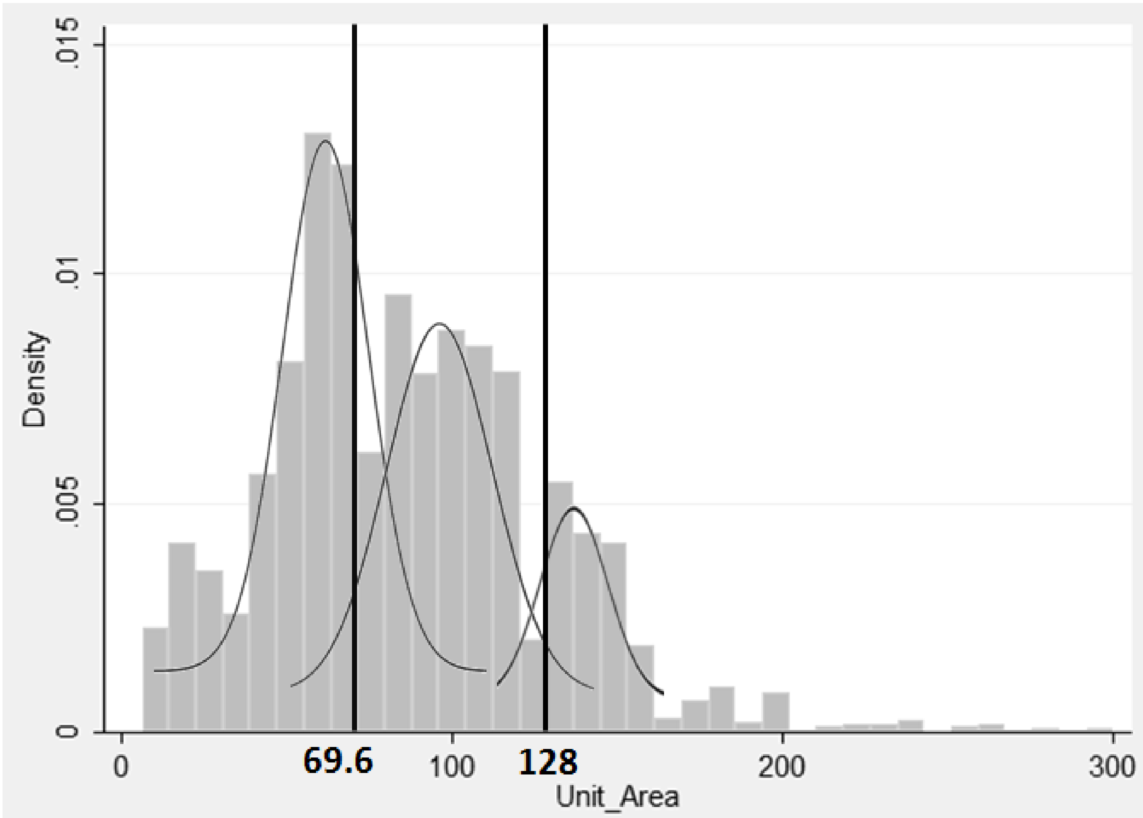


Figure 6.3 Histogram of Housing Unit Size (<300 m^2)

Therefore, the lifestyle bundle choice alternatives are the three housing unit size choices by the five vehicle portfolio choices discussed in Chapter 5. This produces fifteen different potential lifestyle bundle choices (Figure 6.4).

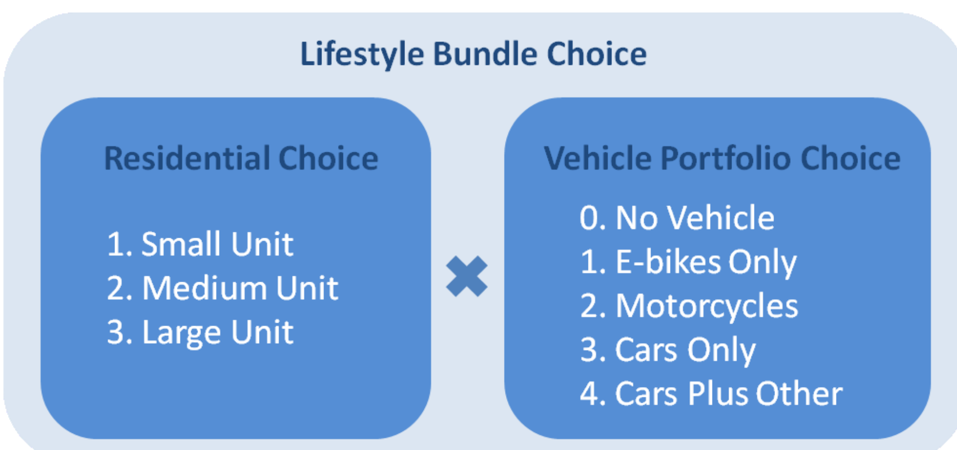


Figure 6.4 Lifestyle Bundle Choice Structure

6.1.3 Hypotheses

A rich literature exists on the factors influencing households' residential choice and vehicle choice, as well as lifestyle orientation within the context of residential choices and travel and activity choices (reviewed in Chapter 2 and Chapter 3). The lifestyle bundle choice in this Chapter aims to partially test two hypotheses raised in Chapter 4: (1) distinct lifestyle groups exhibit distinct values and different decision-making mechanisms for residential and vehicle portfolio choices; (2) neighborhood design influences a household's lifestyle behavior (the lifestyle bundle choice) and group.

This next section will first describe the lifestyle bundle patterns in Jinan using the household survey. Then a basic multinomial logit (MNL) model will be estimated to reveal the relationship between neighborhood design and household lifestyle bundle choice, controlling for demographic and socio-economic characteristics, and travel-related attitudes. Finally, a latent class choice model (LCM) will be used to test for unobserved heterogeneity among the households—distinct lifestyle groups—using demographic and socio-economic characteristics, attitudes, and neighborhood design variables as lifestyle group indicators. Including neighborhood design variables in the class membership model of the LCM allows us to test the association of neighborhood design with lifestyle groups. Simulations will be used to interpret the estimation results.

6.2 Lifestyle Bundle Choice of Residence and Vehicle Ownership in Jinan

6.2.1 Lifestyle Bundle Pattern in Jinan

Figure 6.5 shows the lifestyle bundle pattern in all 4123 observations from the household survey. Due to the small number of observations in the bundle choice category large unit-motorcycles, this alternative (and these households) were subsequently removed from the models presented below. Apparently households living in small housing units tend to own no motor vehicles or only e-bikes, therefore alternatives 1 and 2 make up the majority of all bundle alternatives for the small housing unit. Compared with those living in the small unit, more households living in medium housing units own cars, and most of those living in large housing units own cars. This correlation is expected due to the income effect, and as a result of the lengthy discussion in previous chapters on the interdependencies of residential choice and vehicle portfolio choice.

Alternative ID	Lifestyle Bundle Choice: Residential	Lifestyle Bundle Choice: Vehicle Portfolio	Percentage in sample
1	Small Housing Unit	No Vehicle	19%
2	Small Housing Unit	Own E-bikes only	10%
3	Small Housing Unit	Own Motorcycles (only or plus ebikes)	3.4%
4	Small Housing Unit	Own Cars only	2.0%
5	Small Housing Unit	Own Cars and Other Vehicles	1.5%
6	Medium Housing Unit	No Vehicle	16%
7	Medium Housing Unit	Own E-bikes only	11%
8	Medium Housing Unit	Own Motorcycles (only or plus ebikes)	3.2%
9	Medium Housing Unit	Own Cars only	10%
10	Medium Housing Unit	Own Cars and Other Vehicles	6.8%
11	Large Housing Unit	No Vehicle	3.0%
12	Large Housing Unit	Own E-bikes only	2.3%
*	Large Housing Unit	Own Motorcycles (only or plus ebikes)	0.4%
13	Large Housing Unit	Own Cars only	8.1%
14	Large Housing Unit	Own Cars and Other Vehicles	3.5%

Figure 6.5 Lifestyle Bundle Pattern in Jinan Sample

Table 6.2 shows the means of selected household demographic and socio-economic characteristics by bundle choice: household income, household size, the number of household members currently employed, the number of seniors and children—variables having the strongest influence on residential choice and vehicle ownership choice in the literature as discussed in Chapter 2 as well as in the portfolio choice model in Chapter 5. All five variables reject the multi-group equal mean test (F-test) at the 0.001 level, showing they are significantly different across groups defined by lifestyle bundle.

Generally, households living in large units have higher income levels; but those who live in medium-size units with cars have higher income than those who live in large units without cars. For households living in small units, those who own only cars have significantly higher income than those who own cars and other vehicles. However, for households living in medium and large units, there is almost no difference in income level between those who own cars only and those who own cars and other vehicles. Large and medium housing units have larger household sizes than the small housing units, but the difference between the medium and large units is not significant. Within a given housing unit size category, "no motor vehicle" households have a higher share seniors, while households with motor vehicles, especially with cars, have a higher share of children. This effect is more obvious for households living in medium and large housing units.

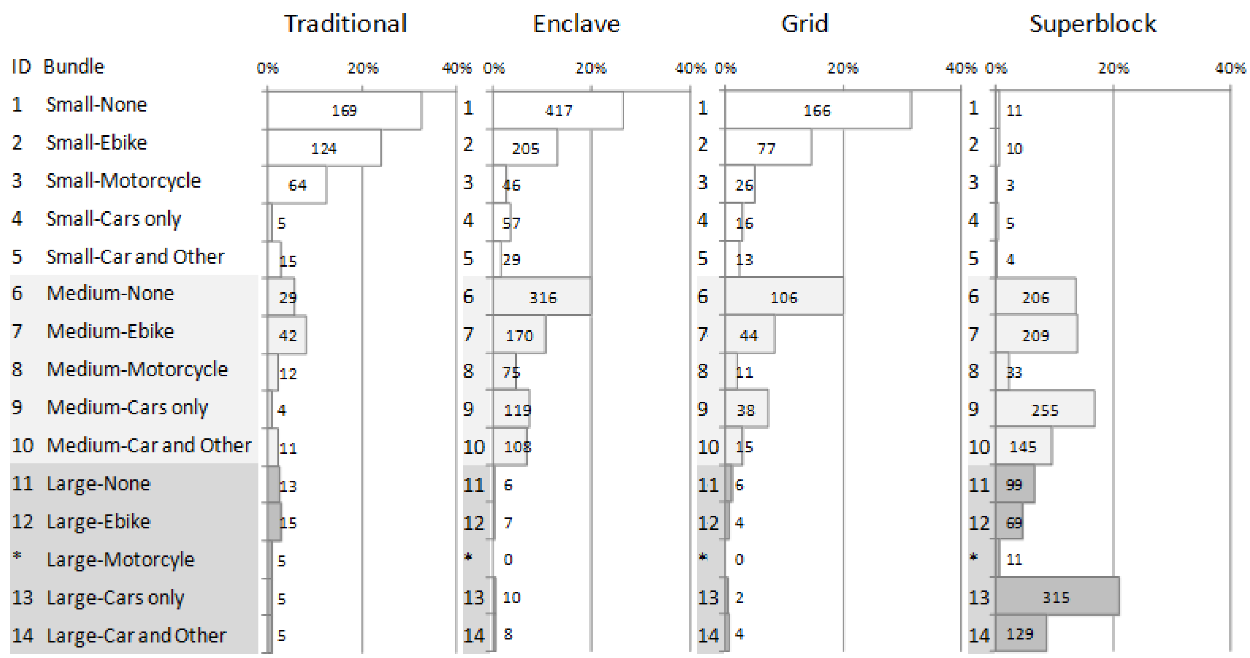
Table 6.2 Means of Selected Household Characteristics by Bundle Choice

ID	Lifestyle Bundle	HH income (k rmb/yr)	household size	currently employed	# of seniors	# of kids
1	Small-None	43.2	2.5	1.2	0.49	0.30
2	Small-Ebike	52.8	3.0	1.6	0.37	0.50
3	Small-Motorcycle	53.2	2.8	1.6	0.22	0.46
4	Small-Cars only	75.3	2.9	1.8	0.25	0.46
5	Small-Car and Other	67.7	3.0	1.9	0.27	0.54
6	Medium-None	67.7	2.9	1.5	0.68	0.40
7	Medium-Ebike	71.9	3.2	1.8	0.45	0.56
8	Medium-Motorcycle	66.9	3.3	1.8	0.34	0.59
9	Medium-Cars only	105.2	3.2	1.9	0.33	0.64
10	Medium-Car and Other	108.3	3.5	2.1	0.34	0.71
11	Large-None	90.3	3.0	1.6	0.77	0.40
12	Large-Ebike	93.8	3.3	1.7	0.60	0.51
13	Large-Cars only	134.5	3.4	2.0	0.35	0.66
14	Large-Car and Other	134.2	3.6	2.1	0.34	0.75
		***	***	***	***	***
	Average	77.9	3.0	1.7	0.45	0.51

*** means are different at the 0.001 level using multi-group equal mean test (F-test)

Figure 6.6 shows the bundle choice pattern by neighborhood type. It is obvious that a higher percentage of households living in superblocks occupy larger units and own more vehicles, including e-bikes and cars, but not motorcycles. Inside traditional neighborhoods, more households occupy large units than those in the enclave and grid ones. The traditional neighborhoods built as early as the 1920s were designed to accommodate large families before the one-child policy. With urbanization and industrialization, cities got crowded and several families were packed into one suite into traditional neighborhoods. However, a small portion of households still enjoy the original large space in the traditional neighborhood. Households living in medium-sized units in enclave and grid neighborhoods tend to own fewer vehicles than their counterparts in the superblock. Unsurprisingly, superblock neighborhoods do not provide many small units. The majority of households living in small units do not own any motor vehicle.

The apparent correlation between neighborhood type and bundle choice might come from several sources: (1) households' characteristics influencing both neighborhood type choice and bundle choice; (2) self-selection, or unobserved attitudes/preferences/lifestyles that influence both neighborhood type choice and bundle choice; (3) and/or a causal influence of neighborhood design on households' bundle choice. As discussed in 6.1.2, the available data do not allow the inclusion of neighborhood type choice within the lifestyle bundle. However, in order to test if the empirical data from Jinan support hypotheses (2) or (3) (although it is not possible to distinguish the two), it is essential to include neighborhood design indicators as explanatory variables while controlling for other household characteristics.



Note: The bar graph shows the percentage of each bundle choice within each neighborhood type; the number inside the bar represents the number of observations in each category.

Figure 6.6 Lifestyle Bundle Pattern by Neighborhood Type

6.2.2 Neighborhood Design and Lifestyle Bundle—Baseline: Joint MNL

As mentioned, I first estimate an MNL model to attempt to identify any relationship between lifestyle bundle and neighborhood design indicators, after controlling for household demographic and socioeconomic characteristics, as well as attitudes towards travel. Table 6.3 shows the estimation results. Overall, we can observe a large number of variables – including demographic, attitudinal, and those related to neighborhood design – are significant in predicting household lifestyle bundle choice. However, the large number of alternatives makes it very difficult to interpret the results by simply examining the parameter estimates. One way to understand the relative effects of the variable estimates is through simulations. Therefore using the method described in Chapter 3, I run simulations on some key variables in order to get an idea of how certain factors influence the lifestyle bundle choice (Figure 6.7 and Figure 6.8 are the simulated lifestyle bundle choices for household income in 1,000 rmb per year; Figure 6.9 and Figure 6.10 for underground parking space per household; Figure 6.11and Figure 6.12 for percentage of roads with walking facilities).

Table 6.3 MNL Estimation Result

Variables	Lifestyle Bundle Alternatives													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	S-0	S-1	S-2	S-3	S-4	M-0	M-1	M-2	M-3	M-4	L-0	L-1	L-3	L-4
Constant	0	-2.48***	-4.03***	-6.83***	-6.22***	-2.88***	-2.57***	-4.44***	-5.08***	-5.43***	-7.79***	-7.81***	-11.74***	-12.38***
Log(hhincome_k)	0	0.34***	0.63***	1.08***	1.11***	0.70***	0.64***	0.64***	1.50***	1.58***	0.87***	1.06***	1.93***	2.07***
household size	0	0.25**	0.059	-0.0399	0.089	0.19*	0.62***	0.53***	0.37***	0.61***	0.59***	0.64***	0.59***	0.78***
single	0	-0.72**	-0.587	-0.208	-0.534	0.59*	0.509	-0.624	0.86**	-0.422	1.91***	0.934	1.189**	1.05
couple	0	0.024	-0.118	-0.37	-0.725	0.34*	0.42*	-0.385	-0.261	-0.229	0.61	0.461	-0.151	0.078
have_kid	0	0.411**	0.486*	0.483*	0.548*	0.29*	0.35**	0.287	0.52***	0.73***	-0.119	-0.060	0.294	0.45*
have_old	0	-0.42***	-0.50*	-0.77**	-0.961**	0.44***	-0.31*	-0.44*	-0.42**	-0.75***	0.52*	-0.11	-0.54**	-0.88***
a1_drive_prestige	0	0.024	-0.0354	-0.167*	-0.189	-0.087*	-0.051	-0.074	-0.084	-0.22***	-0.19**	0.024	-0.121*	-0.089
a2_bus_convenient	0	-0.15**	-0.105	-0.020	-0.30**	0.033	-0.18***	-0.056	-0.32***	-0.32***	0.033	-0.075	-0.20***	-0.34***
a3_bike_liking	0	-0.040	-0.017	-0.118	-0.157	-0.093*	-0.062	-0.17**	-0.19***	-0.12*	-0.107	-0.098	-0.31***	-0.13
a4_travel_time_waste	0	0.0654	0.17**	0.105	0.139	0.0608	0.058	0.163*	0.114*	0.15**	0.020	-0.151	0.068	0.16*
comcar	0	-0.242	-0.941	1.38**	0.594	0.990**	-0.164	0.259	0.789	-0.078	1.18*	0.47	0.367	0.238
renting	0	0.078	0.73***	-0.332	-0.335	-0.56***	-0.91***	-0.77**	-1.62***	-1.23***	-0.75**	-2.15***	-1.82***	-2.78***
res_density_hh_acre	0	0.003	0.0147	0.020	0.0245	-0.0077	-0.013**	-0.007	-0.02***	-0.02***	-0.04***	-0.04***	-0.023***	-0.03***
parking_under_s	0	1.43	-45.3***	2.639	-2.912	5.684***	7.55***	5.99***	7.86***	7.56***	13.32***	13.71***	14.06***	11.95***
parking_surface	0	0.071	2.27***	0.57***	0.434*	0.48***	0.44***	0.41***	0.38***	0.42***	0.076	0.0287	0.049	0.158
motor_width	0	-0.10**	0.169	-0.24**	-0.141	-0.09***	-0.19***	-0.13**	-0.14***	-0.18***	-0.28***	-0.28***	-0.30***	-0.27***
bus	0	0.083***	0.23***	0.044	0.115**	0.018	0.06**	0.035	0.07**	0.068*	0.27***	0.27***	0.32***	0.26***
brt	0	-0.302**	-1.01***	-0.28	-0.431	-0.36***	-0.73***	-0.516*	-0.58***	-0.91***	-0.76***	-1.07***	-0.90***	-0.99***
ra_public	0	-0.021	-0.055**	-0.06**	0.030	-0.08***	-0.09***	-0.20***	-0.09***	-0.15***	-0.095**	-0.18***	-0.085**	-0.13***
ra_office	0	-0.0013	0.0301	0.0201	0.0052	-0.013**	-0.02***	0.0038	-0.009	-0.0115	-0.054	-0.005	-0.079*	-0.07*
ra_shopping	0	0.0013*	0.0027*	0.0025*	-0.0007	-0.0004	0.0002	-0.0001	0.0001	0.0017*	0.0024*	0.0005	0.0001	0.003**
road_trees	0	-0.315	-21.7***	-1.096	-1.943	0.999*	0.82	0.761	1.44**	0.537	2.71*	1.21	5.42***	3.56**
street_level_shop	0	-0.316	28.42***	2.774	-0.64	5.85***	6.79***	7.10***	5.91***	6.33***	10.56***	11.47***	14.11***	12.96***
walking_facility	0	0.309	-10.1***	0.517	-0.878	-1.25**	-1.42***	-0.546	-1.73***	-1.48**	-1.046	0.053	-3.10***	-1.85***

N=3,908; # of parameters = 312; Adjusted ρ^2 =0.1774; Log likelihood = -7361.75. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

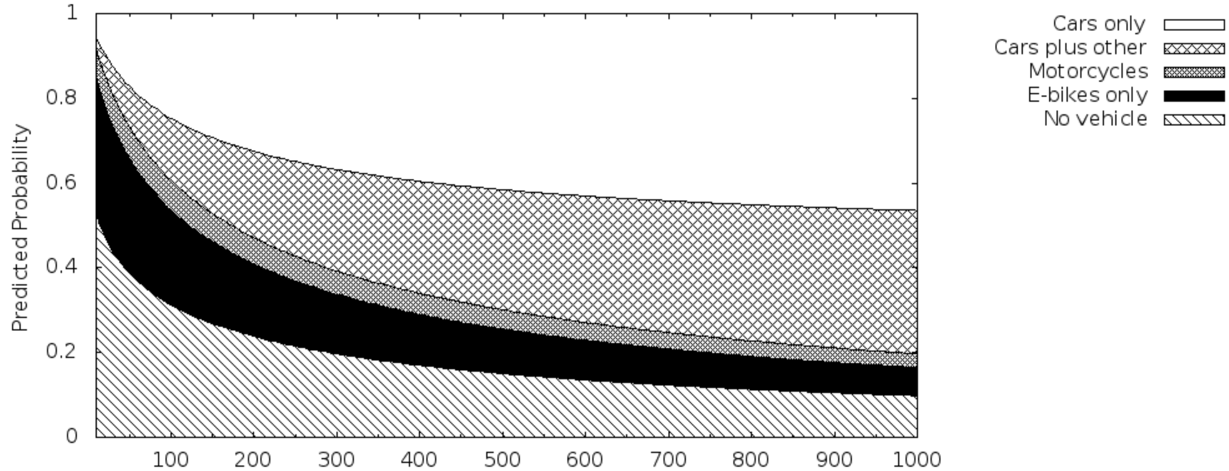


Figure 6.7 Household Vehicle Portfolio Probabilities: Simulated Variation by Household Income Levels (MNL)

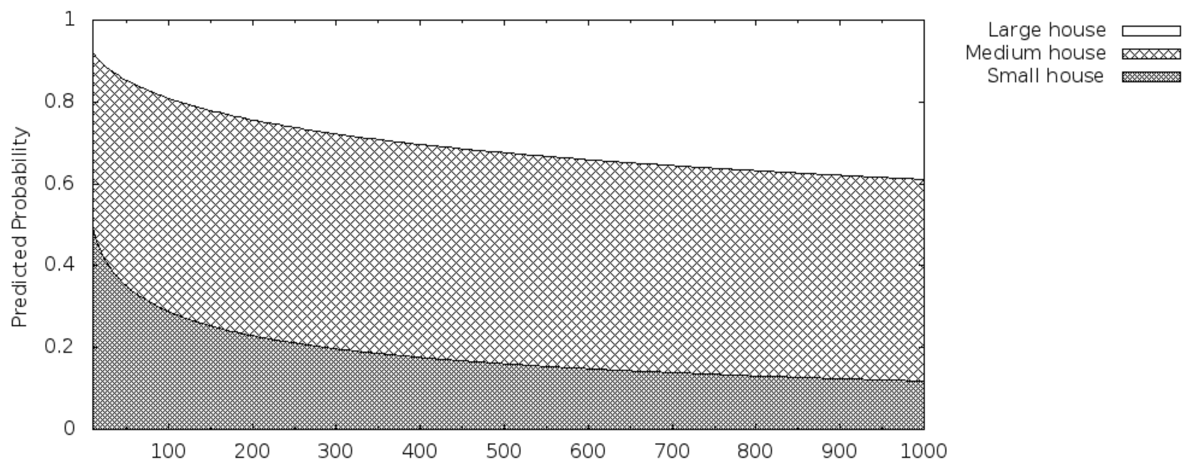


Figure 6.8 Housing Unit Size Probabilities: Simulated Variation by Household Income Level (MNL)

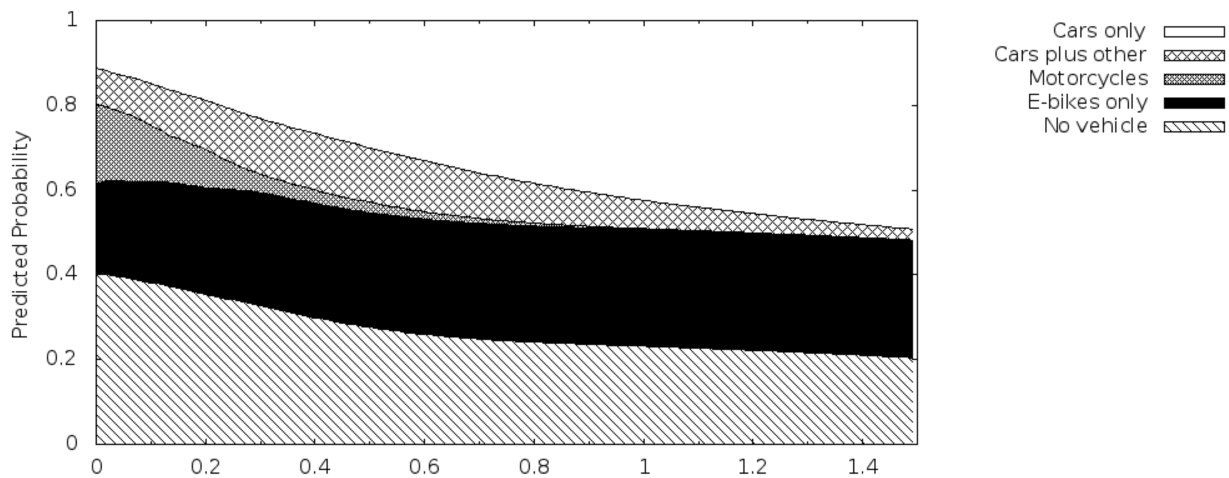


Figure 6.9 Household Vehicle Portfolio Probabilities: Simulated Variation by Underground Parking (MNL)

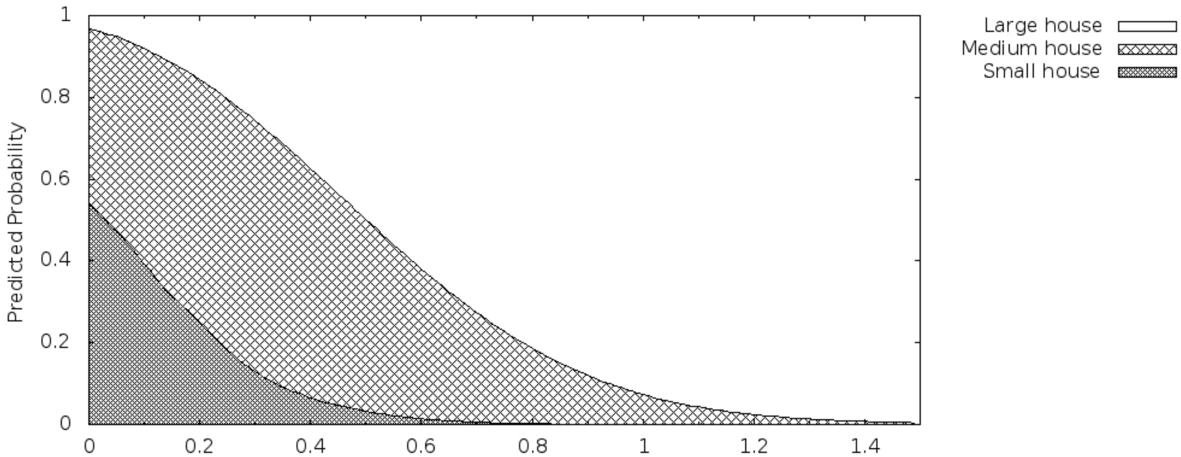


Figure 6.10 Housing Unit Size Probabilities:
Simulated Variation by Underground Parking (MNL)

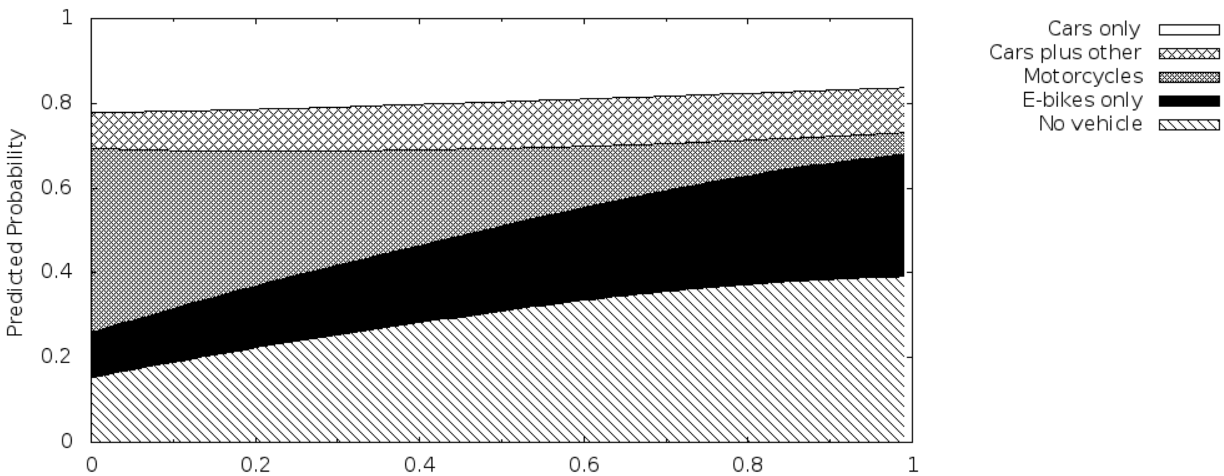


Figure 6.11 Household Vehicle Portfolio Probabilities:
Simulated Variation by Percentage of Roads with Walking Facilities (MNL)

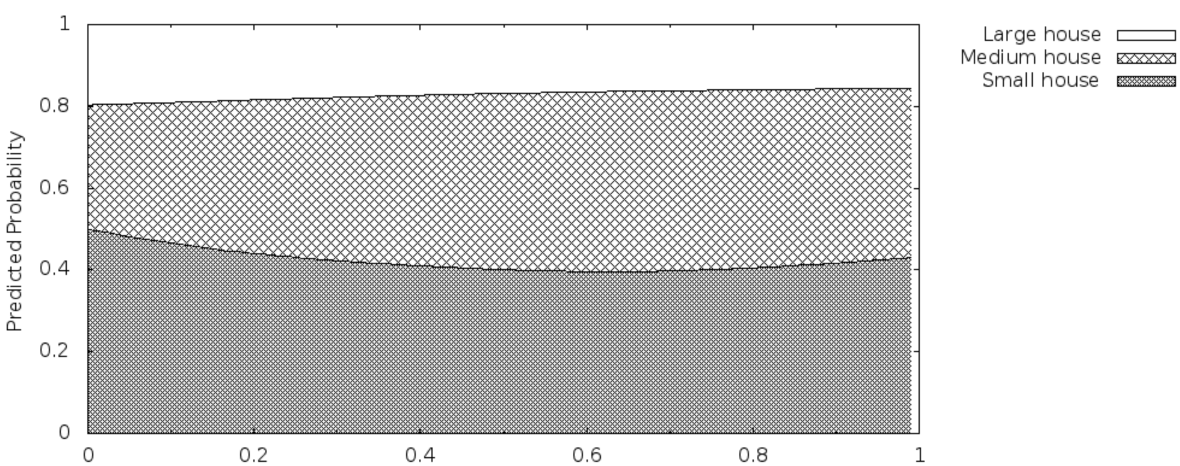


Figure 6.12 Housing Unit Size Probabilities:
Simulated Variation by Percentage of Roads with Walking Facilities (MNL)

6.2.3 Lifestyle Group and Neighborhood Design—Latent Class Model (LCM)

1. Model Results

Relative to the "classical" MNL model approach used in the previous section, a Latent Class Choice Model (LCM) can account for unobserved heterogeneity among households. As described in detail in Chapter 3, LCM choice models capture unobserved heterogeneity among the choosers (households), with the underlying assumption that the heterogeneity is generated by unobserved discrete constructs (i.e., latent classes). This heterogeneity, for example, may be produced by taste variation across the household segments. In this case, we interpret the resulting latent classes as representing the unobserved lifestyle segments that lead to the choice of observed lifestyle bundles.

Table 6.4 shows the final results from the class membership model and Table 6.5 shows the class-specific choice models for the lifestyle bundles.

Table 6.4 LCM Class Membership Model Result [a]

	Class 1	Class 2	[b]	Class 3	[b]	Wald Test	P value
Intercept	0	1.869		-9.33	***	5.9	0.053
hhincome_k	0	0.018		0.03		1.4	0.490
single	0	0.990	**	0.50		11.1	0.004
have_kid	0	0.392	*	-1.10	**	9.3	0.010
dif_income_k	0	-0.012		-0.04	*	1.2	0.540
a1_drive_prestige	0	-0.171	**	0.51		11.4	0.003
a2_bus_convenient	0	-0.148	**	-0.30		7.7	0.022
a3_bike_liking	0	-0.105	*	-0.35		6.7	0.036
a4_travel_time_waste	0	0.116	*	0.25		5.3	0.071
comcar	0	0.613		1.16		2.2	0.340
renting	0	-0.943		-8.24	***	34.5	0.000
parking_under_s	0	25.889	***	68.84	***	17.9	0.000
parking_surface	0	1.335	***	-1.87	***	68.3	0.000
ra_office	0	-0.040		0.23	***	17.7	0.000
ra_public	0	-0.074	**	-0.08		22.7	0.000
ra_shopping	0	0.002		0.01	**	5.3	0.069
road_trees	0	1.098		-14.51	***	8.9	0.012
street_level_shop	0	12.618	***	-11.96	**	34.7	0.000
walking_facility	0	-8.137	***	10.92	***	83.8	0.000
entry_m	0	-0.012	***	0.00	*	13.7	0.001

[a] Coefficient estimations are adjusted by keeping those for Class 1 as zeros.
[b] Significance (p value) for each coefficient in Class 2 and Class 3 are calculated using z-score.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6.5 LCM Choice Model Result

Number of cases	3,908	Number of parameters (Npar)	131
Chi-squared Statistics			
Degrees of freedom (df)	3777	*Log-likelihood Statistics*	
L-squared (L2)	14995.23	Log-likelihood (LL)	-7541.1
X-squared	45248.68	BIC (based on LL)	16166
BIC (based on L2)	-16243.5	AIC (based on LL)	15344
AIC (based on L2)	7441.231	AIC3 (based on LL)	15475
AIC3 (based on L2)	3664.231	CAIC (based on LL)	16297
CAIC (based on L2)	-20020.5		

Classification Statistics	
Classification errors	0.0603
Reduction of errors	0.8968
Entropy R-squared	0.8684
Standard R-squared	0.8695
Classification log-likelihood	-8094.6

	Class1	Class2	Class3	Overall
R^2	0.0564	0.0484	0.0317	0.1641
$R^2(0)$	0.2422	0.1569	0.1114	0.1973

Variables	Lifestyle Bundle Alternatives													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	S-0	S-1	S-2	S-3	S-4	M-0	M-1	M-2	M-3	M-4	L-0	L-1	L-3	L-4
Constant-class 1 [a]	10.50**	7.47*	6.79*	3.40	2.01	1.41	-2.17	1.28	10.4**	-6.71	6.41	-18.4**	-10.86	-11.57
Constant-class 2 [a]	8.67***	3.25*	-3.90	-4.69	-0.21	7.4***	4.8***	4.1***	-0.15	-0.54	-7.4***	-1.76	-5.6***	-3.9***
Constant-class 3 [a]	4.32	5.29	-5.99	-11.45	-6.20	5.03	4.78	1.49	1.53	-0.90	4.72	2.69	-1.13	-4.18
log(hhincome_k)-class 1[b]	-1.14	-0.74	-0.69	0.03	0.15	0.56	0.83	-0.10	-4.04**	1.34	-1.93*	3.45**	1.10	1.18
log(hhincome_k)-class 2[b]	-2.1***	-0.84*	0.70	1.05	-0.09	-1.1***	-0.8***	-1.0***	0.41**	0.27*	1.5***	-0.03	1.26***	0.7***
log(hhincome_k)-class 3[b]	-0.76	-1.34	0.12	2.22	-0.09	-0.56	-0.77	-0.43	0.14	0.34	-0.55	-0.34	0.84	1.18
household size-all classes[c]	-0.6***	-0.2***	-0.4***	-0.4***	-0.2**	-0.16***	0.25***	0.27***	0.17***	0.39***	0.01	0.3***	0.2***	0.4***

[a] Wald test score= 513.2503, P value = 5.10E-84, hypothesis for equal coefficient across classes is rejected at the 0.01 level (Wald test = 119.721).
[b] Wald test score= 315.3788, P value = 6.10E-45, hypothesis for equal coefficient across classes is rejected at the 0.01 level (Wald test = 74.6665).
[c] Wald test score= 110.4965, P value = 1.50E-17.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$ (Significance for each coefficient are calculated using z-score.

It is important to note that, due to the large number of choice alternatives and the lack of alternative-specific attributes, the class-specific choice model cannot have many explanatory variables, which would dramatically increase the number of parameters to be estimated and makes the LCM unable to identify. The issue of weak identification is also due to the lack of multiple replications[21] which differ across several attributes (or choice set variation for each respondent), more so if more than 3 classes are specified. Therefore, in order to have an identifiable and stable LCM, the class-specific choice model only has two explanatory variables (besides the constant): household income and household size, while only the coefficient for income is specified to vary across classes. The models are specified to have no more than three classes.

2. Characterizing Classes

By examining the class membership model in Table 6.4, the choice patterns of each class (Figure 6.13), and the membership profile (as measured by the mean values of explanatory variables in Table 6.6), distinct characteristics can be summarized for each class.

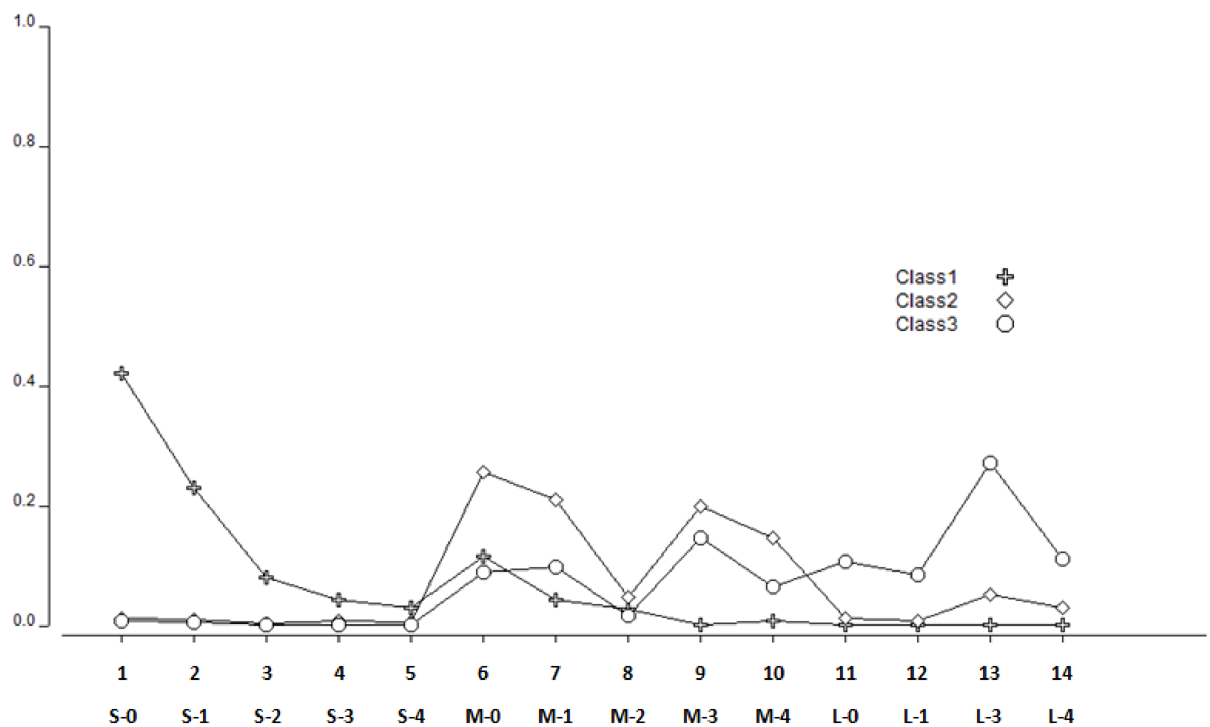


Figure 6.13 Choice Pattern of Three Classes in the LCM

Class 1 contains 41.54% of the total sample. These households occupy small housing units and some medium housing units. They tend to have no motor vehicles or just ebikes. They have relatively lower income. They think taking the bus is convenient; they like biking; and, they do not consider time spent on travel to be a waste. They live in older but more walkable neighborhoods with better accessibility but very few other amenities (e.g. trees), and, especially, no underground parking. Most renters belong to this class. Their lifestyle—lifestyle bundle

[21] In market studies, stated preference surveys usually ask respondents to make choice among different sets of alternatives, therefore multiple replications are obtained to better understand one respondent's preference.

choice behavior as well as attitudes—fits the "budget-oriented" lifestyle group discussed in Chapter 4.

Class 3 contains 24.4% of the total sample. This group of households occupies medium and large housing units with very high car ownership (including the vehicle portfolios "Cars only" and "Car and other vehicles"). Their income is higher, and few of them have children. Many singles belong to this class. They tend to treat the car as a sign of prestige rather than need. They do not like taking buses or riding bikes. They consider the time spent on travel to be a waste. Many of those having access to a company or business car belong to this class. They are more affluent, probably with extra resources not reflected by their income as they live in neighborhoods with average income higher than their own. They live in newer car-oriented superblocks with the most underground parking and more amenities (such as roads with trees and with sidewalks). Their lifestyle, including the bundle choice behaviors and attitudes towards travel, fits the "amenity-oriented" lifestyle group discussed in Chapter 4.

Table 6.6 Membership Profile (Means of Explanatory Variables) in LCM

	"Budget-oriented" (Class 1)	"Typical Urban" (Class 2)	"Amenity-oriented" (Class 3)
hhincome_k	55.803	86.018	104.601
single	0.099	0.059	0.041
have_kid	0.377	0.508	0.579
dif_income_k	-2.912	4.729	-0.549
a1_drive_prestige	2.771	2.605	2.448
a2_bus_convenient	3.908	3.566	3.292
a3_bike_liking	3.613	3.390	3.279
a4_travel_time_waste	2.900	3.189	3.211
comcar	0.016	0.027	0.038
renting	0.327	0.098	0.046
parking_under_s	0.000	0.139	0.528
parking_surface	1.007	3.240	2.069
ra_office	18.123	13.822	6.160
ra_public	6.972	4.032	3.033
ra_shopping	105.990	73.207	52.093
road_trees	0.332	0.532	0.535
street_level_shop	0.181	0.135	0.059
walking_facility	0.593	0.363	0.592
entry_m	189.189	263.546	691.390

The remaining 34.06% of households belongs to Class 2. These households occupy medium-sized housing units and have a relatively average vehicle portfolio. They tend to have children in their family. Their income level and attitudes are between Class 1 and Class 3. The characteristics of the neighborhoods of Class 2 households are also somewhere in the middle of Class 1 and Class 3. Given the modeling limitations discussed at the beginning of this section, it is not possible to try to distinguish in LCM the "job-oriented" and "child-oriented" households identified in Chapter 4. Here I call Class 2 as the "typical urban" lifestyle group.

The three classes that emerge from the LCM generally fit the characteristics of those identified from the interview study. For example, the coefficient for the variable representing the difference of the household's income from its neighborhood's average income level ("dif_income_k") is significant and negative for "Amenity-oriented" group (Class 3), taking "Budget-oriented" group (Class 1) as base. The positive sign on this variable for "Budget-oriented" group (Class 1) means that these households tend to buy/rent houses below the average housing spending ability, an indication of "conservative home purchasing", meaning that they either spend more elsewhere, and/or save more. On the contrary, the negative sign on this variable for "Amenity-oriented" group (Class 3) means that these households buy/rent housing units in neighborhoods with higher average income level than their own. They apparently "spend more" on housing, either because they have extra resources not reflected by reported income (e.g. parents' or employer support), or they value the amenity of "nicer" neighborhoods more than saving. This is consistent with the key distinguishing characteristic of "budget-oriented" versus "amenity-oriented" lifestyle groups.

As discussed earlier, due to the data-related limitations on model specification, household income ("hhincome_k") is the only predictor in the choice model that has different coefficients across classes. That is, the choice behavior of the three classes only differs with respect to the sensitivity or responsiveness to income change. For each class, the income elasticity changes at different income values; therefore, simulations provide a more complete view of the variation in the income effect across classes for range of possible household income levels (Figure 6.14).

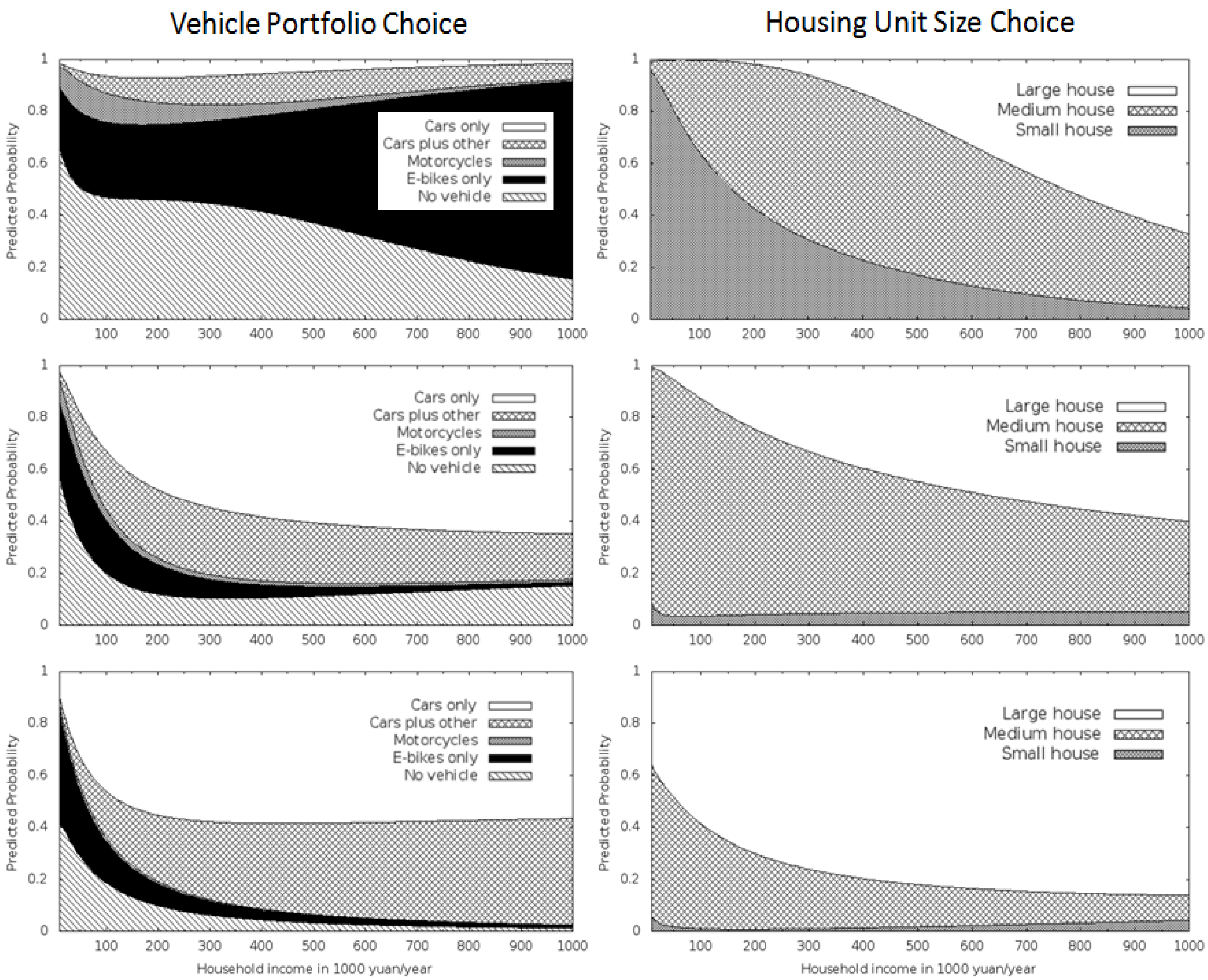


Figure 6.14 Household Vehicle Portfolio and Housing Unit Size Probabilities (Class-specific Models): Simulated Variation by Household Income for Three Classes of Households (Budget-oriented, top row; Typical urban, middle row; Amenity-oriented, bottom row)

The top row in Figure 6.14 show how "Budget-oriented" (Class 1) households respond to income change in terms of lifestyle bundle choice. It seems that these "budget-oriented" households tend to buy more e-bikes for their mobility needs when they have higher income. They tend to occupy medium sized housing units at lower income levels—the proportion of medium-size unit starts to decline around household income of about 400,000 yuan (US $63,500[22]). Not until very high income levels, around 800,000 yuan ($127,000), does the proportion of large housing units exceed 50%. This "conservative" consumption of bundle choice both in vehicle and home purchase reflects the exact lifestyle characteristics of "budget-oriented" households discussed in Chapter 4, consistent with the values of saving as a virtue and important for the future and consuming for practical utility.

[22] All dollar values are converted using nominal exchange rate of 6.3 (CNY /1 USD) : 1 yuan = US $6.3

The middle row in Figure 6.14 shows the income effect on lifestyle bundle choice for "Typical Urban" households (Class 2). Compared with the "budget-oriented" group, this "typical urban" group (likely including the "job-oriented" and "child-oriented" households identified qualitatively in Chapter 4) has a much more rapid increase in the "Cars only" category at a much lower level of income. For housing consumption, even at low levels of income, these households have a minimal portion of small units; as income increases, these households only gradually shift from medium-sized to large sized units, with the latter accounting for the majority at about 800,000 yuan ($127,000).

The bottom row in Figure 6.14 shows the income effect on bundle choice for the "Amenity-oriented" households (Class 3). These "amenity-oriented" households switch to "Cars only" and "Cars plus other" even earlier than the "typical urban" group (Class 2). Car ownership saturates after income hits 400,000 yuan ($63,500) when almost every household owns at least one car. Almost no households in Class 3 live in small housing units, even at very low income. The proportion of households living in large housing units quickly becomes the majority, even at low income levels. This behavior pattern for Class 3 fits well the lifestyle characteristics of the "amenity-oriented" group described in Chapter 4.

3. Model Results: Interpreting Combined Effects

Since household income is in the bundle choice model *and* the class membership model, a change in income also leads to a change in the probability of a household belonging to each of the three lifestyle groups. Therefore, the "total" or combined effect of income on the bundle choice involves two pathways: (a) the income effect on the likelihood of a household belonging to a particular lifestyle group (class effect); and, (b) the income effect on the choice-making process of each lifestyle group (choice effect).

Figure 6.15 shows the combined class and choice effects on the vehicle portfolio probabilities (or, aggregate proportions), estimated via simulation for different household income levels. The pattern is similar to that in the MNL model (Figure 6.7). While the MNL model predicts a similar growth in "Cars only" and "Cars plus other" category and a steady portion of motorcycles at the high income level; the LCM predicts a steeper increase in the "Cars only" category, a slight decrease in the "Cars plus other" portfolio when income is very high, and almost no motorcycles at high income levels.

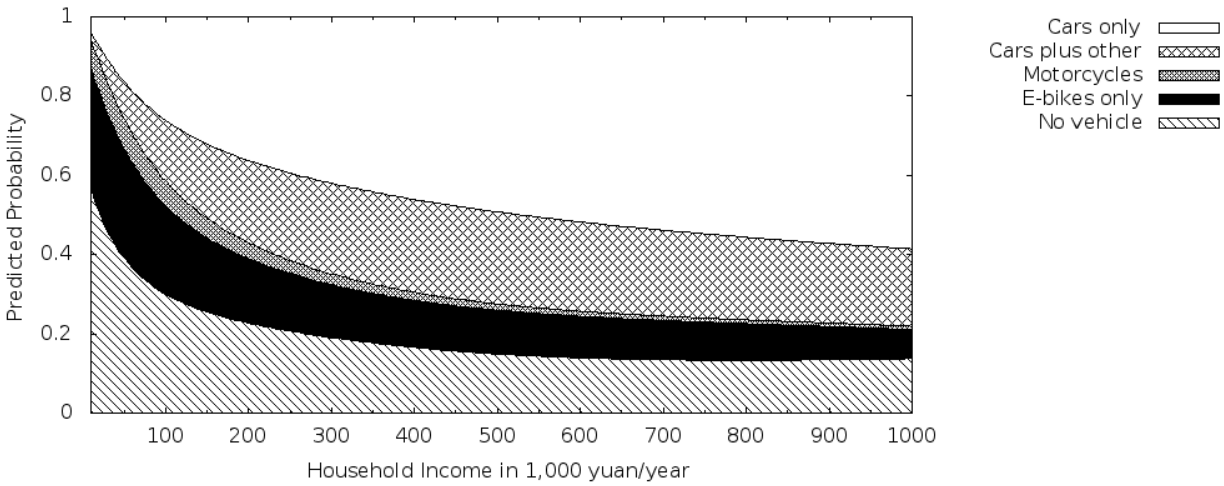


Figure 6.15 Household Vehicle Portfolio Probabilities: Simulated Changes due to Combined Class Membership and Choice Model Effects of Household Income (LCM)

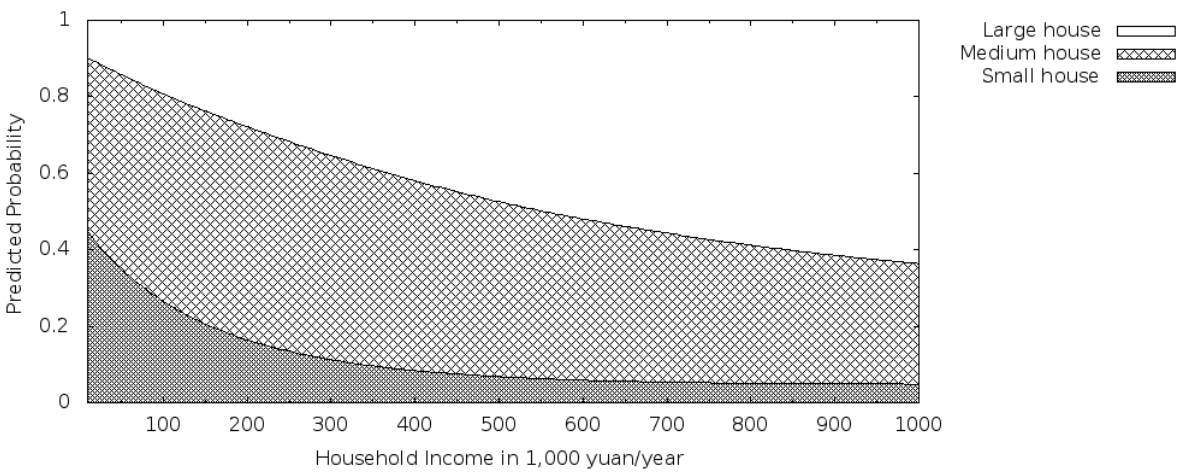


Figure 6.16 Housing Unit Size Probabilities: Simulated Changes due to Combined Class Membership and Choice Model Effects of Household Income (LCM)

Similarly, Figure 6.16 shows the combined income effect on housing unit size. With income increases, the proportion of households occupying large units increases while the proportion of households occupying medium units first increases then decreases at a certain point (around 200,000 yuan ($32,000)/year). The proportion of households living in small units decreases until flattening off at very high income levels. In comparison, the simulated income effect on unit size in the MNL model (Figure 6.8) shows a slower growth in the proportion of households in large housing units, no decrease of in the proportion of medium-sized units, and a larger share of small-sized units at high income levels.

The effects of neighborhood design are significant in the class membership model (Table 6.4). More underground parking, but not more surface parking, is associated with a higher probability of a household belonging to the "amenity-oriented" lifestyle group. It seems that the "amenity-oriented" group values underground parking, not surface parking. On the other hand, more roads with trees, shorter distance between neighborhood entries, more street-level shops, and more accessible public space – that is, a more open neighborhood and a pedestrian-friendly neighborhood with more potential interactions and activities outside the buildings – are associated with a higher probability of a household belonging to the "budget-oriented" group and away from the "amenity-oriented" group.

Once again we turn to simulations in order to see the relative size of the relationship between neighborhood design and lifestyle bundle choice. Figure 6.17 through Figure 6.26 show the simulated effects of several different neighborhood design variables on the lifestyle bundle choice dimensions: size of the housing unit, and vehicle portfolio ownership.

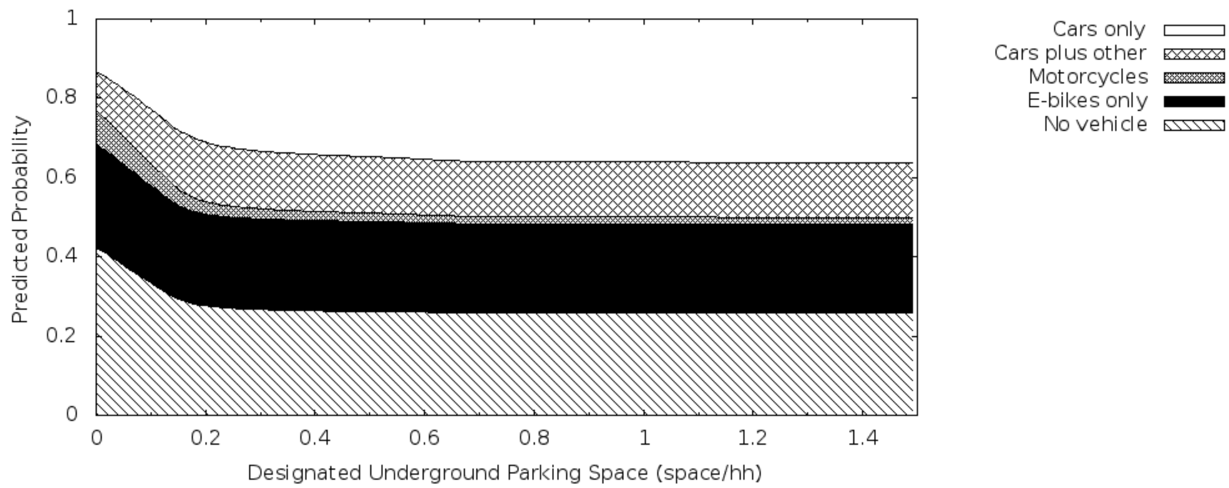


Figure 6.17 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Underground Parking (LCM)

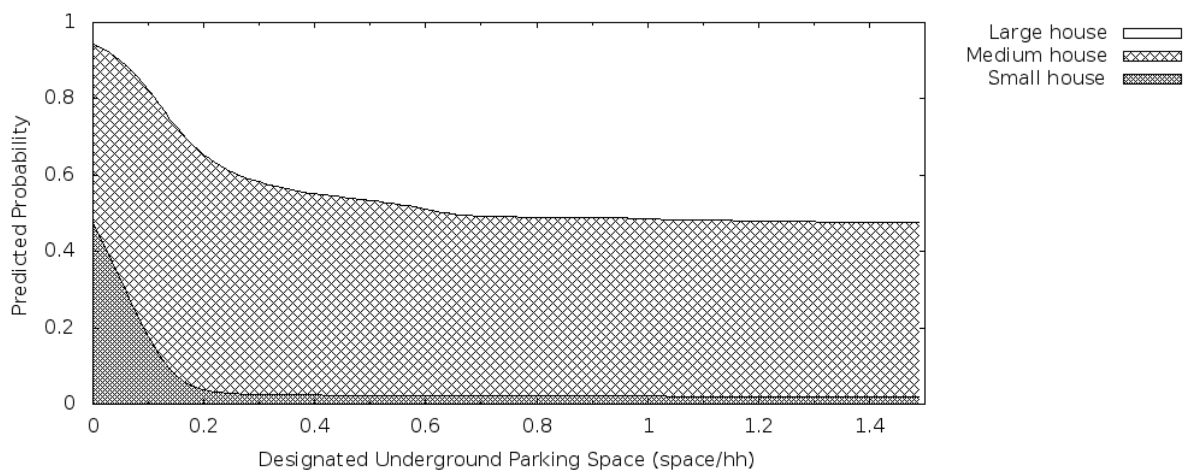


Figure 6.18 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Underground Parking (LCM)

As discussed previously, more underground parking space per household in the neighborhood is associated with a higher probability of one household belonging to the "amenity-oriented" lifestyle group. In terms of the effects on the vehicle portfolio choice (Figure 6.17), more underground parking then increases the probability of owning "Cars only", slightly increases "Cars plus" and decreases the probability of owning motorcycles and no motor vehicles; this effect flattens beyond 0.2 parking spaces per household. Similarly, more underground parking dramatically decreases the small housing unit proportion while increasing medium and large units, with the effect again saturating after the per household underground parking space exceeds 0.2 (Figure 6.18). Considering that, among the neighborhoods studied, only superblocks have designated underground parking spaces, and among them, the lowest parking ratio (# of spaces per household) is 0.2 (the highest being 0.8), it seems that whether the neighborhood has underground parking has the dominant effect over the lifestyle bundle choice (through defining lifestyle groups), while the actual number has a very weak influence.

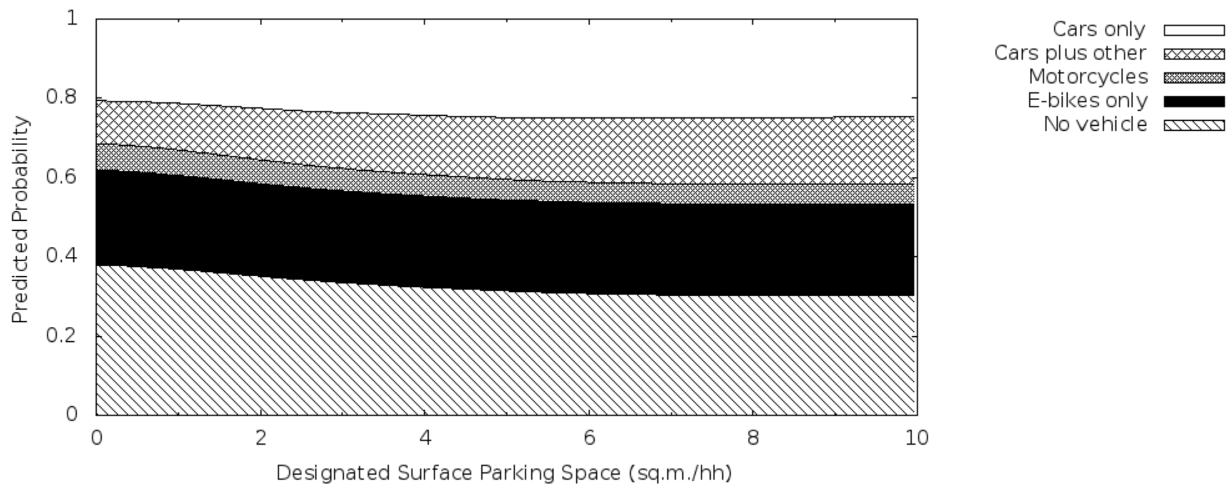


Figure 6.19 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Surface Parking (LCM)

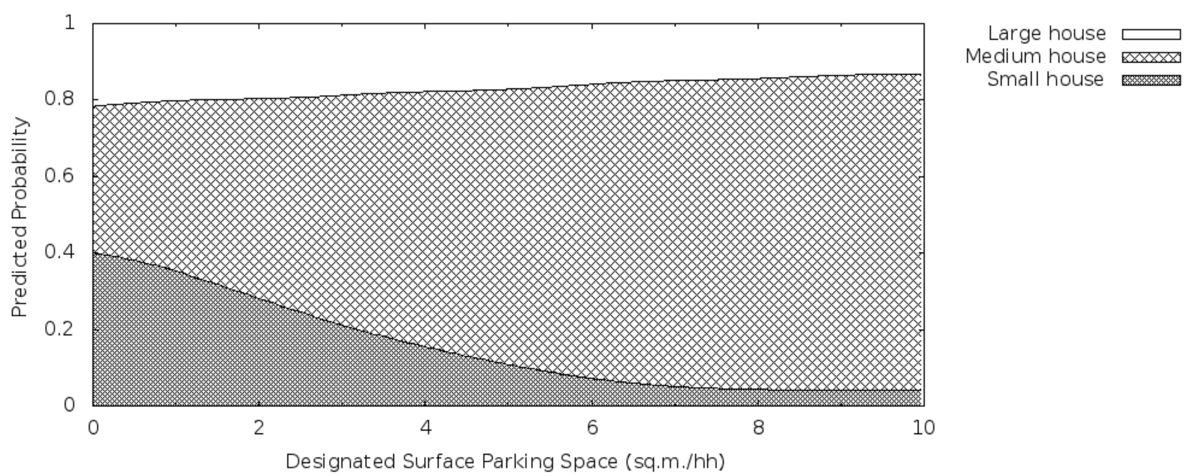


Figure 6.20 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Surface Parking (LCM)

Surface parking tells a different story. While more surface parking leads to more cars at the expense of the “no vehicle” category (although the effect is not very large) in the vehicle portfolio choice (Figure 6.19), more surface parking (sq.m. per household) is associated with a higher likelihood of being in the “typical urban” group (Class 2, probably consisting of job-oriented and kid-oriented households), which translates into more medium sized housing units (Figure 6.20). Apparently compared to underground parking, surface parking is not as nice an “amenity” as underground parking to the “amenity-oriented” group (Class 3). This is probably true because: (1) surface parking is less desirable than underground parking for car owners as it is not covered, thus exposing parked vehicles to weather and intentional or unintentional human damage; and (2) surface parking is generally poorly designed and aesthetically undesirable in the neighborhood public space. Actually, many surface parking spaces in Jinan's neighborhoods appear to have been allocated at random open spaces, presumably after residents' car ownership levels exceeded available street parking.

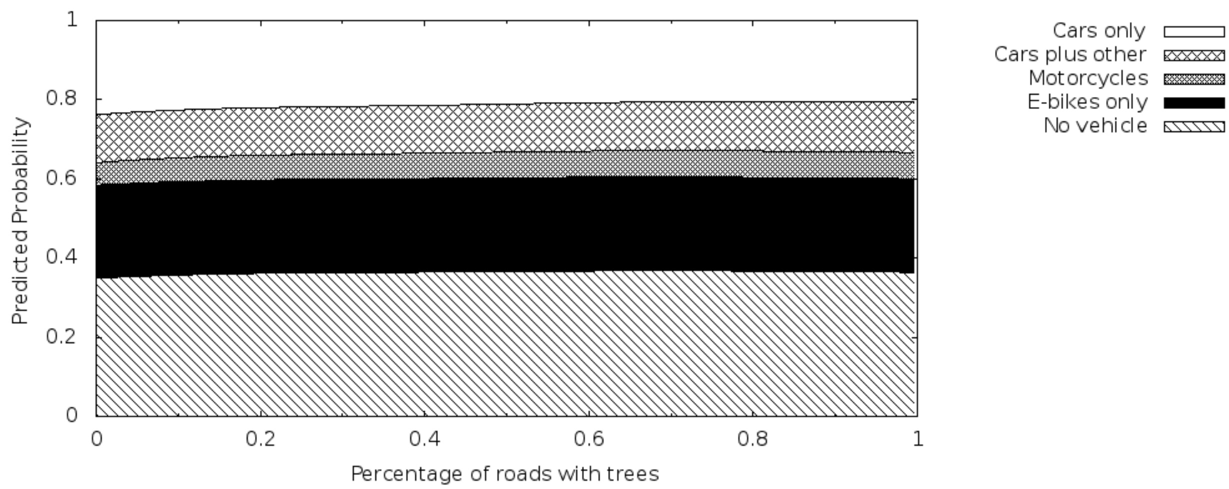


Figure 6.21 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Trees (LCM)

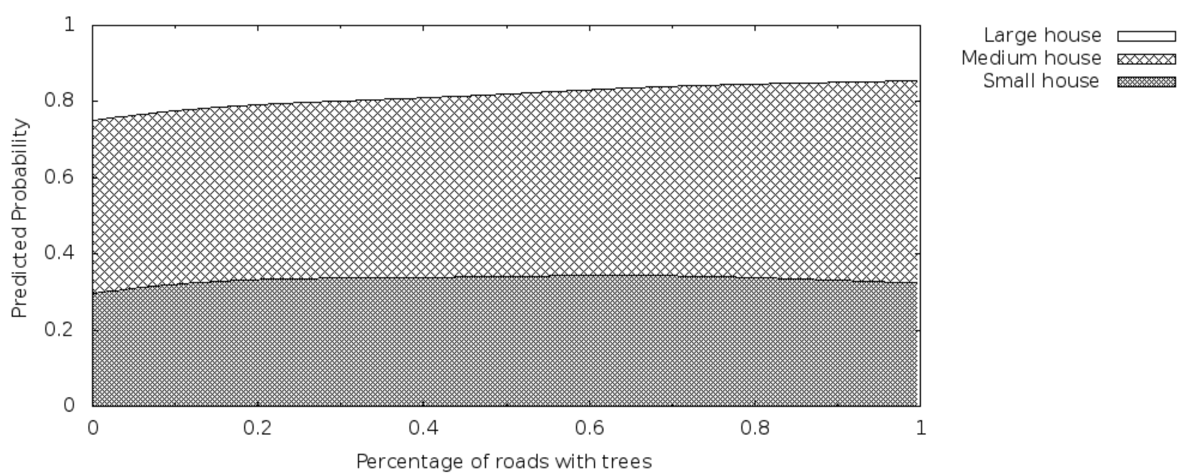


Figure 6.22 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Trees (LCM)

More roads with trees are associated with slightly less car ownership (Figure 6.21) and some moderate reduction in the probability of occupying a large dwelling unit (Figure 6.21). Roads with trees likely make walking more enjoyable, thus this statistical association supports the hypothesis that pedestrian-friendly design could lead to a higher likelihood of "budget-oriented" lifestyle households instead of "amenity-oriented" ones; this effect is very small in magnitude.

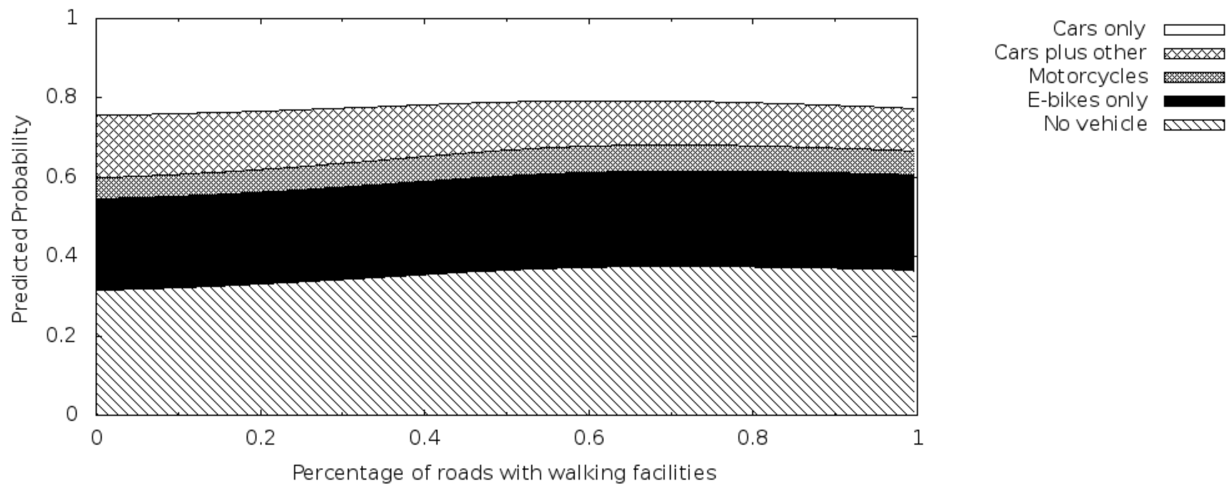


Figure 6.23 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Walking Facilities (LCM)

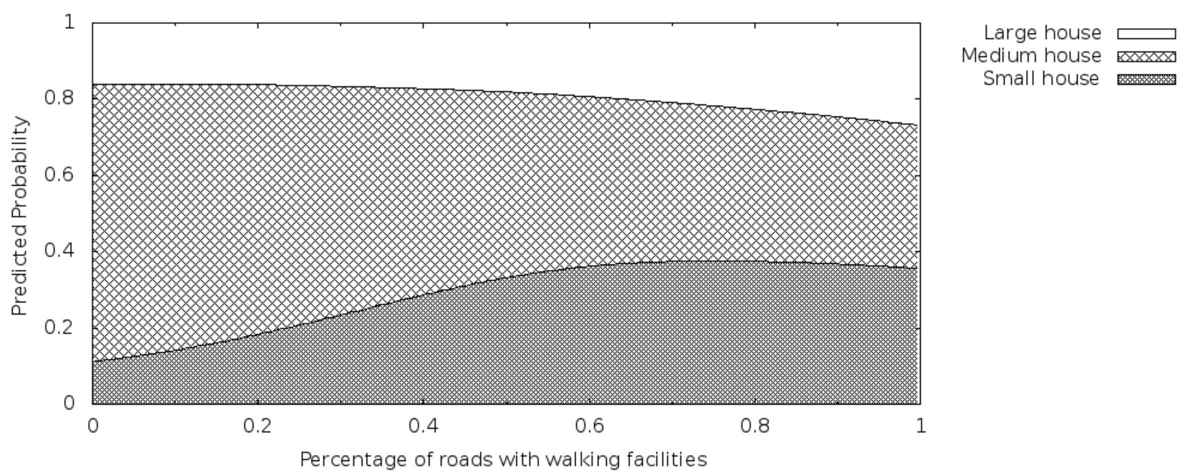


Figure 6.24 Housing Unit Size Probabilities: Simulated Changes due to Class Membership Effect of Percentage of Roads with Walking Facilities (LCM)

The percentage of roads with walking facilities (including sidewalks and pedestrian paths), however, has a positive association with both the "amenity-oriented" lifestyle group and the "budget-oriented" lifestyle group, which translates to a minimal reduction in car ownership and a large reduction in medium units as the share of walking facilities increases (Figure 6.23 and Figure 6.24).

Similarly, the average distance between neighborhood entries, which is an attribute measuring how "open" a neighborhood is, also shows an ambiguous effect on lifestyle bundle choice (Figure 6.25 and Figure 6.26).

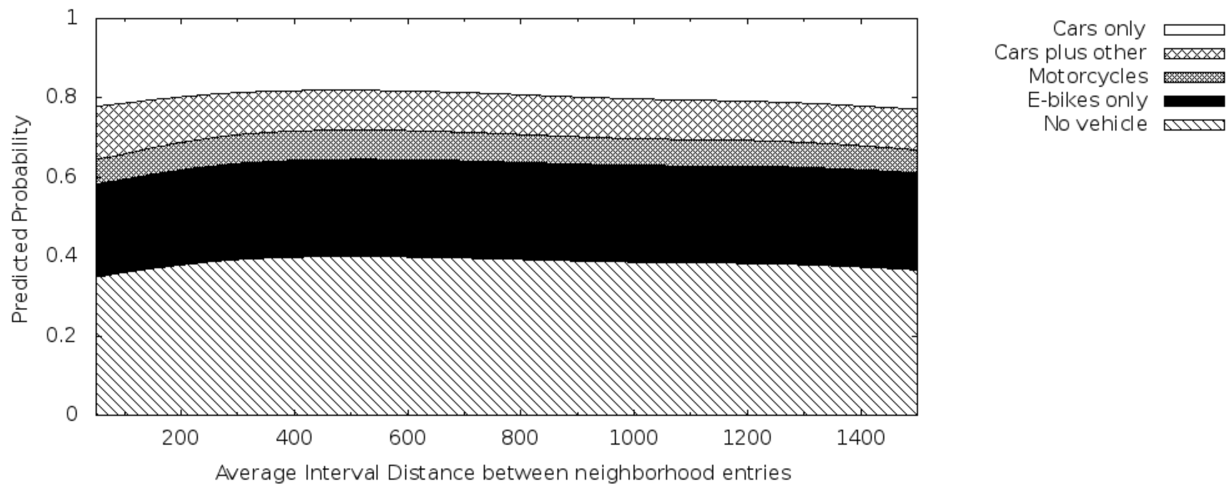


Figure 6.25 Household Vehicle Portfolio Probabilities: Simulated Changes due to Class Membership Effect of Average Distance between Entries (LCM)

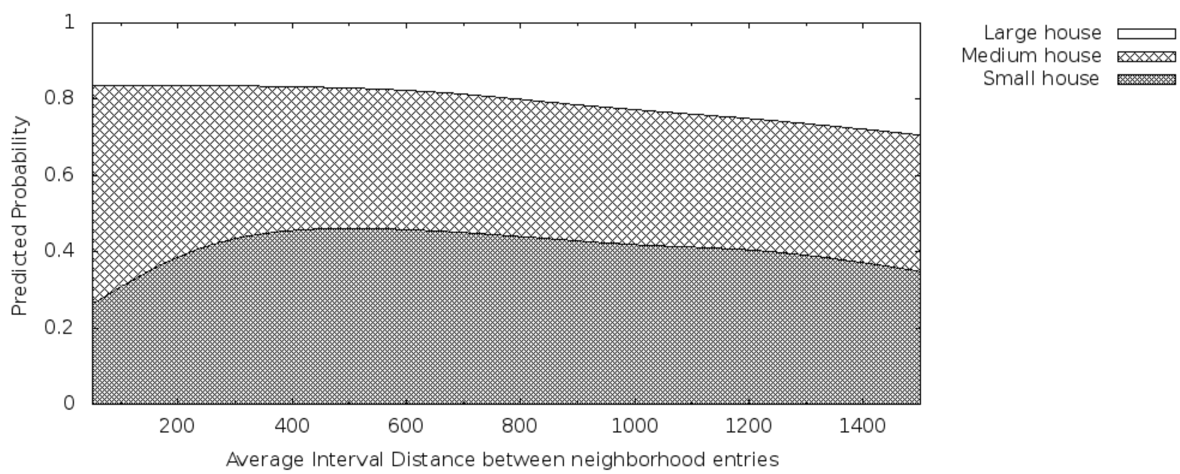


Figure 6.26 Housing Unit Size Simulation with Average Distance between Entries (LCM)

We can also examine, via simulation, the relative effects of dummy variables.

For example, whether a household member has access to a company/business car is associated with households' lifestyle bundle choice. Figure 6.27 shows the simulated effect on vehicle portfolio choice, with the darker lines representing households who have company car access and the lighter lines representing those who do not. Apparently having access to a company car increases the probability of owning cars (including the categories "Cars only" and "Cars and other vehicle") and decreases the probability of owning e-bikes or no motor vehicles. Having access to a company car is associated with lower probabilities of choosing small housing units, higher probabilities of choosing medium sized housing units when income is relatively low, and higher probabilities of choosing large housing units when incomes grows to mid- and high-level (Figure 6.28). Having a company car may enable households to trade-off resources they otherwise would invest into mobility for a larger residential space.

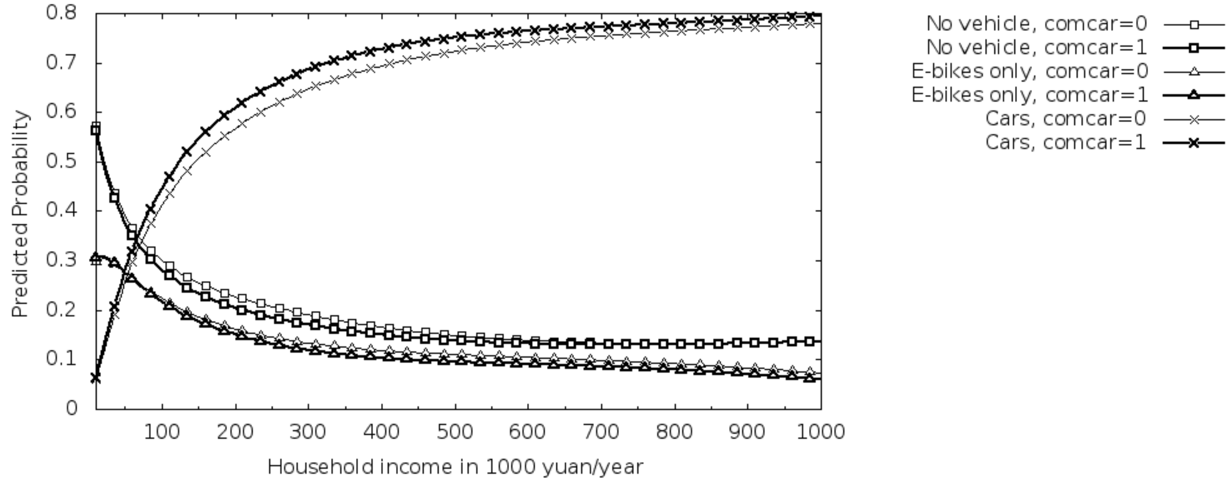


Figure 6.27 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income, by Company Car Access (LCM)

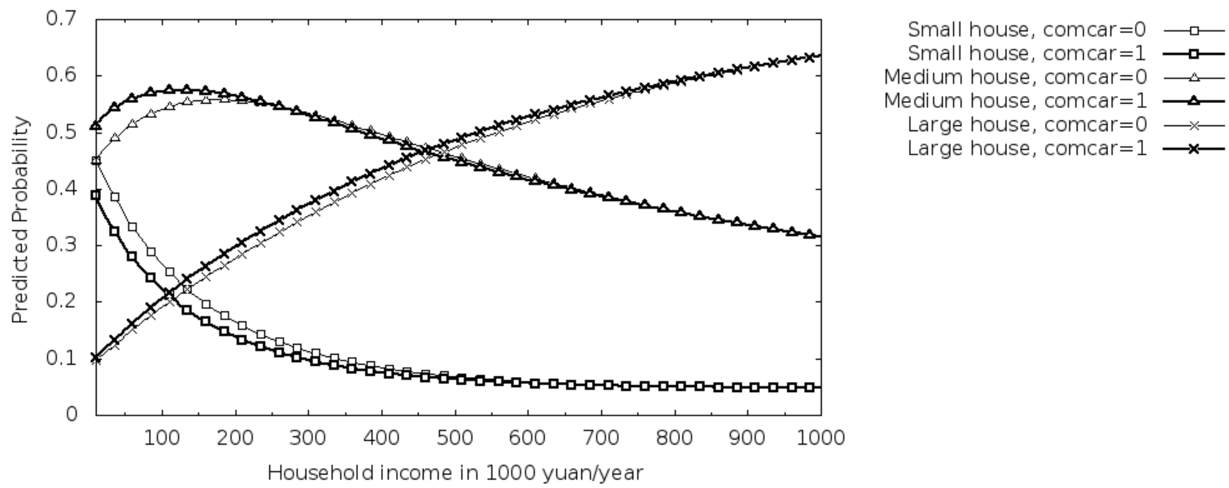


Figure 6.28 Housing Unit Size Probabilities: Simulated Variation due to Household Income, by Company Car Access (LCM)

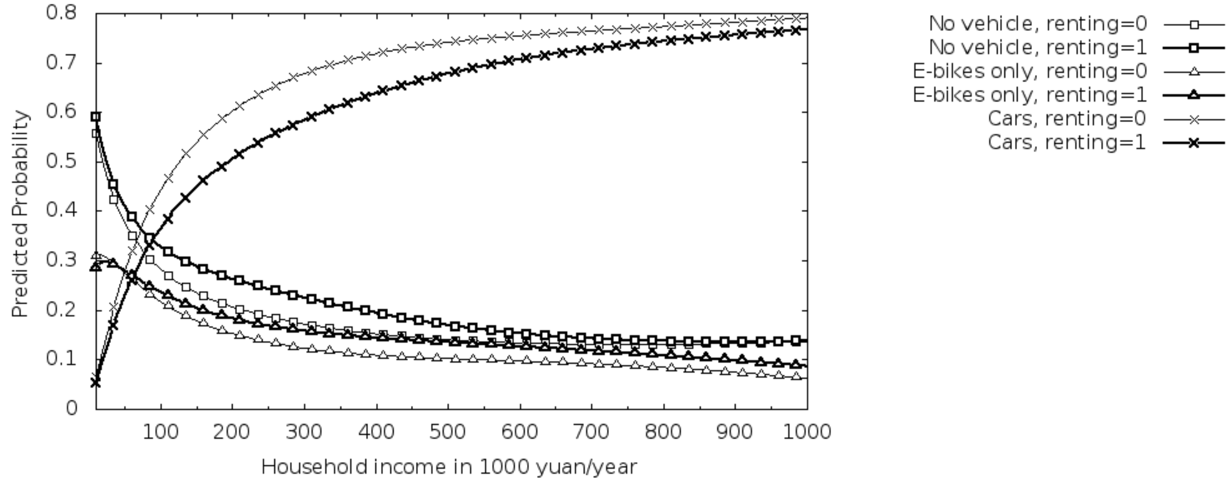


Figure 6.29 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income, by Whether Renting (LCM)

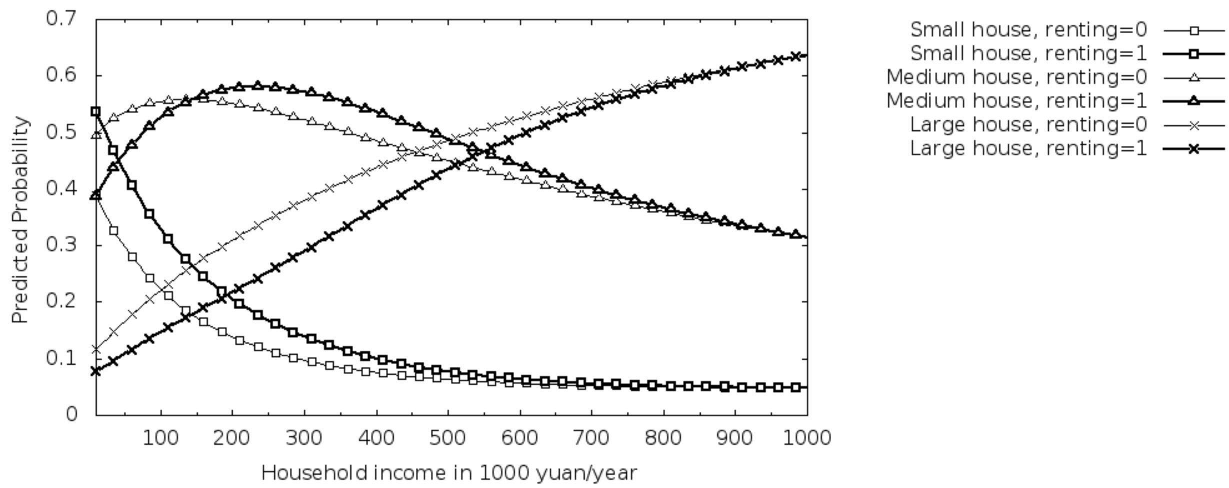


Figure 6.30 Housing Unit Size Probabilities: Simulated Variation due to Household Income, by Whether Renting (LCM)

Figure 6.29 and Figure 6.30 shows the associations between home rental status and lifestyle bundle choice. The darker lines represent simulations for those who rent, while the light lines represent simulations for those who buy homes. Relative to homeowners, renters (most of them belonging to the "budget-oriented" lifestyle group) apparently own fewer cars but more e-bikes, and more of them choose not to own any motor vehicles. Also relative to homeowners, renters have a higher tendency to occupy small housing units when income is low and medium housing units when income gets higher and a lower tendency to occupy large units compared to home buyers/owners.

As described in the methods section in Chapter 3, all previous simulations are done using the actual values of the other available explanatory variables[23] for each respondent in the sample.

[23] Except for the variable being changed in the simulation, i.e.: household income. For the income-based variation simulation, the variable "dif_income_k" also changes as the simulation assumes the neighborhood average income does not change.

The bundle probabilities for each of the 14 alternatives are calculated using the class-specific choice model coefficients and weighted by the probability of that respondent household belonging to each of the three classes; and then the simulated bundle probability curves for all respondent households are averaged across the complete sample. This approach is different than using a "typical" (or median) household, with the medians values for the explanatory variables as the default for the simulation. Comparing Figure 6.31 with Figure 6.15 (or Figure 6.32 with Figure 6.16) we can see that the two approaches produce different apparent results. Generally, the sample-average approach produces a smoother graph than the median-household approach. As discussed in Chapter 3, one issue with the "median household" approach is that this assumed "typical household," supposedly representing the majority (or average) characteristics of the total sample, might not even exist in the real world. And it can be a challenge (and sometimes arbitrary) to choose one "default" value for a variable that class membership is very sensitive to.

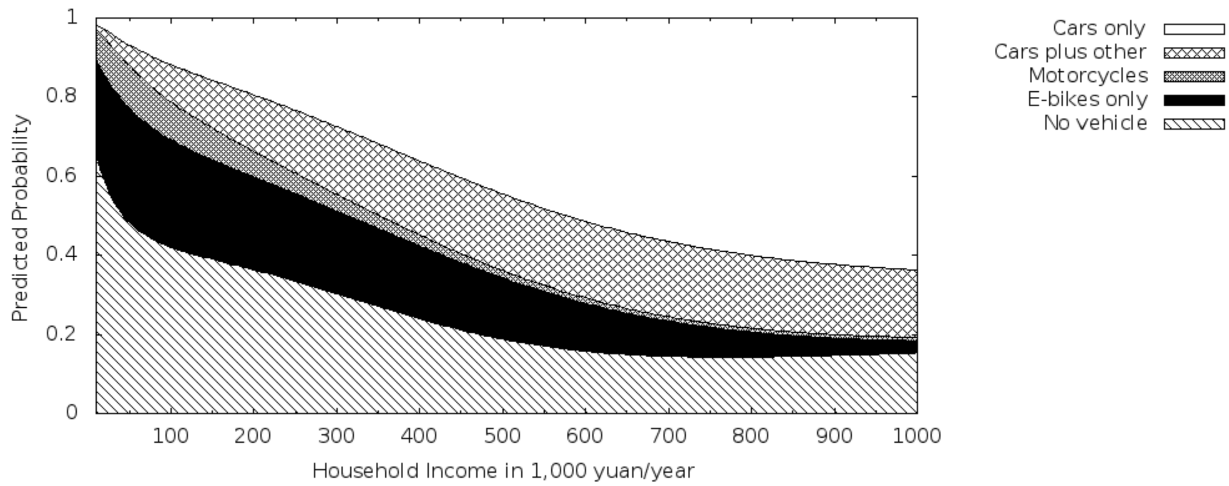


Figure 6.31 Household Vehicle Portfolio Probabilities: Simulated Variation due to Household Income (Median Household Approach)

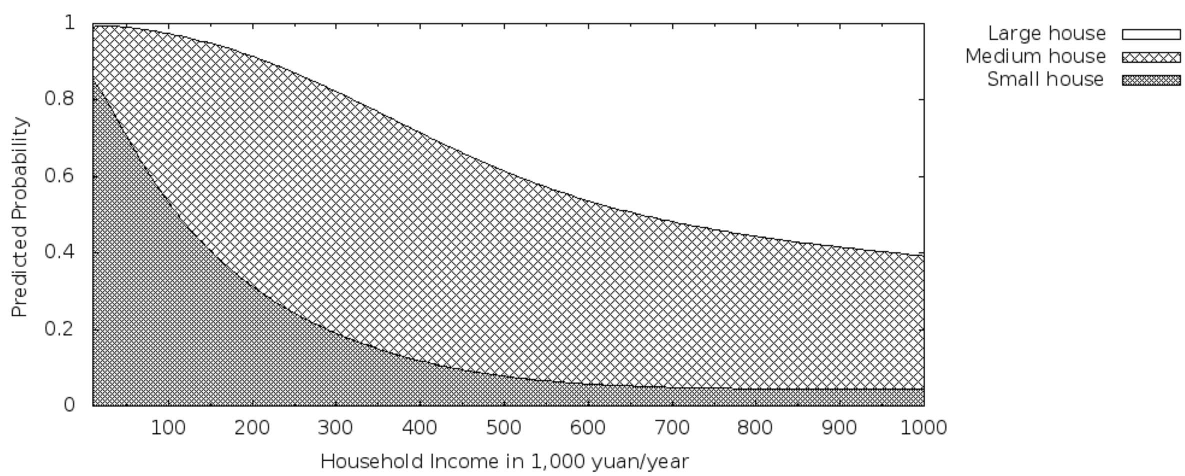


Figure 6.32 Housing Unit Size Probabilities: Simulated Variation due to Household Income (Median Household Approach)

6.3 Conclusion

Lifestyle bundle choice and lifestyle groups comprise the core of this dissertation. In this Chapter, residential choice (housing unit size) and vehicle portfolio choice are bundled as a joint choice made by the household. An MNL model is utilized to test the associations of neighborhood design and lifestyle bundle choice controlling for households' individual characteristic, and the result supports the hypothesis that neighborhood design is associated with household lifestyle bundle choice.

Furthermore, the LCM supports the categorization of the "budget-oriented" lifestyle group and "amenity-oriented" group identified in Chapter 4, and shows that neighborhood design is associated with group membership probabilities.

Simulations based on the model results help to better interpret the direction and magnitude of the tested neighborhood design variables; these simulations reveal that, in Jinan, more underground parking increases the probability of owning cars as well as the probabilities of occupying medium and large units; more roads with trees are associated with slightly less car ownership and some moderate reduction in probability of occupying a large dwelling unit. The percentage of roads with walking facilities and the average distance between neighborhood entries show ambiguous effect on lifestyle bundle choice. Having access to a company car not only increases the probability of owning cars, but is also associated with higher probabilities of choosing medium sized housing units when income is relatively low, and higher probabilities of choosing large housing units when income is relatively high. The following Chapter attempts to incorporate these results into a second stage model of household in-home and travel energy use.

Chapter 7 Household Direct Energy Consumption

7.1 Introduction

7.1.1 Overview

The previous chapter used a latent class model to estimate the influences of various factors on household's lifestyle bundle choice, i.e. housing unit size choice and vehicle portfolio choice. Model estimation revealed that different household types exhibit different decision-making mechanisms. In other words, households have different probabilities of belonging to a particular "lifestyle group," as determined by the modeled choice process, and these different groups have different choice processes. This chapter utilizes the results of the household lifestyle bundle choice models in Chapter 6, and explores the factors influencing household direct energy consumption.

Household direct energy consumption consists of travel energy and in-home energy. Both of these condition the lifestyle bundle choice, and are influenced by household characteristics and neighborhood design (Figure 7.1).

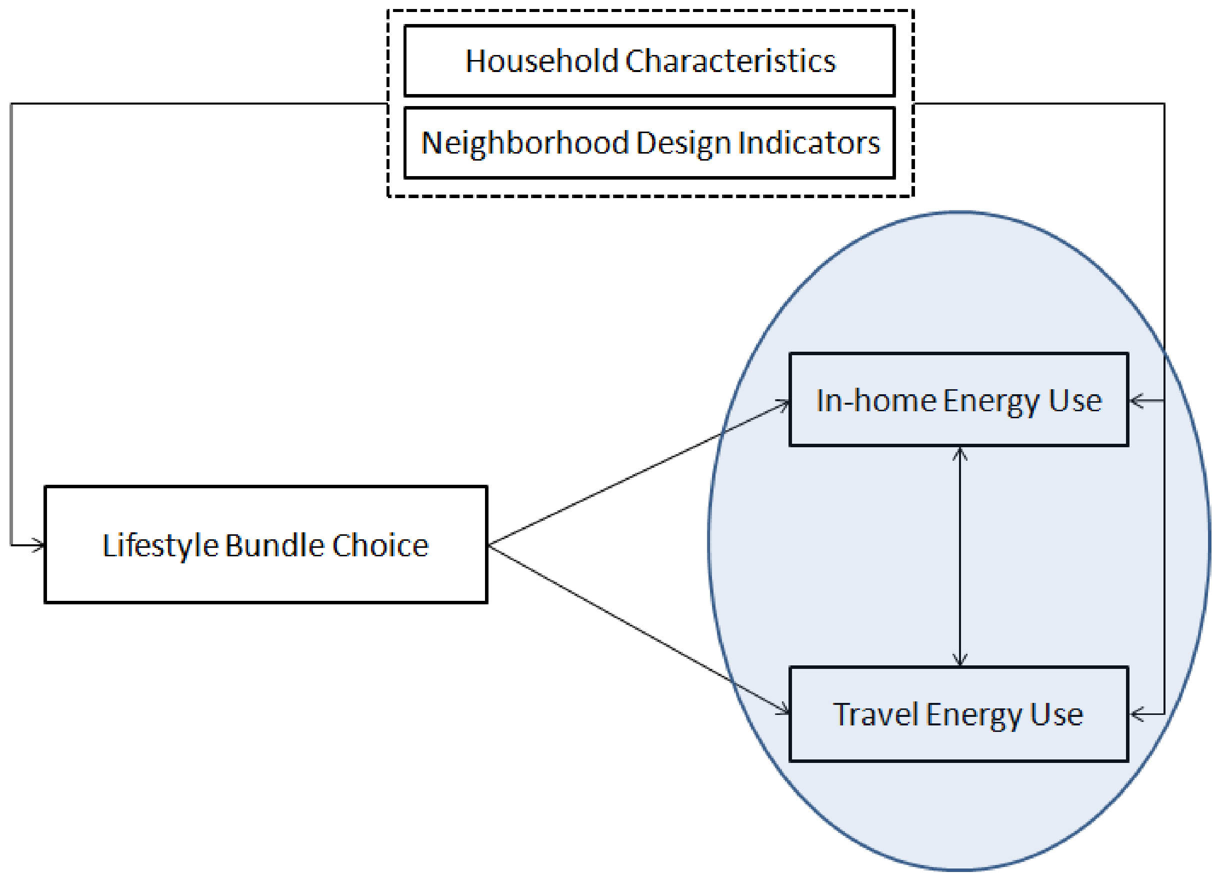


Figure 7.1 "Energy Use" Component in the Theoretical Model

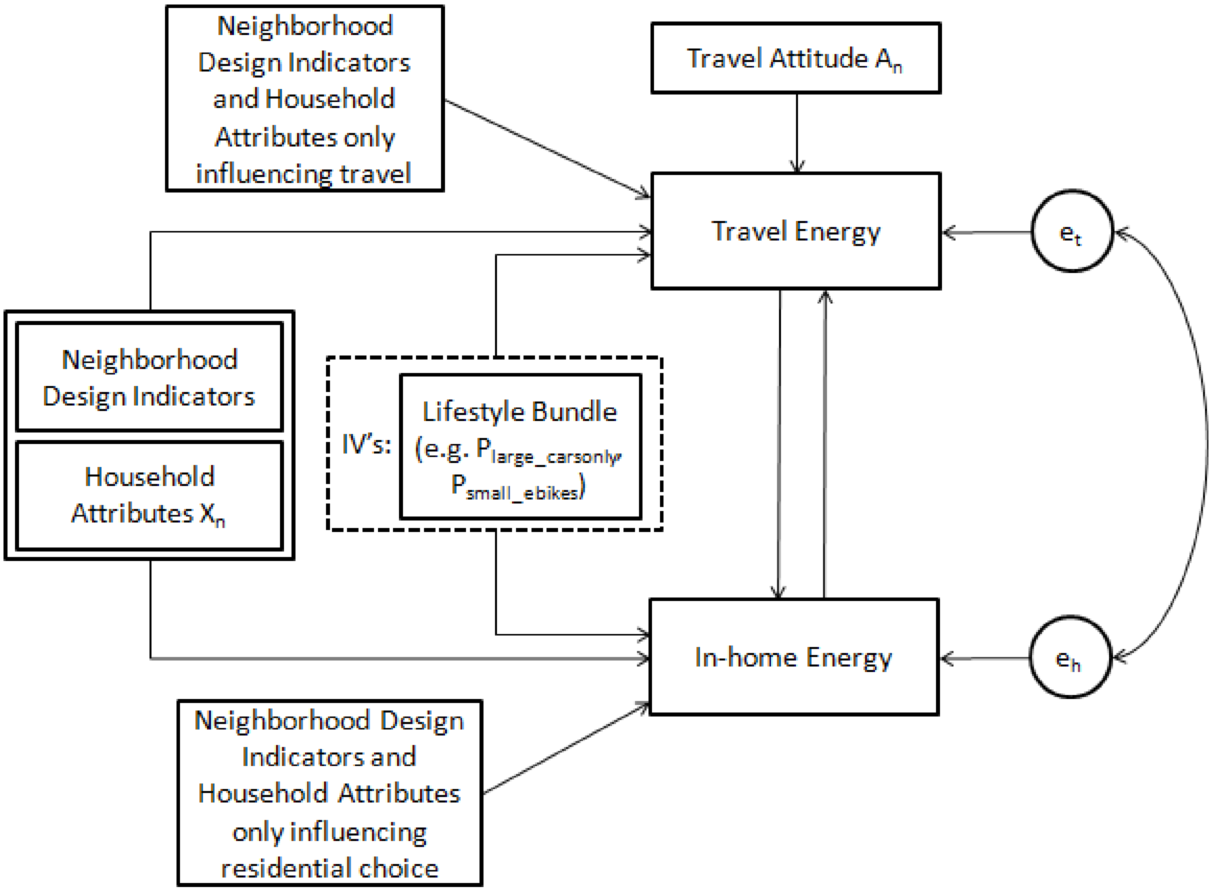


Figure 7.2 SEM Structure with Bundle Choice as IV's

As discussed in the methods section of Chapter 3, a structural equations model (SEM) is well-suited to test the influence of neighborhood design on energy consumption. In this case, I use the fitted probabilities of a household's lifestyle bundle choice as instrumental variables to help account for the potential endogeneity problem in modeling bundle ownership and use. Although the household lifestyle bundle choice model already captures the heterogeneity of different lifestyle orientations, which are incorporated in the ownership bundle choice probabilities as weights, households might still exhibit different lifestyle orientations when using energy. The possibility of unobserved "energy-use-stage lifestyle" factors will make travel energy and in-home energy have positive association. On the other hand, travel energy and in-home energy both contribute to the household's daily consumption of time and resources (money). Therefore, a possible substitution effect exists. The above two potential effects make travel and in-home energy depend on each other, and their error terms in a model correlated as well. This is represented graphically in the two causal arrows drawn between the two energy end uses and the covariance arrow drawn between their two error terms (Figure 7.2); their significances will be tested.

This chapter will first discuss the direct energy consumption patterns revealed in the Jinan sample households and present detailed hypotheses on the expected effects of different variables. Then, an ordinary least squares regression model on total direct energy use will be built, utilizing instrumental variables and discussing their validity. Then the estimation results from the SEM, using the model structure in Figure 7.2 will be presented and interpreted. Simulations will be utilized to illustrate the potential effects more clearly.

7.1.2 Energy Consumption pattern in Jinan

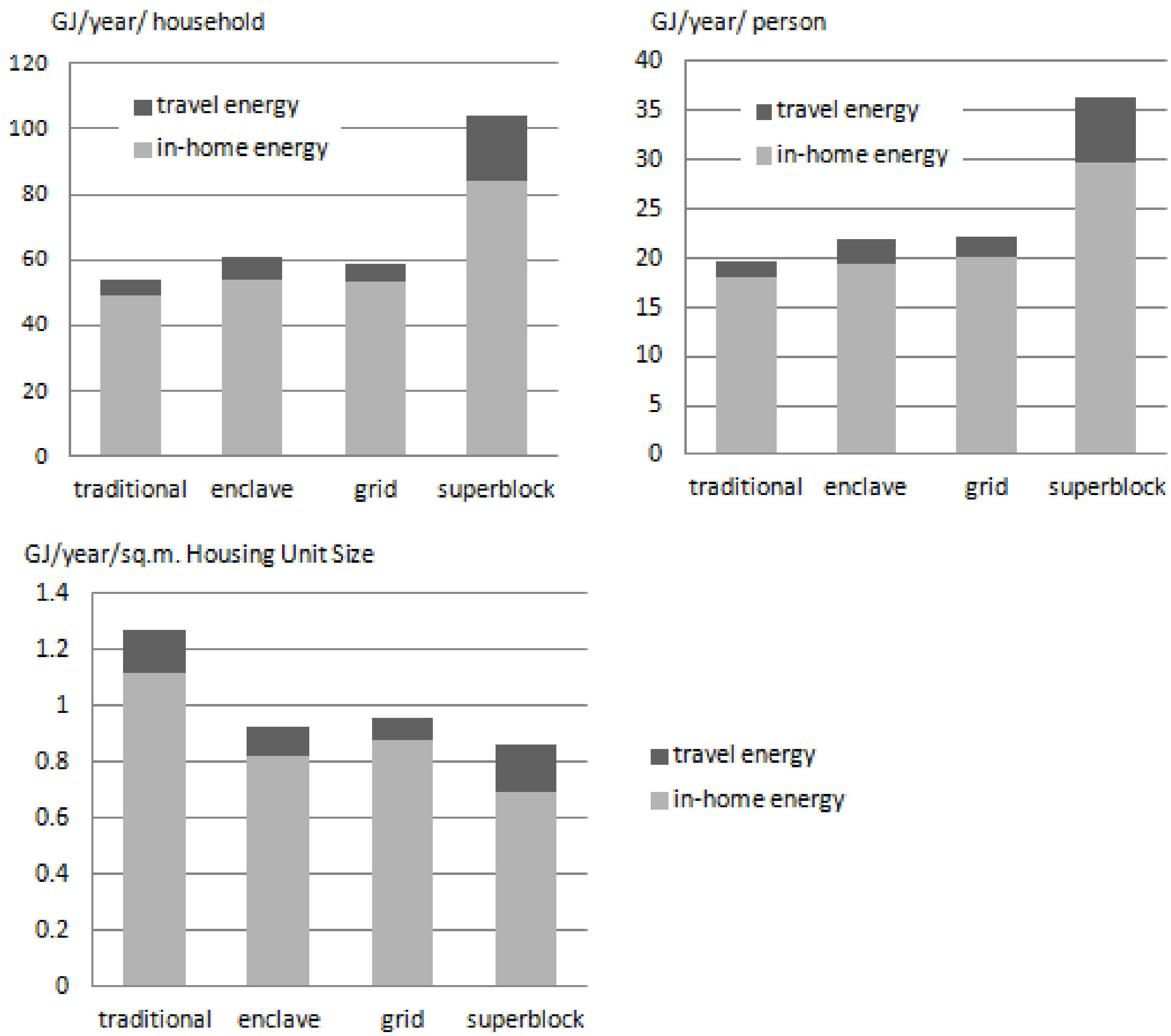


Figure 7.3 Total Direct Energy Consumption in Jinan Neighborhoods by Type

According to the self-reported results in the household survey and the subsequently calculated energy consumption (see Appendix A2), a household in Jinan uses on average 75.5 GJ of direct energy in-home and for travel each year. Figure 7.3 shows that households residing in different neighborhood types consume different levels of energy. Those living in superblock neighborhoods consume more than 100 GJ per year per household, while those in the three other neighborhood types use only 50- 60 GJ per year. Per capita energy use shows a similar pattern, with superblock households using over 50% more energy per person than those in the other three neighborhood types. However, after accounting for the size of the housing unit a different picture emerges: households in traditional neighborhoods consume more energy per square meter than those in the other three types.

On average, travel energy accounts for a small share of household energy consumption, just 15% of the total. Electricity and centralized heating take up the majority portion of in-home energy use (Figure 7.4).

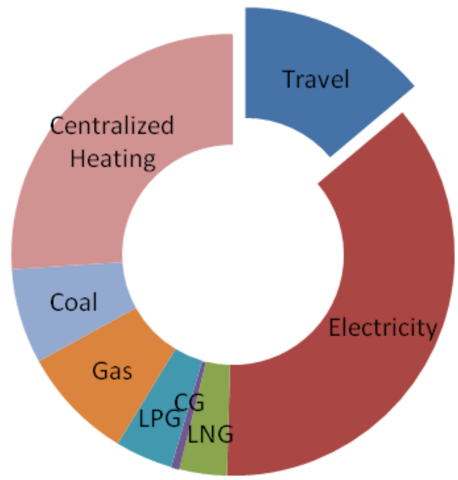


Figure 7.4 Per Household Total Direct Energy Consumption Composition by Source

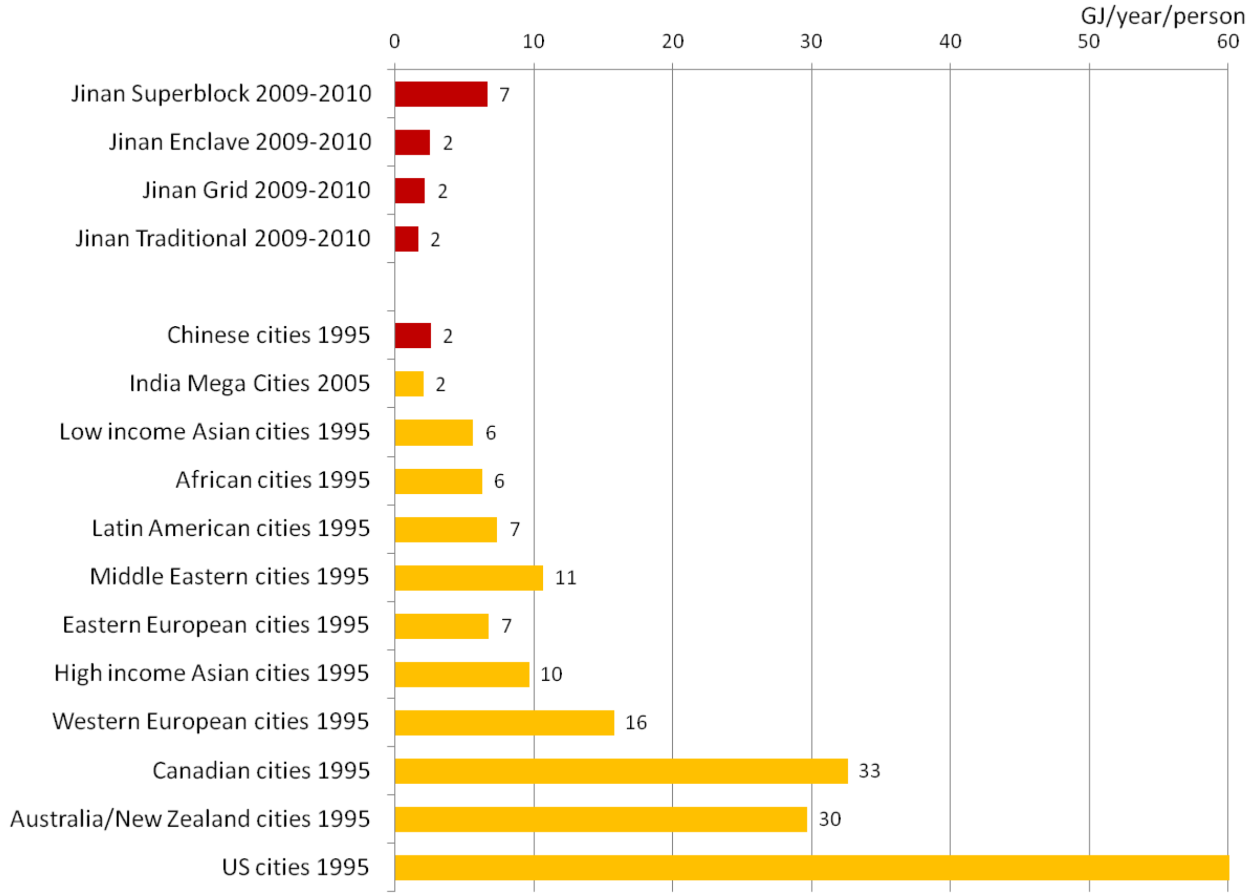


Figure 7.5 Per Capita Travel Energy Consumption in Jinan Compared with Other Cities

Notes: India 2005 data extracted from Reddy and Balachandra (2010), the rest of the data for international cities extracted from Kenworthy (2008, p. 215-220).

To put the estimated travel energy consumption numbers for Jinan into a broader context, we compare the calculated personal annual travel energy use in Jinan with similar figures for international cities. From Figure 7.5 we can see that, although the Chinese still consume a relatively low level of transport energy compared to developed countries, consumption levels in the "superblock" already comes close to that of affluent cities in Asia.

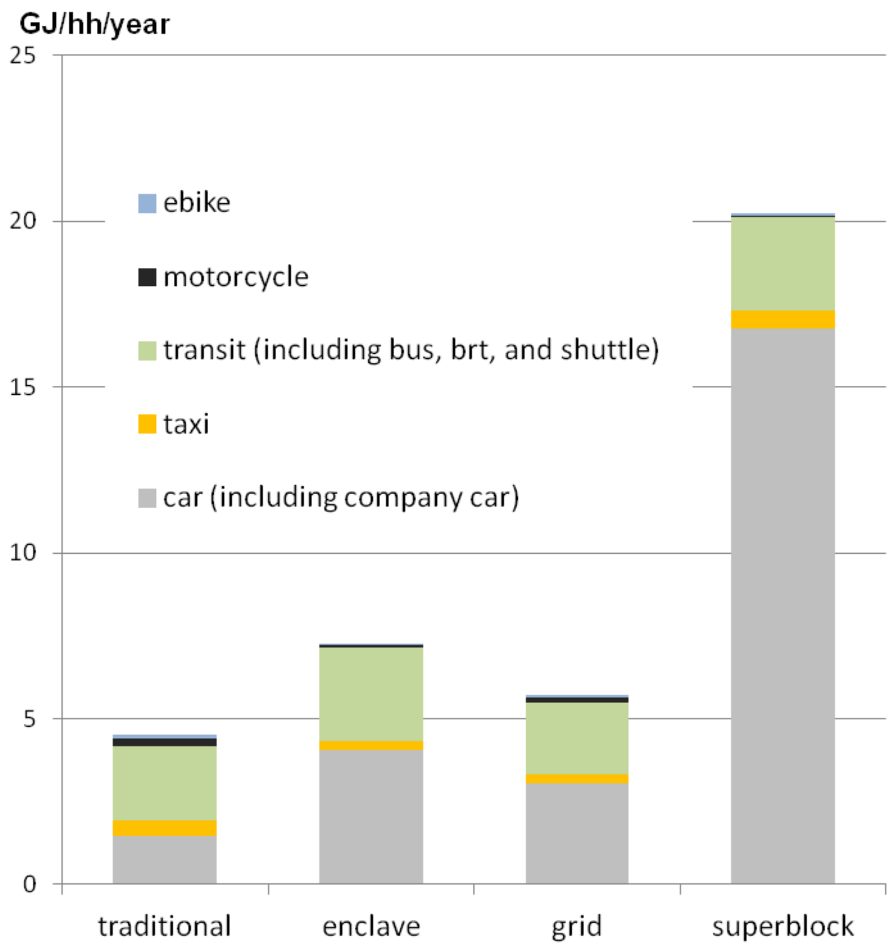


Figure 7.6 Breakdown of Travel Energy Consumption by Neighborhood Type

We can observe very different travel energy consumption levels across neighborhood types with households in superblock neighborhoods consuming much more (3 to 4 times) travel energy than their counterparts in the other three types. Almost all of the difference comes from the energy used by car (including company car) (Figure 7.6). Therefore we might expect car ownership, which can be obtained from the vehicle portfolio ownership part of the lifestyle bundle choice, to be the dominant factor influencing travel energy use.

Compared with other cities in the world, Jinan households do not use much less in-home energy than those in the developed countries. While the households residing in superblock neighborhoods consume similar level of residential energy as those in the U.S. and Western European countries, Jinan households in traditional, enclave, and grid neighborhoods use in-home energy comparable to those developed Asian countries like Japan and South Korea (Figure 7.7).

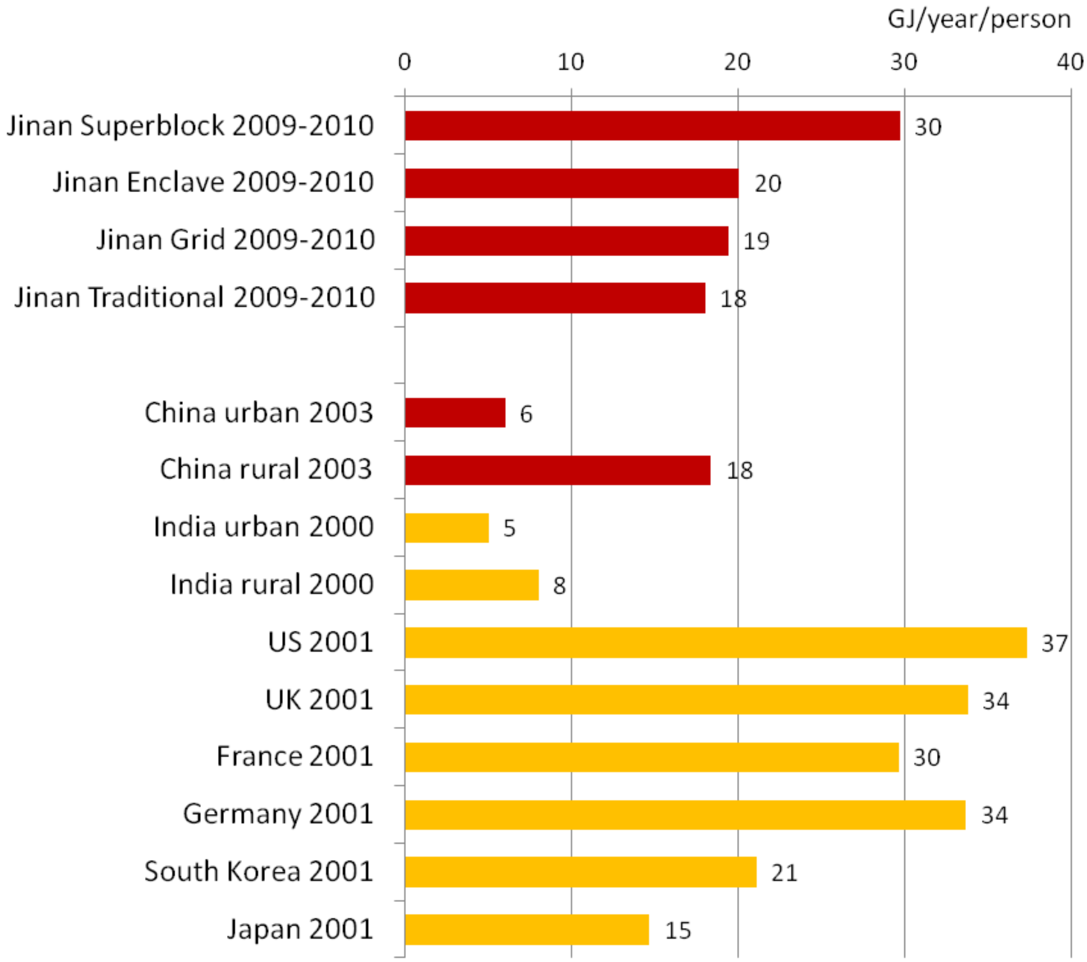


Figure 7.7 Per Capita In-home Energy Consumption in Jinan Compared with Other Countries

Notes: International comparison data from Nakagami et al. (2008); Per capita travel energy consumption is calculated from household residential energy consumption using national average household size (ECESD, 2001)

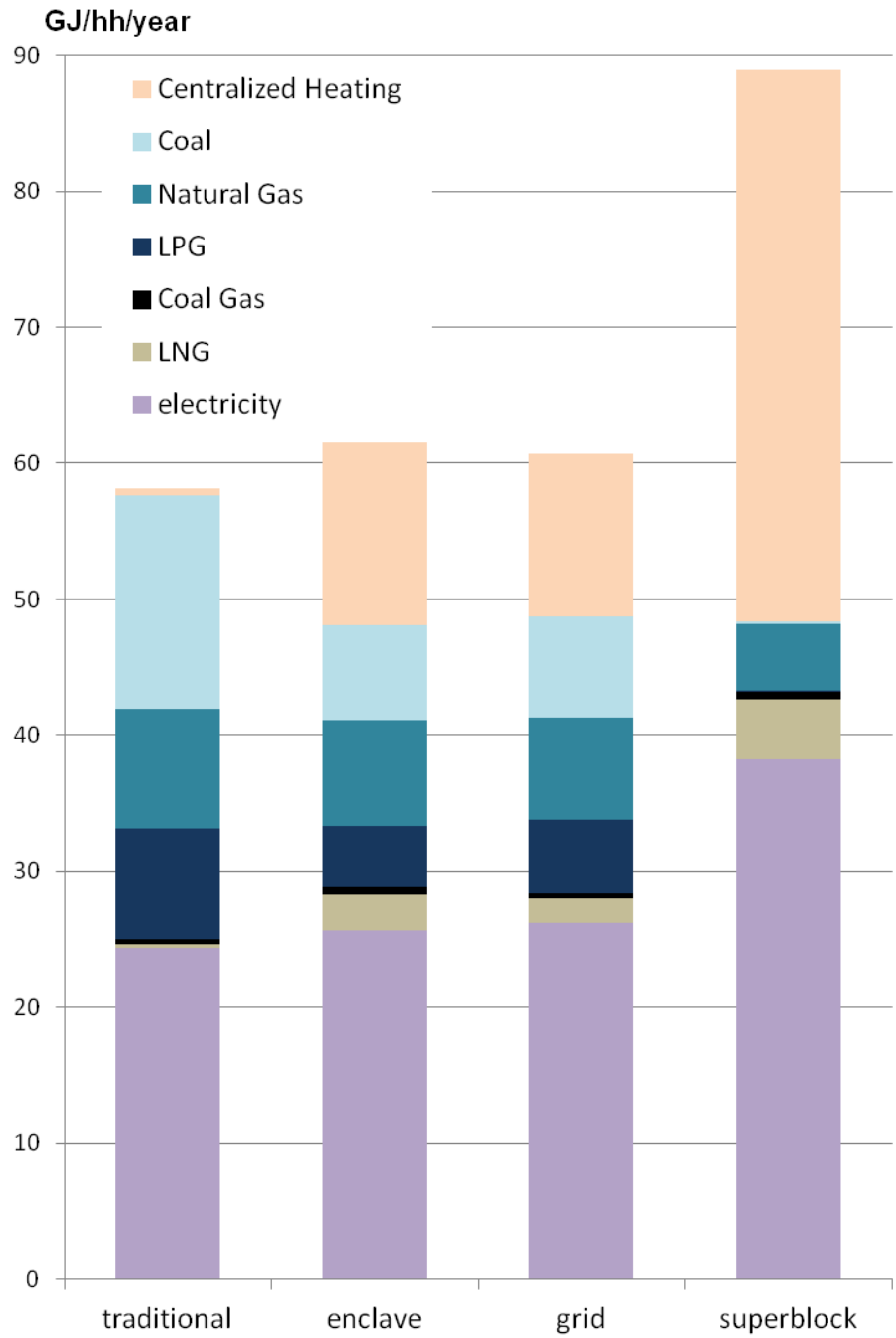


Figure 7.8 Breakdown of In-home Energy Consumption by Neighborhood Type

The largest portion of in-home energy difference across neighborhood types comes from centralized heating. While all superblock neighborhoods provide centralized heating, only some households in enclave and grid neighborhoods have access to centralized heating, and almost none do in traditional neighborhoods. Households living in traditional neighborhoods still use coal for cooking and heating purposes, but none do in the superblock neighborhoods (Figure 7.8).

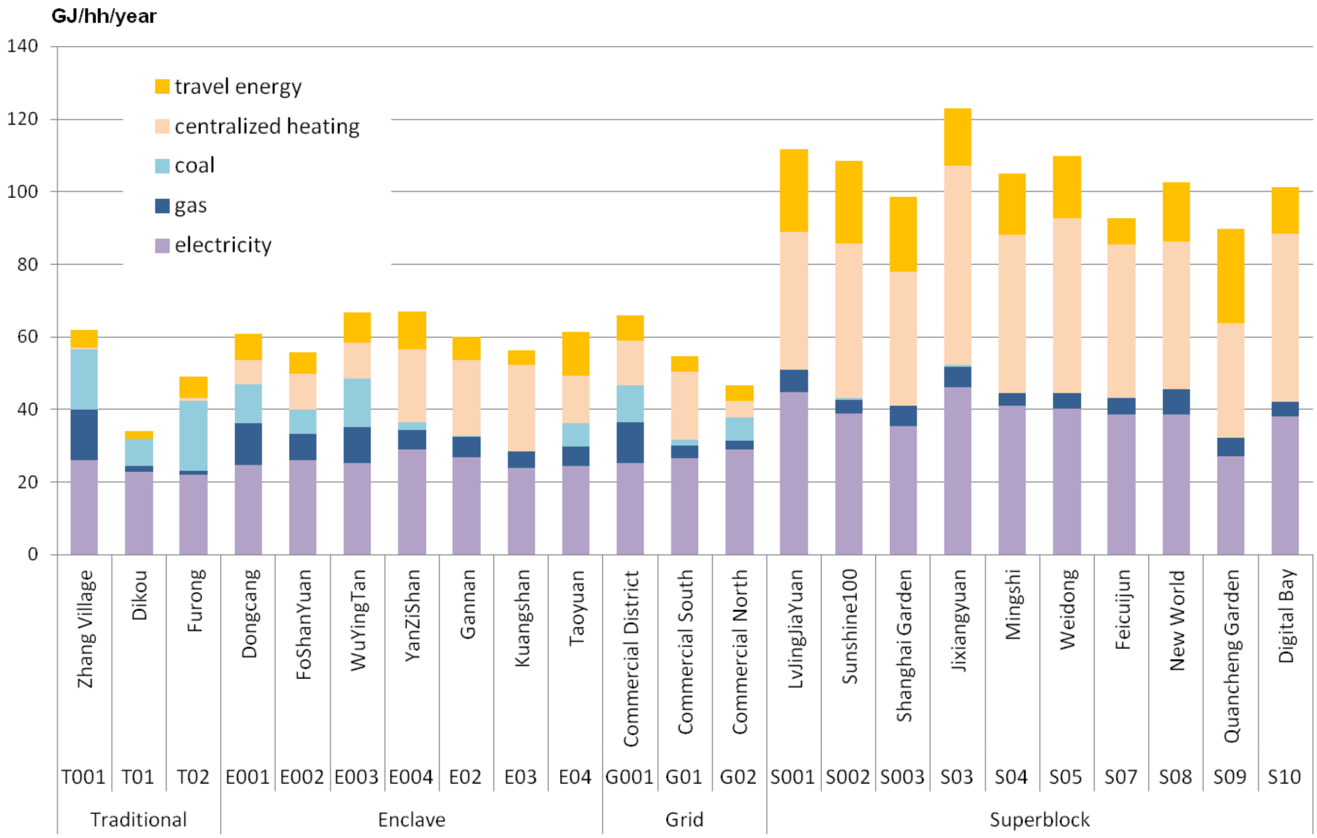


Figure 7.9 Household's Direct Energy Consumption in Jinan Sampled Neighborhoods

Variations within neighborhood types exist as well (see Figure 7.9). Taking electricity as an example, households residing in superblock neighborhood S09 (Quancheng Garden) consume the same level of electricity as those in grid and enclave neighborhoods, while households in superblocks S001 (LvjingjiaYuan) and S03 (Jixiangyuan) consume higher levels of electricity. Since there are also variations in household characteristics (including income level, household structure, etc.) as well as neighborhood design characteristics within neighborhood types, we have to rely on statistical regression models which control for as many observed attributes as possible to assess the relationships between each factor and energy consumption.

7.1.3 Hypotheses

From previous theory development and empirical literature, and given the data availability and model structure, the following effects of observed attributes are expected.

1. Lifestyle bundle

The potential effect of lifestyle bundle choice on energy consumption is straightforward. A larger housing unit is expected to be associated with higher in-home energy consumption since more heating and cooling of space are needed. Higher motor vehicle ownership levels are also expected to increase travel energy, as car owners will almost certainly consume more travel energy than non-car owners, while motorcycle and e-bike owners probably consume more travel energy than pedestrians and bus riders.

2. Household characteristics

Given the same lifestyle bundle (i.e. same unit size and same vehicle portfolio), households with higher incomes might consume more energy because they have fewer resource constraints and/or carry out more energy-demanding activities. A larger size household is expected to consume more travel and in-home energy. Households with children might consume more travel and in-home energy because children are involved in more activities and may require more care (e.g., more comfortable temperature control). The effects of households with older adults are ambiguous because on the one hand, older people tend to travel less and have smaller activity radii (except, possibly, the need for health care trips); but, on the other hand, older people likely stay at home more and do more in-home activities and they might need warmer (or cooler) room temperature (although they also may be more accustomed to a less energy-intensive living environment). The number of household members currently employed can have two-sided effects too: more employed persons mean more trips to work (although possibly offset by fewer trips for other purposes); but fewer employed household members means more people may stay at home and carry out more in-home activities. Renters are expected to use less in-home energy as they tend to occupy smaller housing unit (as shown in the lifestyle bundle choice) and given the same bundle, they might not own or use as many appliances as home owners due to the temporary nature of their residence. Renters possibly have lower travel energy use as well since they maybe have been more flexible to choose a less travel-intensive location. Given the same lifestyle bundle at the ownership level, attitudes toward travel modes are expected to have a similar effect on travel energy as on vehicle portfolio choice, but less likely to influence in-home energy unless some travel attitudes also capture the usage level lifestyle effects.

3. Neighborhood design variables

Holding constant lifestyle bundle choice and household characteristics, I also hypothesize that neighborhood design will influence a household's direct energy consumption. For example, a more walkable environment in a neighborhood (e.g. roads with trees, roads with walking facilities, building footprint, continuity along roads) might cause people to walk and bike more instead of driving, therefore use less travel energy; a more walkable environment could also encourage people to get out of their home and stroll around more often and therefore consume less in-home energy as well. However, given ambiguous theoretical outcomes and potential rebound effects (see discussion in Chapter 2) and the intertwining nature of travel and in-home energy use (e.g. competing in terms of time and other resources, but sharing same attitudes, preference, lifestyle, etc.), some of the directions of effects are ambiguous. For example, more underground parking space may increase households' tendency to own cars, but make them drive less (due to the possible inconvenience of having to go underground to retrieve the vehicle). Unlike underground parking, surface parking may increase the convenience to car owners and make pedestrians and bicyclists less comfortable therefore potentially increase travel energy use. However, surface parking is usually free (or very cheap) and not designated to a particular household, which might discourage driving as car owners might not want to risk losing the parking space.

7.2 Neighborhood Design and Households' Direct Energy Consumption

7.2.1 Total Energy Consumption with lifestyle bundle choice as IV's

As discussed in Chapter 3, section 3.2.2, this research adopts the two-step instrumental variable approach to deal with the discrete-continuous endogeneity issue in the ownership and usage behaviors of energy consumption. The key requirement for choosing instrumental variable is that it has to be correlated with the endogenous explanatory variable (in this case, the lifestyle bundle choice in the ownership component), conditional on the other covariates, but not correlated with the error term in the explanatory equation for energy use. In other words, we have to find at least one explanatory variable that helps explain bundle choice (i.e. housing unit size, and vehicle portfolio ownership), but has a low correlation with energy consumption in order to have a consistent estimation (correcting for endogeneity of lifestyle bundle). Finding an instrument that theoretically makes sense is essential to confidently utilizing the fitted bundle choice probabilities as IVs in the energy model estimation.

Fortunately at least two theoretically valid instruments exist among the explanatory variables used in the lifestyle bundle choice model.

For travel energy consumption, almost all explanatory variables are correlated with both vehicle ownership and vehicle use, as almost all demand for vehicle ownership comes from the demand for vehicle use: including both "practical" (e.g. commuting, household errands, etc.) as well as symbolic (e.g. driving as sign of prestige) utility. Therefore, these demand-side variables are probably correlated with both ownership and use and cannot be the instrument. The only variable not from the demand side is access to a company/business car. This "supply-side" amenity (i.e. a substituting effect that reduces the need for a household to own their own vehicles) theoretically only influences the vehicle ownership, not the vehicle use directly (only conditional on the ownership), as access to a company car is provided by the employer instead of coming from the mobility need of household, therefore it is not correlated with the error term in the usage model, and is a valid instrument.

For in-home energy consumption, the potential instrument is the difference between household size and the number of household members who are currently employed. When households make the decision of how large a home to purchase they usually take the current total number of household members into account, as all of them need a place to sleep; however, after a household occupies the unit (conditional on the given housing unit), in-home energy consumption is likely negatively correlated with number of household members who are currently employed, which means the difference (non-employed household members) could serve as a valid instrument, implemented by including both variables in the bundle choice, and only number of employed household members in the energy use model.

From the discussion above we can somewhat safely conclude that it is valid to use the fitted probabilities estimated in the lifestyle bundle choice model as IVs for the energy use model.

Table 7.1 Lifestyle Bundle Choices as Instrumental Variables

Alternative ID	Lifestyle Bundle Choice: Residential	Lifestyle Bundle Choice: Vehicle Portfolio	IVs
1	Small Unit	No Motorized Vehicle	**P(small unit without car)**
2	Small Unit	Own E-bikes only	
3	Small Unit	Own Motorcycles (only or plus e-bikes)	
4	Small Unit	Own Cars only	**P(small unit with car)**
5	Small Unit	Own Cars and Other Vehicles	
6	Medium Unit	No Motorized Vehicle	**P(medium unit without car)**
7	Medium Unit	Own E-bikes only	
8	Medium Unit	Own Motorcycles (only or plus e-bikes)	
9	Medium Unit	Own Cars only	**P(medium unit with car)**
10	Medium Unit	Own Cars and Other Vehicles	
11	Large Unit	No Motorized Vehicle	**P(large unit without car)**
12	Large Unit	Own E-bikes only	
13	Large Unit	Own Cars only	**P(large unit with car)**
14	Large Unit	Own Cars and Other Vehicles	

The fitted probabilities for all 14 lifestyle bundle alternatives are calculated using the lifestyle bundle choice model specified under the LCM structure in Chapter 6, section 6.2.3 (Table 6.4 and Table 6.5). Considering the high correlations among certain groups of the 14 bundle choice alternatives (e.g. 4 and 5, 9 and 10, 13 and 14) and the hypothesized effects of bundle choice on energy (i.e. car ownership's contribution), I group the fitted probabilities for 14 alternatives into six probabilities by housing unit size and car ownership. For example, the probability of owning a large unit with a car equals the sum of the probability of occupying a large unit and owning cars only, i.e., P(alternative 13), and the probability of occupying large unit and owning cars plus other vehicle, i.e. P(alternative 14) (see Table 7.1). The P(small unit without car) is treated as the base, and the remaining five probabilities are used as IVs in the energy model.

Table 7.2 presents the estimation results of the OLS regression for household total direct energy use (on ln[MJ]).

Table 7.2 OLS Estimation Result on Total Direct Energy Consumption (ln[MJ])

Variables	Coef.	Robust z		VIF [a]
Intercept	7.506	10.83	***	
Predicted lifestyle bundle choice				
P(small unit with car)	3.050	4.43	***	2.87
P(medium unit without car)	0.761	6.32	***	2.34
P(medium unit with car)	1.037	8.43	***	2.84
P(large unit without car)	1.860	8.65	***	2.71
P(large unit with car)	1.644	12.9	***	5.04
Household demographics				
single	-0.427	-4.27	***	1.51
couple	-0.075	-2.16	**	1.55
no_employ	0.058	1.37		1.92
twoplus_employ	0.060	1.75	*	1.8
have_kid	0.039	1.29		1.49
have_old	0.084	3.78	***	1.29
Housing Tenure				
renting	-0.261	-6.29	***	1.6
Neighborhood Design Indicators				
underground parking space per hh	-0.211	-2.03	**	8.61
surface parking per hh (sq.m/hh)	0.020	2.76	***	2.62
functin_mix	0.480	4.57	***	3.46
footprint	0.000	6.15	***	3.57
continuity	-2.458	-6.34	***	4.07
Solar/Wind Indices				
surface_to_volume	0.533	3.52	***	6.02
height_irregularity	-0.006	-2.38	**	2.95
building_wind_summer	-1.525	-2.67	***	1.44

N = 3,955; F(20, 3934) = 112.01; R^2 = 0.3461; Root MSE = 0.7110

Note: *** p<0.01, ** p<0.05, * p<0.1

[a] Variance Inflation Factor, measuring the severity of multicollinearity.

All bundle choice variables are significant with the expected signs. The result of testing various forms of household income shows that income does not exhibit any significant association with total energy use when bundle choice is given. [24] It seems that the income effect is already captured in the lifestyle bundle choice (the ownership component), which also results in a high correlation of income with the predicted bundle choice probabilities. The correlation matrix of all independent variables is given in Appendix A6, and the variance inflation factors (VIF) for independent variables in the final OLS model specification are shown in Table 7.2. The VIFs reveal some multicollinearity problem. Specifically, underground parking, surface to volume ratio, and predicted probability of owning large unit and car are close to the borderline of severe multicollinearity (e.g. rule of 10). For example, the correlation matrix shows that underground parking is highly correlated with predicted probabilities of owning cars (obviously), and several form-variables (e.g. height irregularity, function mix, and continuity) due to its correlation with the superblock neighborhood type and the limited variation within the type. However, as the variances of the parameters are not too large in this model (most of the parameters are significant), multicollinearity does not seem to be problematic. [25]

Given the predicted lifestyle bundle choice, the variable of number of employed household members is positive for two or more people employed in the household, probably due to the increased travel energy resulting from need for commuting. Renters consume less energy even with same unit size and vehicle ownership, probably due to less ownership and use of home appliances due to the temporary nature of the residence. Underground parking shows a negative sign, supporting the hypothesis that given car ownership, more designated underground parking is associated with less driving. Surface parking shows a positive and significant sign, supporting the hypothesis that surface parking promotes more driving, and reduces walking and biking. Building function mix exhibits a positive association with energy use, holding lifestyle bundle choice constant; this result defies an immediately plausible explanation, but may be due to association with other unobserved neighborhood attributes. A larger building footprint corresponds to larger size buildings, which translates into a less pedestrian-friendly and more car-oriented neighborhood environment, therefore more energy consumption. The continuity of building facades along roads and building height irregularity (standard deviation of building heights) are significantly associated with less energy consumption, as expected, probably due to their contribution to a more pedestrian friendly environment and, thus, less travel energy use.

The above coefficient estimates are based on a given (predicted) bundle choice, but the total influence of household and neighborhood factors on energy consumption must also consider those factors relationships with lifestyle bundle choice as well. That is, two pathways of potential effects exist: a variable's direct effects on household energy use; and/or a variable's indirect effects, via the effect on bundle choice and bundle choice's relationship with energy use. To understand these combined effects, I carry out simulations on all sample households, simulating bundle choice changes and subsequent energy use changes (following the approach outlined in Chapter 3, Section 3.2.3) and generate average curves representing estimated changes in total energy use corresponding with estimated changes in the variable of interest (Figure 7.10, Figure 7.11, Figure 7.12, Figure 7.13, Figure 7.14, Figure 7.15).

[24] Various forms include: household income, ln(household income), (household income)^2, etc., and none of them shows significant effect at the 5% level.

[25] O'Brien (2007) shows that large values of VIF do not by themselves discount the results of the regression analysis.

The simulation shows household's total direct energy consumption increases with income level with decreasing slope due to the change in lifestyle bundle towards larger housing and more motor vehicles through both class membership and bundle choice (Figure 7.10).

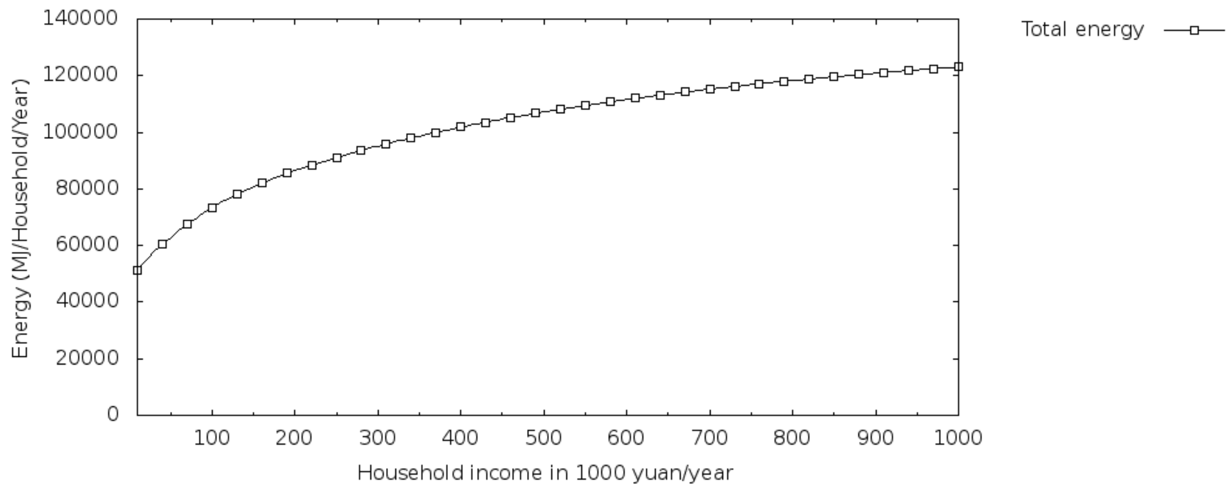


Figure 7.10 Household Total Direct Energy Use: Simulated Variations by Household Income

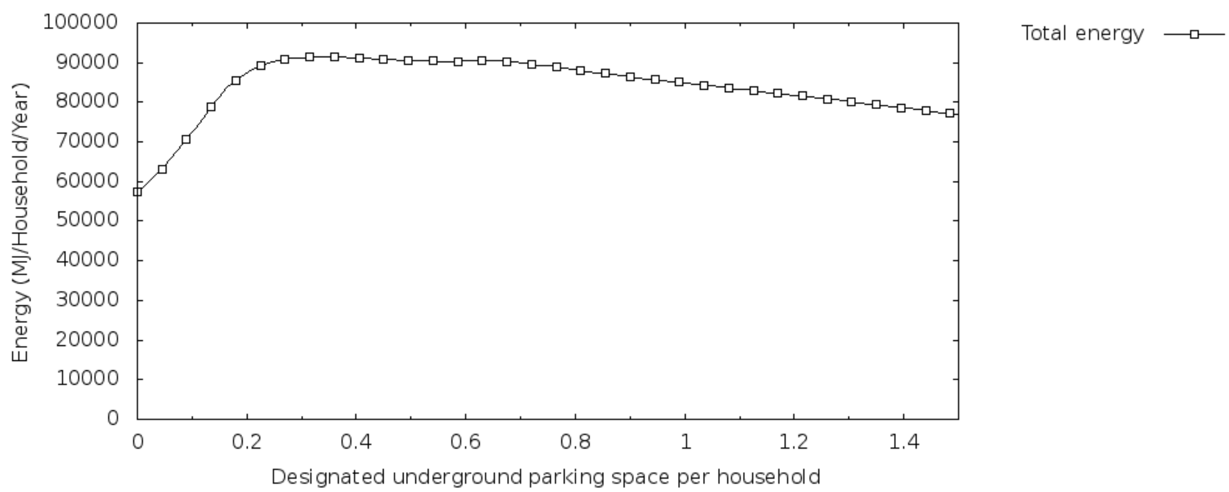


Figure 7.11 Household Total Direct Energy Use: Simulated Variations by Underground Parking

The simulated effect of underground parking has two directions (Figure 7.11). As discussed in the bundle choice model in Chapter 6, more underground parking space per household in the neighborhood is associated with higher probability of one household belonging to the "amenity-oriented" lifestyle group, and more underground parking increases the probability of car ownership and a larger housing unit, but the effect flattens beyond 0.2 parking spaces per household, reflecting a discrete effect. As long as the neighborhood has underground parking, the effect of reducing usage dominates and total energy use decreases with more underground parking, possibly because people park more and drive less due to the inconvenience of retrieving the vehicle, or because "amenity-oriented" people have less in-home time.

More surface parking is associated with more direct energy consumption (Figure 7.12), resulting from a more "typical urban" lifestyle orientation in ownership and more usage, as surface parking makes pedestrians and bicyclists less comfortable and/or car use more convenient therefore potentially increasing travel energy use.

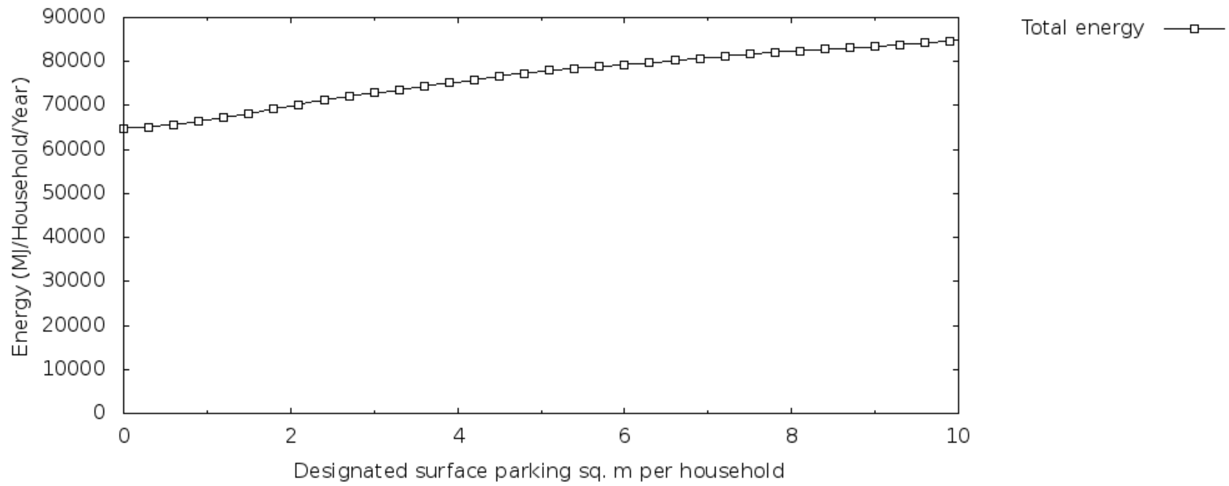


Figure 7.12 Household Total Direct Energy Use: Simulated Variations by Surface Parking

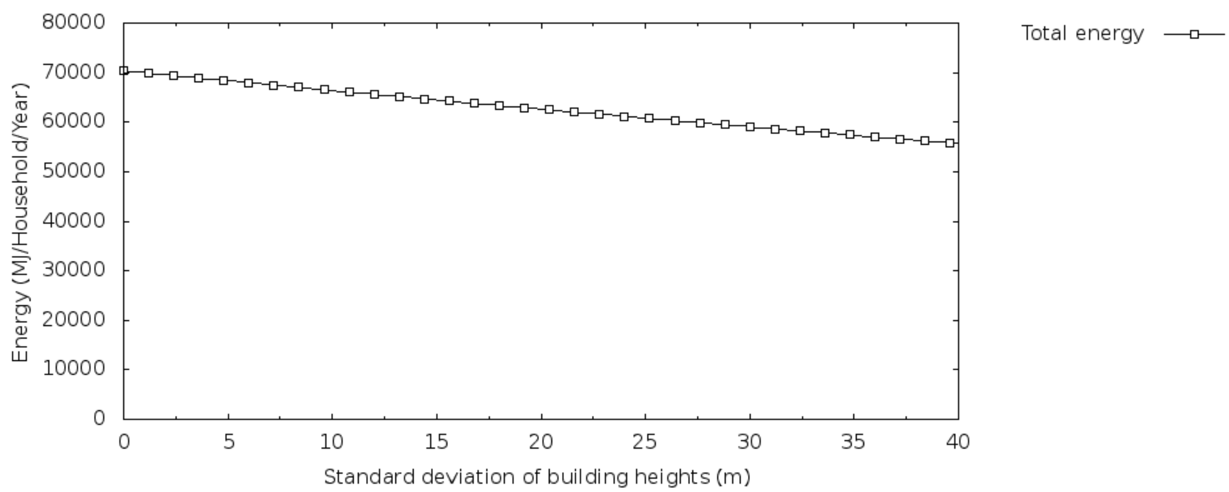


Figure 7.13 Household Total Direct Energy Use: Simulated Variations by Building Height Irregularity

More variety in building heights is associated with less energy consumption and the relationship is quite linear (Figure 7.13) due to the solar and wind benefits which result in less demand in heating and cooling.

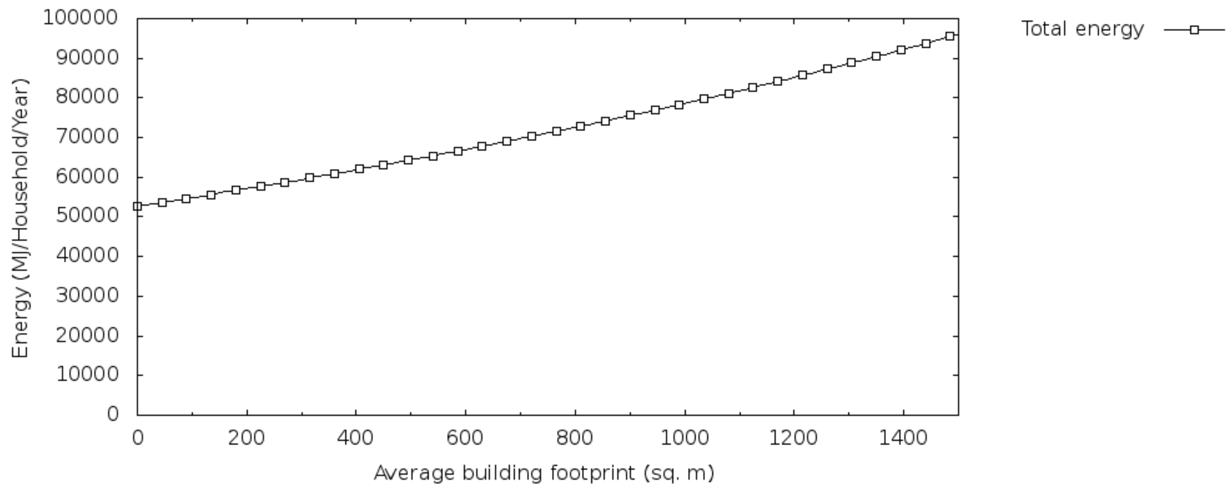


Figure 7.14 Household Total Direct Energy Use: Simulated Variations by Average Building Footprint

Larger average building footprint and less continuity in the street façade are associated with more direct energy consumption by household (Figure 7.14 and Figure 7.15), probably because larger buildings and less continuous street façade are associated with a less pedestrian-friendly environment, therefore more car dependency, and probably more in-home time.

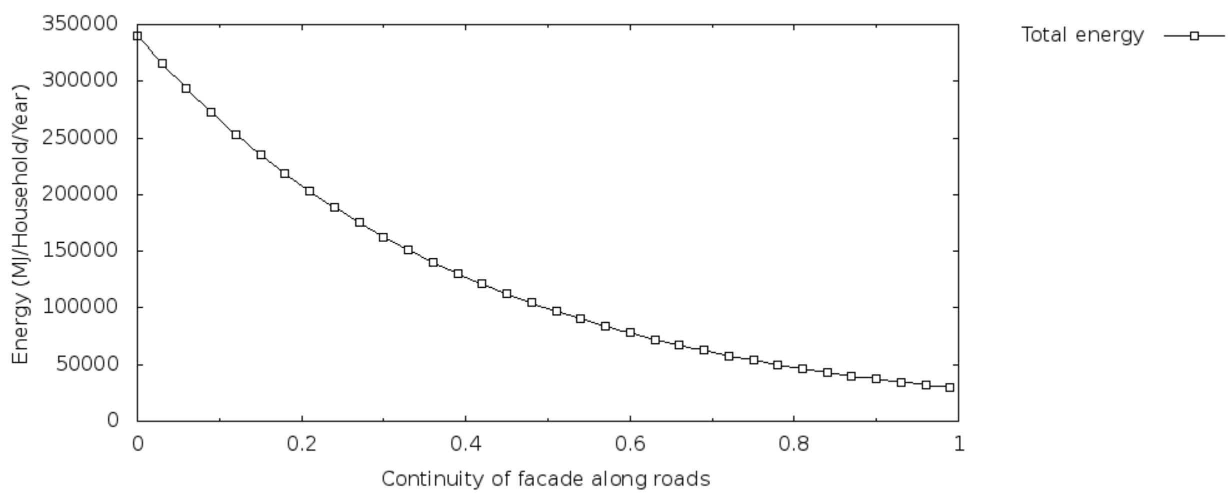


Figure 7.15 Household Total Direct Energy Use: Simulated Variations by Façade Continuity

7.2.2 SEM with lifestyle bundle choice as IV's

As elaborated in Chapter 3 and discussed in section 7.1.1, travel energy and in-home energy might be interdependent and their error terms might be correlated as well. Therefore in order to explore how factors influence each of the two, I specify and estimate a structural equations model (SEM; see Chapter 3), again, using the fitted probabilities of bundle choice as IVs (the model structure shown in Figure 7.2). There are two endogenous variables, travel energy consumption and in-home energy consumption with structural equations specified as below. So, this is a SEM without measurement equations, or path analysis.

$$E_i^{inhouse} = \beta_1^{inhouse} X_i^{inhouse} + \beta_2^{inhouse} IV_i^{inhouse} + \beta_3^{inhouse} N_i^{inhouse} + \beta_4^{inhouse} E_i^{travel} + \varepsilon_i^{inhouse}$$

$$E_i^{travel} = \beta_1^{travel} X_i^{travel} + \beta_2^{travel} IV_i^{travel} + \beta_3^{travel} N_i^{travel} + \beta_4^{travel} E_i^{inhouse} + \varepsilon_i^{travel}$$

The SEM estimation result shows that neither $\beta_4^{inhouse}$ and β_4^{travel} is significantly different from zero, and $\varepsilon_i^{inhouse}$ and ε_i^{travel} are not correlated. It seems that either the lifestyle bundle model has already captured the lifestyle orientation households exhibit towards energy consumption, or, the lifestyle effect at the energy usage stage cancels out the substitution effects between travel and in-home energy use. The current model structure is not able to test which is the case, but the SEM structure can remove the hypothetical causal links between the two endogenous variables. The final estimation result is shown in Table 7.3. Estimations for covariance between the explanatory variables, and standardized regression coefficients are shown in the Appendix A7 Table A.7, and Table A.6, respectively.

Similar to the OLS model, household income (tested in various ways) does not show any significant association with either in-home or travel energy use. Again, this suggests that the income effect is already captured in the lifestyle bundle choice (the ownership component).

All bundle choice IVs are significant with expected positive signs. Interestingly, the probability of owning a small housing unit and cars has a larger effect on both travel and in-home energy, compared to other bundle choices. This might be the case as a household with small housing size but cars might represent the most “amenity-oriented” lifestyle in energy using behavior while the other variables driving up energy demand such as household demographics are controlled for. Intuitively, bundles with cars have larger coefficients for travel energy consumption while, with the exception of the aforementioned small unit with cars case, the bundles with larger housing unit size have larger coefficients for in-home energy consumption.

Similar to the OLS model, the estimated coefficients for household characteristics show expected effects. The number of household members currently employed is not significant in the in-home energy model, but significantly increases travel energy. Having children in the household increases both travel and in-home energy consumption. Expectedly, older adults in the household decrease travel energy use, but increase in-home energy use. Furthermore, if the household is headed by an older adult, travel energy consumption further decreases. Renting decreases in-home energy use but not travel energy, holding the ownership bundle (and thus, vehicle portfolio) constant (remember renting does decrease car ownership in the bundle choice model thus would indirectly decrease household travel energy use). Attitudes on travel modes influence travel, but not in-home, energy use.

Neighborhood design variables also show a significant causal link to both forms of household energy consumption. Similar to the OLS model, average building footprint and continuity show large effects on both energy uses, probably due to less pedestrian friendly environment which is associated with car dependency, less outdoor activities, and possibly more in-home time. FAR, building function mix, and percentage of street-level shops show effects on travel energy consumption only.

Table 7.3 Model Summary and Regression Coefficient Estimations of SEM

Variables	ln(Travel Energy)			ln(In-home Energy)		
	Coef.	z		Coef.	z	
Intercept	7.506	10.83	***	12.400	18.77	***
Predicted lifestyle bundle choice						
P(small unit with car)	15.235	5.64	***	2.977	3.51	***
P(medium unit without car)	2.011	4.52	***	0.617	4.17	***
P(medium unit with car)	4.803	9.34	***	0.784	4.89	***
P(large unit without car)	1.458	1.75	*	1.519	5.66	***
P(large unit with car)	4.818	8.55	***	1.082	6.22	***
Household demographics						
single	-0.738	-3.32	***	-0.372	-5.28	***
couple	-0.255	-1.64	*			
no_employ	-2.151	-10.27	***			
twoplus_employ	0.311	2.28	**			
have_kid	0.302	2.59	***	0.095	2.81	***
have_old	-0.447	-3.31	***	0.160	4.36	***
senior_hh	-0.577	-2.37	**			
Housing Tenure						
renting				-0.328	-6.58	***
Travel Attitudes						
a1_drive_prestige	-0.085	-2.11	**			
a2_bus_convenient	-0.066	-1.64	*			
a4_travel_time_waste	0.093	2.33	**			
Neighborhood Design Indicators						
far	-0.283	-1.71	*			
function_mix	1.327	3.38	***			
footprint	0.001	3.47	***	0.0005	4.41	***
continuity	-4.714	-5.23	***	-1.885	-5.54	***
street_level_shop	-1.241	-2.64	***			
Solar/Wind Indices						
surface_to_volume				0.437	2.90	***
building_wind_summer				-1.911	-2.27	**

N = 3,955; Number of parameters = 196; Chi-square = 1918.837; degree of freedom = 154;
NFI[a] = 0.955; RFI[b] = 0.912; TLI[c] = 0.918; CFI[d] = 0.958; RMSEA[e] = 0.054; AIC[f] = 2310.837

[a] Normed fit index (Bentler & Bonett, 1980)
[b] Relative fit index (Bollen, 1986)
[c] Tucker-Lewis coefficient (Bollen, 1989) , also known as the Bentler-Bonett non-normed fit index (NNFI)
[d] Comparative fit index (Bentler, 1990)
[e] Root mean square error of approximation, called RMS (Steiger and Lind) or RMSEA (Browne and Cudeck,1993)
[f] Akaike information criterion (Akaike, 1973; Akaike, 1987)

As many of these variables also influence lifestyle bundle choice, to get a sense of the direction and magnitude of the total effect of each variable on energy consumption, I calculate aggregate elasticities (by sample enumeration, for the detailed calculation procedure please refer to the method section in Chapter 3) of in-home energy consumption, travel energy consumption, and total direct energy consumption with respect to household income and neighborhood design variables. These elasticities reflect the full, cascading, effects of the variable of interest on energy use, due to effects (if any) on bundle choice, and the effects on energy use, including due to changes in bundle choice. The elasticity results are shown in Table 7.4. Elasticities for dummy variables cannot be calculated in this fashion, so separately I present the estimated effects of a household switching from one category to the other. These values cannot be directly compared to the elasticities. The effect of dummy variables (e.g. have_kid, have_old, comcar, and renting) is calculated by the percentage energy consumption change due to the dummy variable change from 0 to 1, shown in Table 7.5.

The income elasticity of energy consumption seems to be quite small, due to its lack of significance in the usage model. This could be the case in China when income difference is relatively large but the variation in energy consuming behaviors is relatively small (i.e. given the same bundle ownership, rich households do not use more home appliances or travel more than the poorer households) so we do not observe a huge income effect. Also, some of the possible variation in the energy consuming behaviors is captured by neighborhood indicators.

Table 7.4 Elasticity of Energy Consumption

Variable	E (In-home)	E(Travel)	E(Total Energy)
Household Income	0.038	0.168	0.042
Provision of Designated Surface Parking (m^2/hh)	0.046	0.214	0.051
Provision of Designated Underground Parking (space/hh)	0.004	0.002	0.003
F.A.R.	0	-1.027	-0.048
Average Building Footprint (m^2)	0.483	1.326	0.529
Continuity of Street façade	-2.531	-6.206	-2.684
Average Distance between Neighborhood Entries (m^2)	-0.045	-0.213	-0.050
Building Function Mix	0	0.591	0.019
Surface-to-volume Ratio	0.354	0	0.342
Building Wind Index (summer)	-2.750	0	-2.627
Regional Accessibility (Public Space)	-0.018	-0.071	-0.019
Regional Accessibility (Shopping)	0.011	0.036	0.011
Regional Accessibility (Office)	-0.008	-0.084	-0.010
Percentage of Roads with Trees	0	0.037	0.001
Percentage of Roads with Street-level Shops	0.070	0.150	0.071
Percentage of Roads with Walking Facilities	-0.093	-0.470	-0.103

Given the small share of travel energy in a household's total energy use compared to in-home energy, variables influencing in-home energy tend to have elasticities larger in magnitude on total energy, e.g. the index for building_wind_summer. As expected from the model estimation results, two neighborhood design variables stand out: a household's predicted total energy use will decrease by 2.7% with a 1% increase in a neighborhood's continuity index and total household energy use will increase 0.5% if the neighborhood's average building footprint increases 1%. FAR also has an elasticity larger than 1 for travel energy consumption. These three variables have much larger effects on travel than the effects of form-based variables in other studies (as reviewed in Ewing and Cervero, 2010).[26] Several explanations for the differences exist. First, it may be due to a difference in context and levels of urban development and behavioral differences in China versus the western countries. In addition, it may be due to accounting for combined effects here (ownership and use) as well as the lifestyle group changes (simulated through the LCM bundle choice). The modeling approach may also produce different magnitudes of inter-related effects. It may also be due to the difference in approach to elasticity calculation (see footnote 26) and/or the particular variables used in this analysis. Finally, it could be related to the type or quality of data used for model estimation. Footprint and continuity have not been used in any of the studies Ewing and Cervero reviewed.

Interestingly, the effects of regional accessibility indicators found in this research are modest relative to findings from empirical studies in developed countries. Again, this may be due in part to the difference in context. Compared to metropolitan areas in the developed countries, Chinese cities are denser across a much wider expanse, implying a more evenly distributed regional accessibility across different parts of the city. Furthermore, as the accessibility to destinations of daily activities is less important as a reason for vehicle purchase or residential choice, the mechanism through which regional accessibility influences travel energy consumption works with less strength in the China context.

Table 7.5 Simulated Effects of Dummy Variables on Household Energy Consumption

Variable	Percentage change in In-home Energy	Percentage change in Travel Energy	Percentage change in Total Direct Energy
have_kid	10.784	41.298	11.888
have_old	17.376	-36.071	14.760
comcar	2.781	11.014	2.966
renting	-32.892	-16.465	-31.905

In terms of changes in the categorical variables, all else equal, having children in the family will increase the household total energy consumption by 11.9%, by increasing both in-home and travel energy demand. Interestingly, the presence of older adults in the family increases energy use even more, by 14.8%, due to a 17.4% rise in in-home energy use and despite a 36.1% reduction in travel energy use. Whether the household is renting shows the largest effect among all categorical variables: a renting household has 32% lower total direct energy consumption compared to homeowners, with reductions in both in-home and travel energy. Households with access to a company car on average consume 3% more energy than those without, all else equal (Table 7.5).

As the elasticity varies at different values of an explanatory variable, simulations that incorporate bundle choice model results are needed to understand the total effects of these

[26] Ewing and Cervero (2010) calculate the elasticity at the means instead of the aggregated elasticity averaged over the sample—which may make a big difference as the "mean" condition of the built environment can vary a lot in different contexts.

variables on household total energy consumption along a range of values (see Figure 7.16, Figure 7.17, Figure 7.18, Figure 7.19, Figure 7.20, Figure 7.21, Figure 7.22, Figure 7.23, Figure 7.24, Figure 7.25, Figure 7.26, Figure 7.28, Figure 7.29, Figure 7.27).

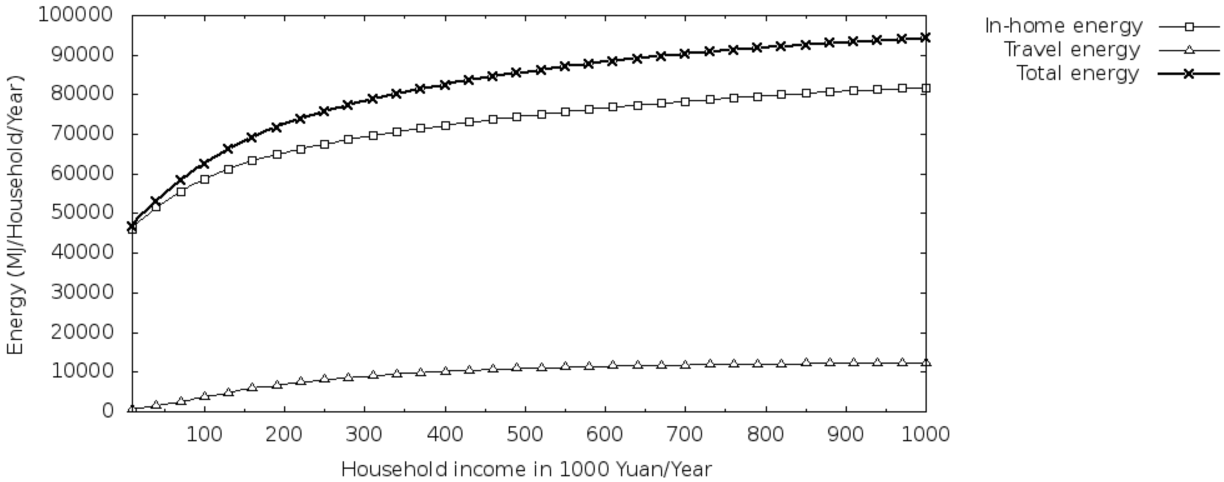


Figure 7.16 Household Direct Energy Consumption: Simulated Variations by Household Income

The effect of household income on energy use is similar to the result from the OLS model—increasing with a flattening slope (Figure 7.16), due to the higher tendency to be in the "amenity-oriented" group with bundle ownership of larger housing unit and more cars.

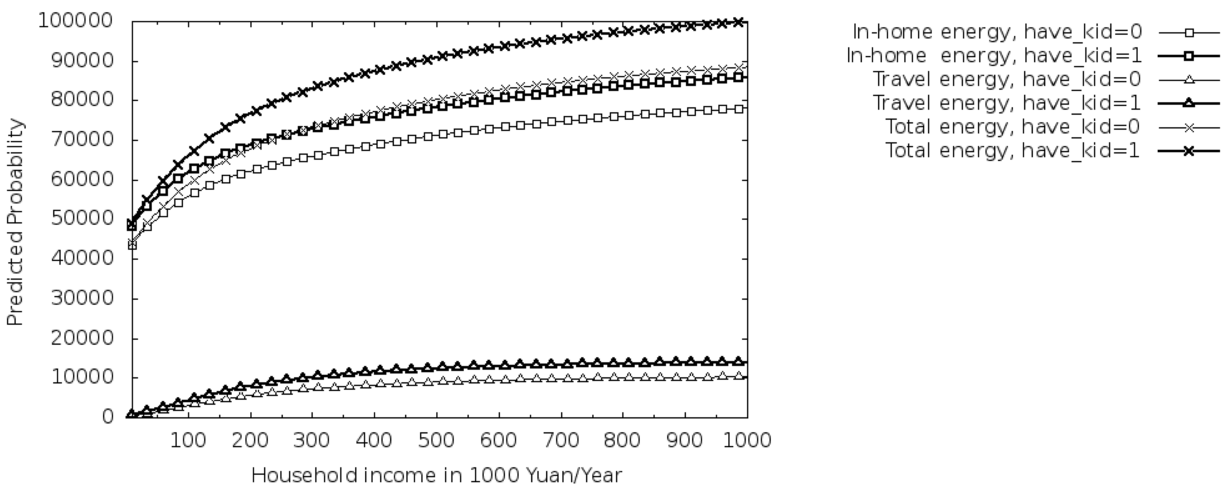


Figure 7.17 Household Direct Energy Consumption: Simulated Variations due to Household Income, With Kids or Not

Having a kid in the family increases both travel energy use and in-home energy use therefore higher total direct energy (Figure 7.17). In comparison, having older adults in the family reduces travel energy but increase in-home energy by a greater magnitude, probably due to more in-home time and activity of senior people. The total effect is more total direct energy use by the household (Figure 7.18).

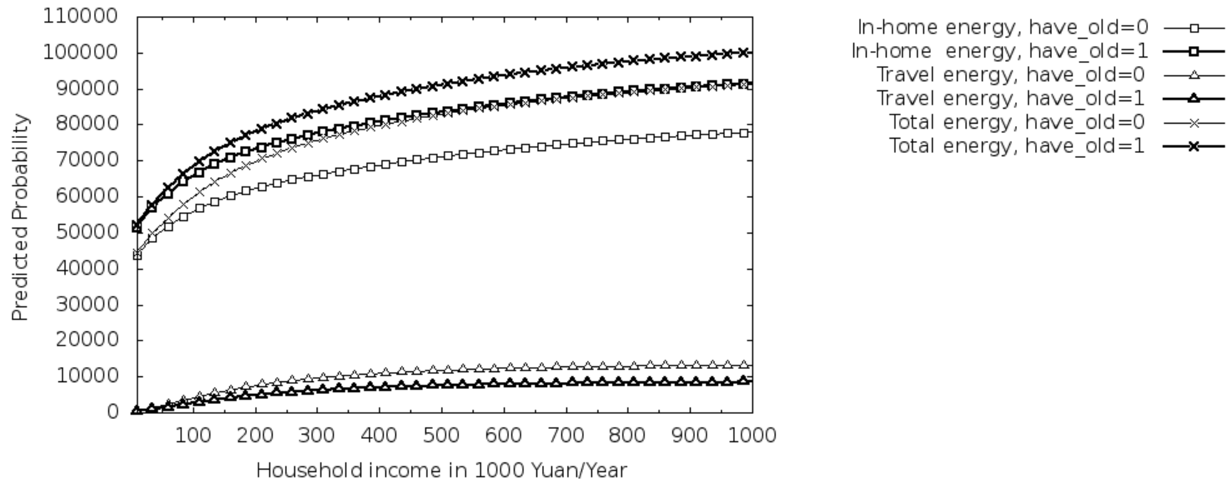


Figure 7.18 Household Energy Consumption:
Simulated Variations due to Household Income, With Seniors or Not

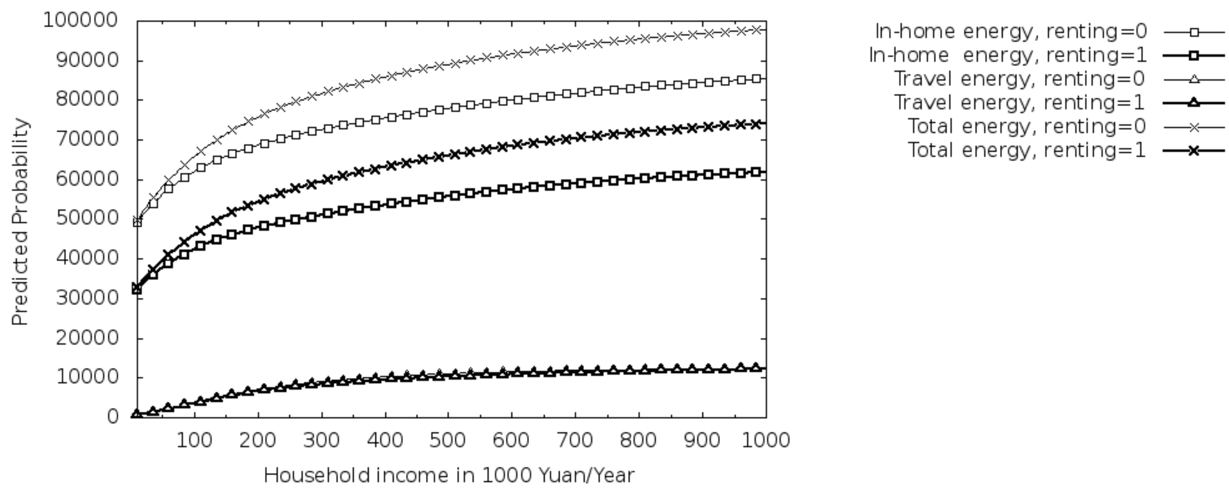


Figure 7.19 Household Direct Energy Consumption:
Simulated Variations due to Household Income, Renting or Not

Renters consume slightly less travel energy, but considerably less in-home energy due to larger tendency to be "budget-oriented," occupying smaller housing units with fewer motor vehicles, and probably using fewer appliances with much less in-home time because the temporary nature of their residence (Figure 7.19).

A household having access to a business/company car consumes slightly more total energy than those who do not, mainly due to the tendency to belong to the "typical urban" and "amenity-oriented" group with larger housing unit and more motor vehicles (Figure 7.20).

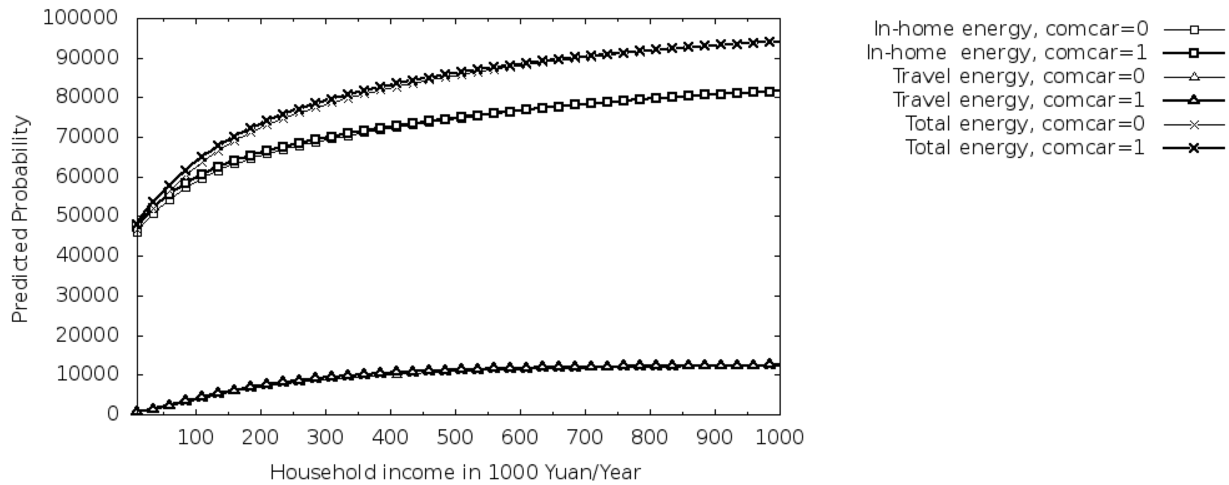


Figure 7.20 Household Direct Energy Consumption: Simulated Variations due to Household Income, Access to Company Car

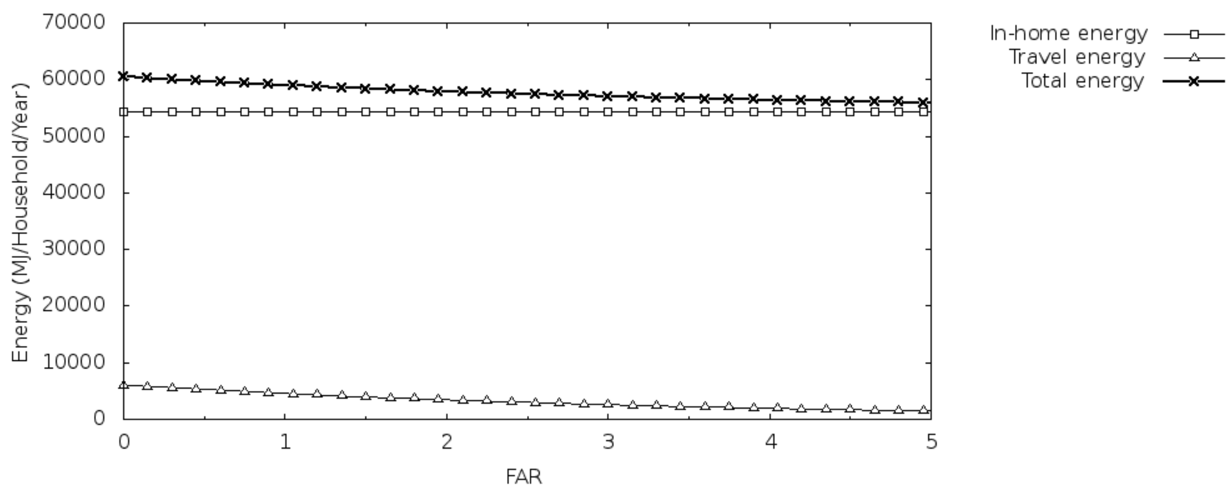


Figure 7.21 Household Direct Energy Consumption: Simulated Variations by FAR

Figure 7.21 shows the effect of residential density measured by FAR on energy consumption. A denser neighborhood is associated with less travel energy use, as higher density is more pedestrian and transit friendly.

Underground parking provision, unlike in the OLS model, shows only one direction that increases energy consumption in the SEM (Figure 7.22), due to a higher likelihood to be in the "amenity-oriented" lifestyle group with larger housing unit and more cars; it is not significant in the usage model.

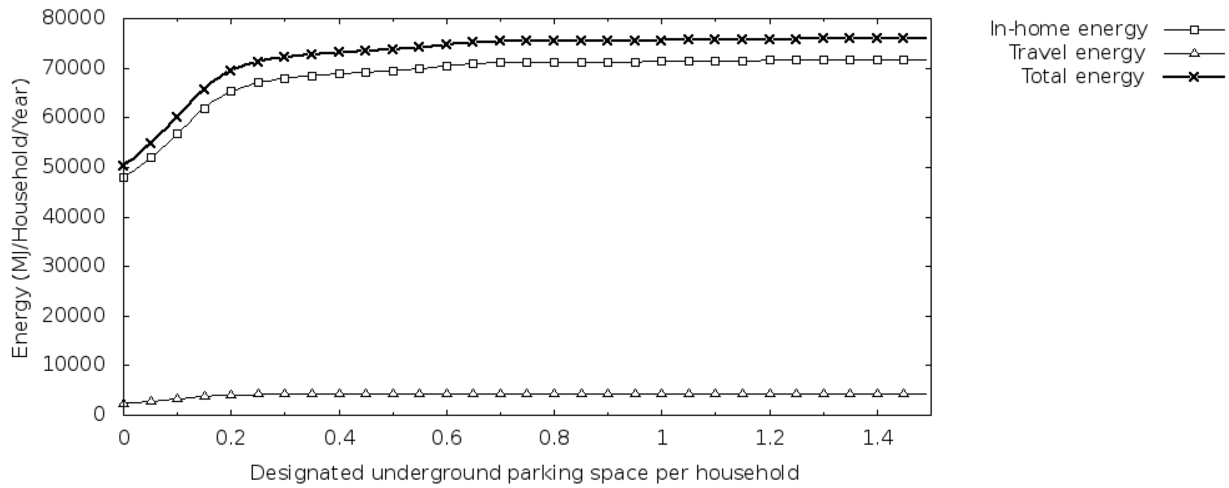


Figure 7.22 Household Direct Energy Consumption: Simulated Variations by Underground Parking

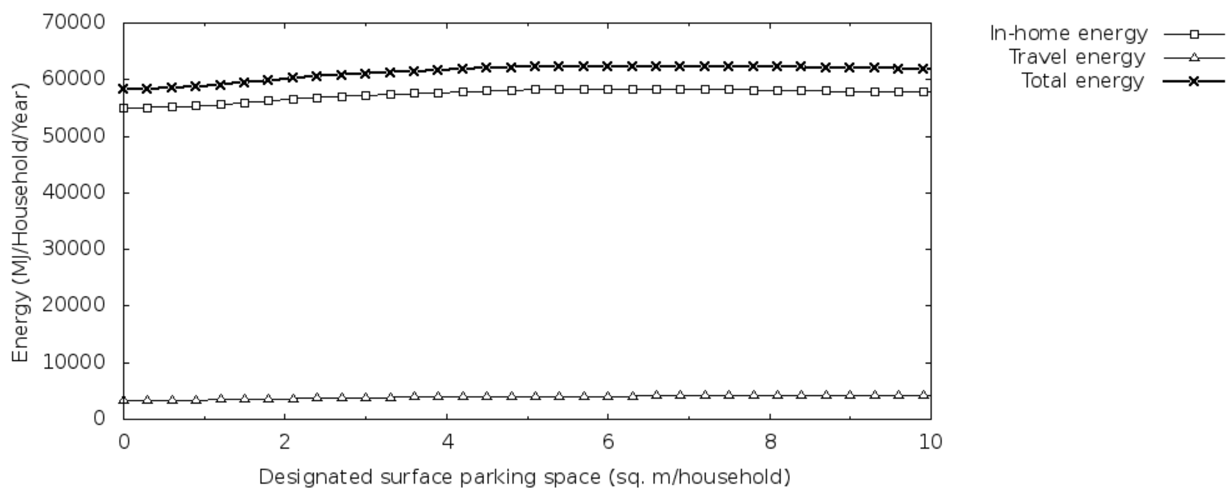


Figure 7.23 Household Direct Energy Consumption: Simulated Variations by Surface Parking

More surface parking provision, on the other hand, increases energy use at low level, but decreases total energy use at higher level, due to its association with the "typical urban" lifestyle group (Figure 7.23).

Larger building footprint and less continuous street façade are associated with more "amenity-oriented" lifestyle group with larger units and more cars, as well as more energy usage behaviors both for travel and in-home (Figure 7.24 and Figure 7.25). As discussed earlier, this might be related to more car dependency, more "amenity-oriented" energy using behaviors, and more time spent in-home.

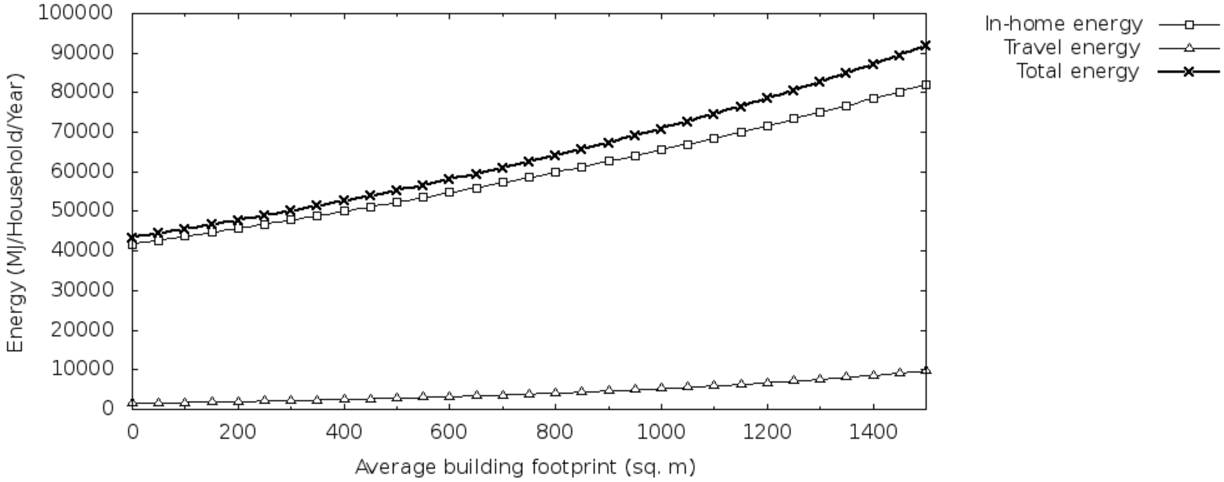


Figure 7.24 Household Direct Energy Consumption: Simulated Variations by Building Footprint

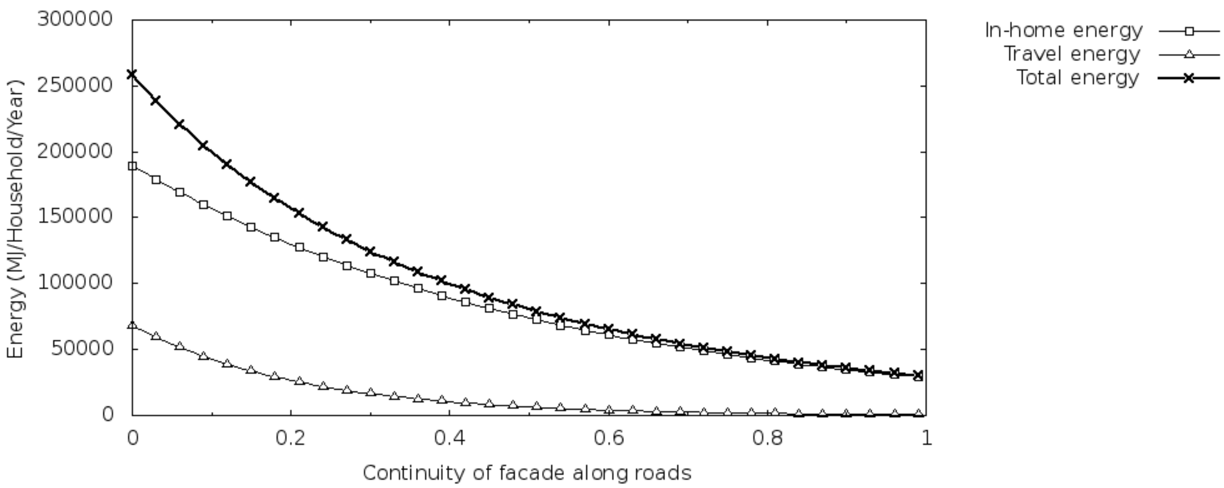


Figure 7.25 Household Direct Energy Consumption: Simulated Variations by Façade Continuity

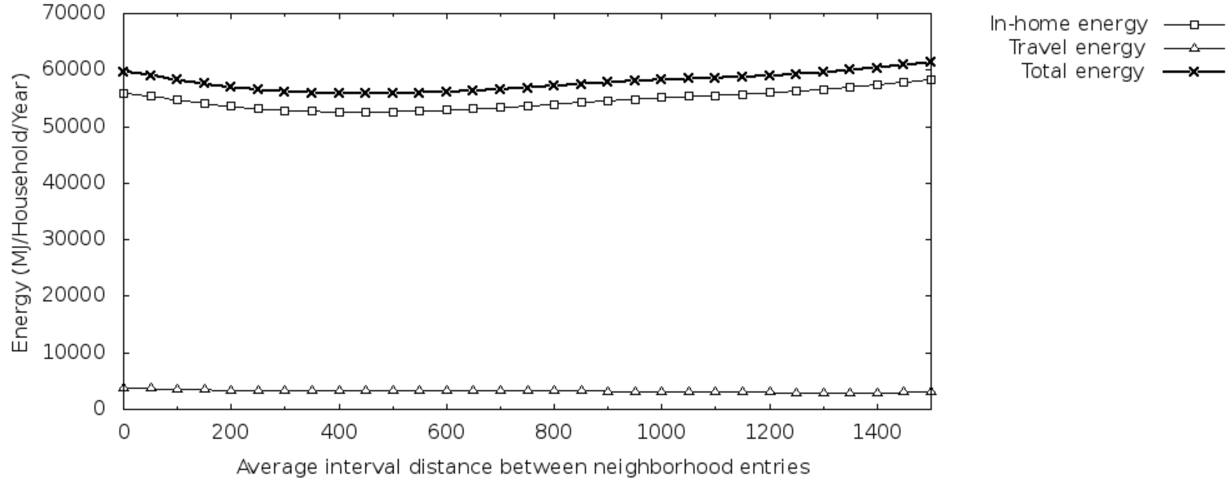


Figure 7.26 Household Direct Energy Consumption:
Simulated Variations by Entry Interval Distance

The effect of average distance between neighborhood entries apparently has an "optimal" point (around 400 m) where the total energy consumption is the lowest (Figure 7.26). The further away the neighborhood entries are, the more "closed" or "gated" the neighborhood is, which is associated with larger tendency to be "amenity-oriented", while the "typical urban" do not like the associated inconvenience (see Chapter 6 for the resulted bundle choice).

Similarly, the percentage of road with walking facilities has an optimal point at around 0.6 (Figure 7.27). More walking facilities in the neighborhood attract both the "amenity-oriented" lifestyle (as it is a neighborhood amenity with better facility quality and aesthetic value) and the "budget-oriented" people as they do not own cars so they value the pedestrian environment more (see Chapter 6 for the resulted bundle choice).

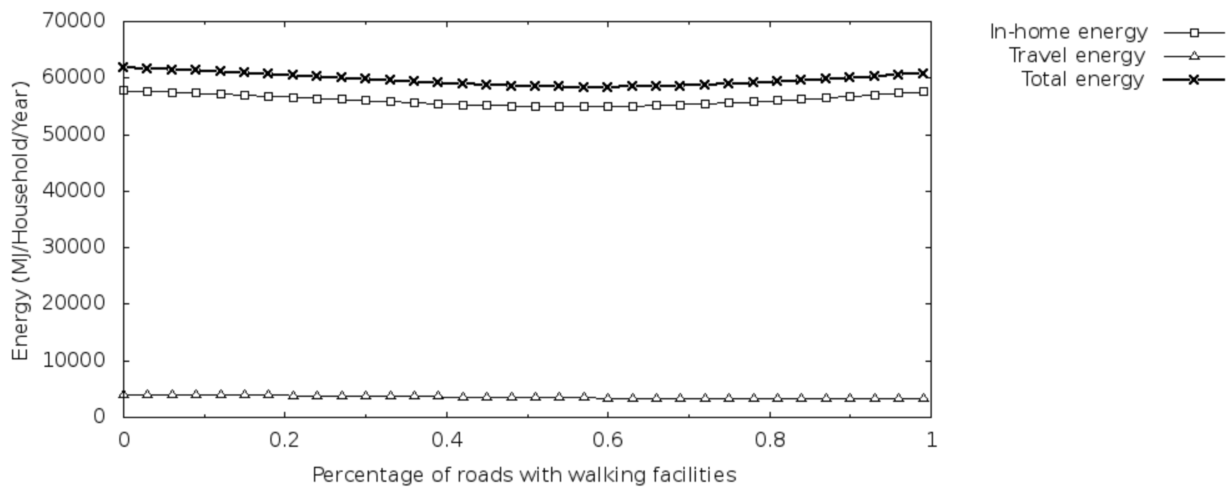


Figure 7.27 Household Direct Energy Consumption:
Simulated Variations by Percentage of Roads with Walking Facilities

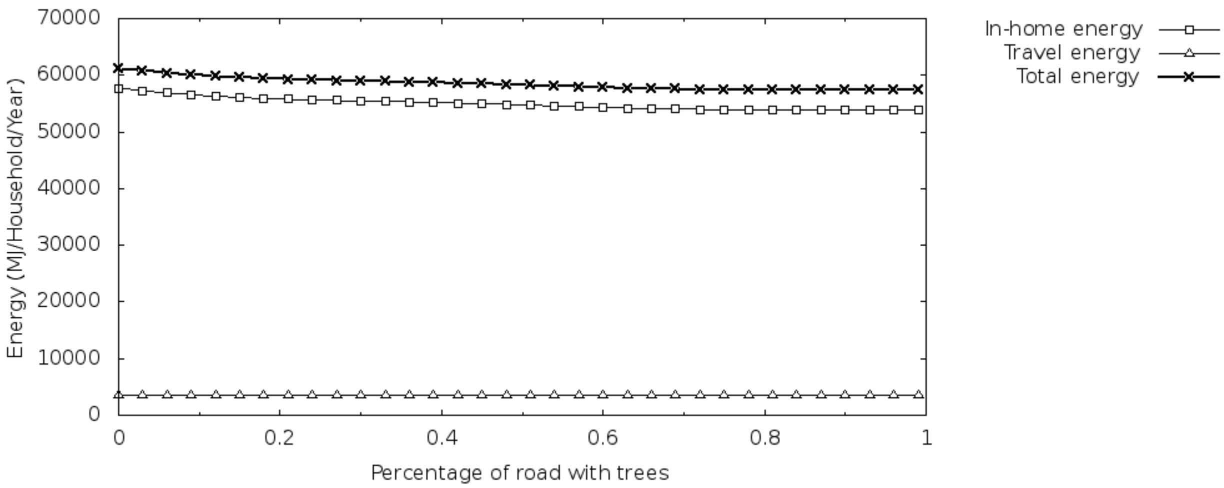


Figure 7.28 Household Direct Energy Consumption:
Simulated Variations by Percentage of Road with Trees

More roads with trees are associated with less in-home energy consumption, due to the class membership effect of being more "budget-oriented" (Figure 7.28).

The effect of street-level shops in residential buildings in the neighborhood is negative for travel energy but positive for in-home energy, through both the ownership and usage components (Figure 7.29). While "typical urban" lifestyle likes street-level shops with more medium size housing unit (see Chapter 6 for bundle choice results), more street-level shops helps reduce the need for vehicle travel.

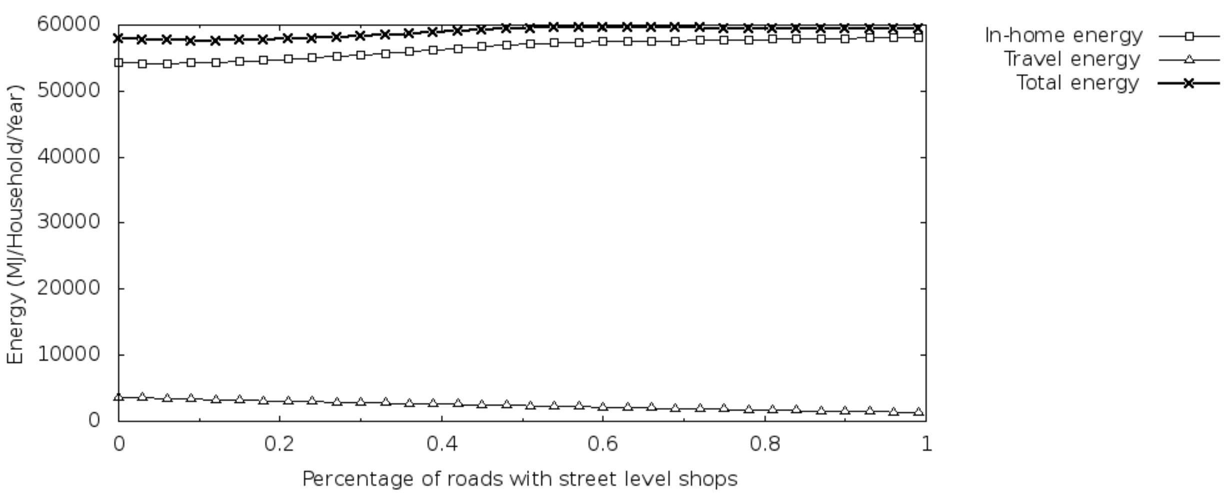


Figure 7.29 Household Direct Energy Consumption:
Simulated Variations by Percentage of Roads with Street-level Shops

Note that, similar to the approach in Chapter 6 (bundle choice), all simulations use individual household characteristics to then generate the average curves presented in the Figures. To get a sense of the distribution of the estimated energy consumption for all households in the sample, I generate the candle-stick graph (e.g. Figure 7.30 and Figure 7.31) via simulation. Similar to a boxplot, the thin rectangle in the middle shows the 25th to 75th percentile range of predicted energy while the thinner line extensions show the maximum and minimum estimates. Median and mean curves are also shown (all previous simulation graphs only plot the mean curves). The variation of predicted energy consumptions is quite large among households. For example, Figure 7.30 shows the simulated travel energy consumption by income for all sample households, and the size of variance increases with simulated income level. The size of variation in in-home energy consumption, in contrast, is somewhat consistent across income levels (Figure 7.31).

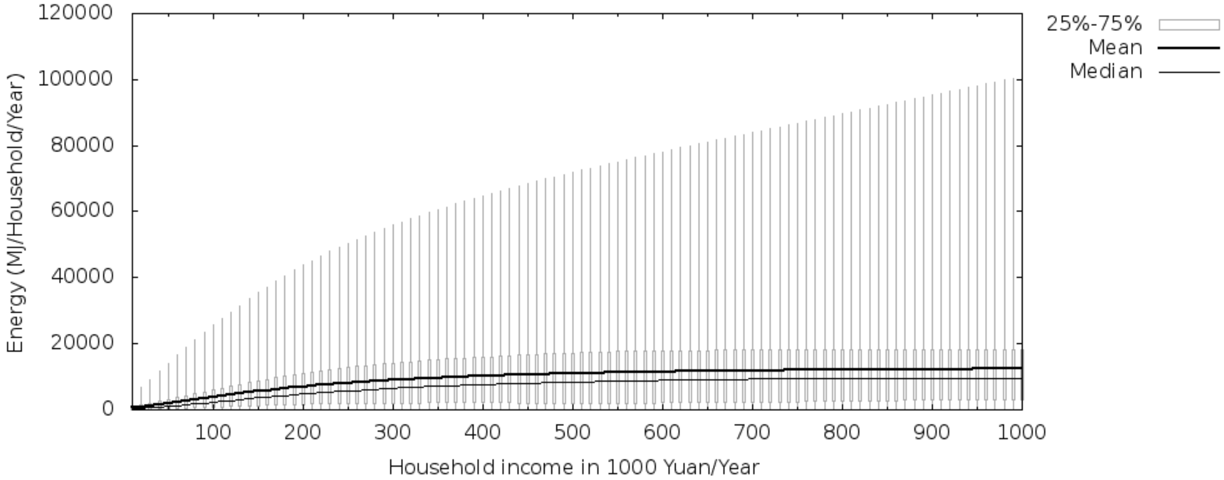


Figure 7.30 Household Travel Energy Consumption: Simulated Variations by Household Income (Candle Stick Graph)

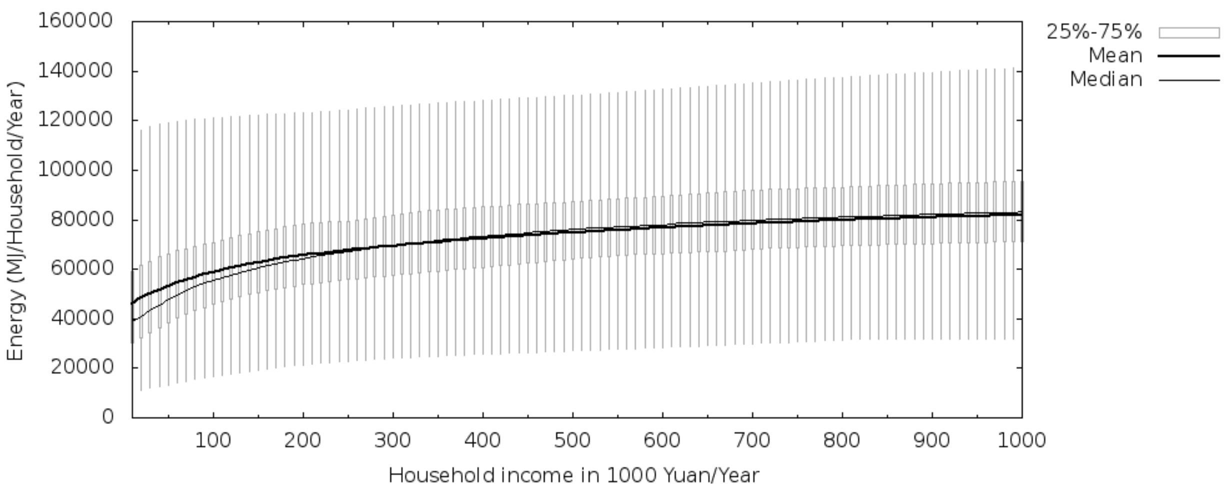


Figure 7.31 Household In-home Energy Consumption: Simulated Variations by Household Income (Candle Stick Graph)

7.3 Conclusion

Empirical results of household energy use, estimated using OLS and SEM with bundle choice probabilities as instrumental variables, support the hypothesis that household direct energy consumption is influenced by neighborhood design. Specifically, higher FAR, fewer designated parking spaces (including underground parking and surface parking), smaller size of buildings (smaller building footprint), more continuity of street façades, more roads with trees, smaller distances between neighborhood entries (optimal around 400m from the simulation Figure 7.26), and a higher percentage of roads with walking facilities (optimal around 0.6 from the simulation Figure 7.27) are associated with lower direct energy consumption by households. The implications and shortcomings of these estimates will be discussed in the following Chapter.

Chapter 8 Policy Implication and Conclusion

8.1 Summary of Findings

There are three main points to take away from this research: (1) household's residential and vehicle ownership choice is made as a bundle reflecting the chosen lifestyle; (2) households belonging to different lifestyle groups have different decision-making mechanisms; and (3) neighborhood design influences household's lifestyle and behavior regarding direct energy consumption.

Theoretically, a household's housing purchase decision and vehicle ownership decision are linked together in three ways: (a) under the household's resource constraint; (b) through interdependent decisions about accessibility and parking considerations; and (c) via the simultaneous influence of the household's attitudes, perceptions, preferences, and values. This suggests that understanding the factors influencing household energy use requires considering residential and vehicle ownership choice together, as a lifestyle bundle choice, which then conditions both travel and in-home energy consuming behavior.

Through interviews with households in Jinan, I identified four lifestyle groups in the city, namely the "job-oriented", "child-oriented", "budget-oriented", and "amenity-oriented," distinguished by behaviors, attitudes, perceptions, and preferences, and most importantly by values. These groups have distinct decision-making mechanisms behind their choices of residence and vehicle ownership, and will likely have different sensitivity or responsiveness to different policies, incentives, or built environments. Quantitative analysis, using a latent class choice model of lifestyle bundle choice, confirmed three groups of households: the budget-oriented, the amenity-oriented, and the typical urban type. This heterogeneity of decision-making mechanisms makes it necessary and useful to classify population into lifestyle groups (or segments) so that certain policies and incentives can be more appropriately designed and targeted.

Neighborhood design influences household direct energy consumption both through the ownership component choice and the usage component. Specifically, the continuity of street façade and average building footprint have the most substantial estimated effect on total energy consumption with an elasticity of -2.68 and 0.53, respectively. This implies that neighborhoods with more continuous façade along street and smaller building footprint size are associated with more energy efficient lifestyle of its residents. Other neighborhood design attributes show a significant relationship with household energy use, but with much smaller effect size. For example, a higher percentage of roads with walking facilities, less provision of underground parking, shorter distances between neighborhood entries, and higher F.A.R. are all associated with lower direct household energy consumption, but with elasticities under 0.1.

These findings have significant policy implications in the Chinese context, as discussed in the following section.

8.2 Towards Energy Efficient Neighborhood Design

8.2.1 Policy Background: Low-carbon City and Urban Planning Process in China

With the nation's unprecedented economic growth for the past few decades, the Chinese government has increasingly realized the importance of sustainability and energy efficiency. In 2005, the 11^{th} five-year plan clearly stated the goal of reducing energy use per GDP by 20%

from 2006 to 2010, the first quantifiable indicator for energy efficiency (NDRC, 2005). In 2007, the Energy Conservation Act was passed, setting up the national legal framework for energy efficiency in several sectors, including the building sector and transportation sector. After reporting the energy saving goal being "almost met" (19.1%) in 2010, the 12th five-year plan gave the ambitious target of cutting energy use per GDP by another 16.1% from 2011 to 2015 (NDRC, 2011). And, for the first time, the consumption side of energy efficiency is emphasized, and "green consumption" is promoted: "Promote civilized, saving, green, and low-carbon consumption styles, and establish the green lifestyle and consumption style suitable to the China condition; Encourage consumers to purchase energy efficient and water conserving products, energy efficient and environmentally friendly cars, energy efficient and land-saving residences; reduce usage of disposable products; limit over packaging, and discourage unreasonable consumption."(NDRC, 2011)

In response to the central government's leadership on and goal setting for energy efficiency, provincial and municipal governments in China have been making their own energy efficiency plans, one after another. The first few low-carbon cities (e.g. in Shanghai and Baoding) were piloted by the World Wildlife Fund (WWF) and MoHURD in 2008. Since President Hu Jintao emphasized developing a green and low-carbon economy at the UN Climate Change Summit in September 2009 (UNDP, 2010), the low-carbon city fervor began, with the financial incentive of $32.8 billion for energy efficiency in China's 2009 economic stimulus package (Li et al., 2012). The 12th five-year plan expects to establish 100 model cities, 200 model counties, 1,000 model districts, and 10,000 model towns under a green and new energy theme to showcase the low-carbon development achievements (Li et al., 2012); 276 Chinese cities have reportedly proposed low-carbon or eco-city goals (Yu, 2011).

Nonetheless, no single clear definition of low-carbon city or eco-city exists in China, partly due to different development scales of these proposed "cities." Furthermore, there is no agreement on a measurement and indicator system to support the planning and design of these presumably energy-efficient and sustainable urban developments, likely due, in part, to a lack of theoretical and empirical studies and fragmented institutional responsibility. For example, China's Ministry of Environmental Protection (MEP) and Ministry of Housing and Urban-Rural Development (MoHURD) developed two sets of standards for eco-cities, while some provinces have also created their own standards and indicators for garden cities, green cities, and other similar concepts (Li et al., 2012). The "green low-carbon town development indicators" issued by the MoHURD and the National Development and Reform Committee (NDRC) include: per 10,000 yuan GDP energy use, existence of a regulatory plan, whether there is a low-carbon development implementation plan, etc. Neighborhood scale form-related indicators include: population density in the built area; building density (the higher the better), green coverage (the lower the better, to prevent "park-style factories"), and road area ratio (the lower the better) of industrial parks (if any); trunk road width (the narrower the better); percentage of green buildings; "reasonable" road network; safe and convenient environment for non-motorized transportation modes (MoHURD & NDRC, 2011). This tentative evaluation system is comprehensive with a clear target of energy efficiency, compact development, and sustainability. Though the theoretical reasoning and support is not provided, the scoring system is a combination of objective measurable indicators and subjective judgments with seemingly carefully designed weights and a series of minimum requirements.

The Caofeidian Eco-city in Hebei Province, one of the largest pilot eco-city developments, has a comprehensive indicator system with 141 indicators (Schylberg & Ying, 2009). Among them are: 2 energy efficiency indicators, i.e. solar water heater ratio and building energy efficiency; 7 transportation system related indicators, namely the continuity of the building facade along the street, the coverage of bus stops with 300m buffer, the coverage of artery bus stops with 500m buffer, public transit mode share, rail transit/BRT stops and Park and Ride parking provision, sectional ratio of non-motorized lane of branch roads, and density of independent pedestrian and bike network; as well as 3 facility and amenity indicators: education, culture and sports facilities in walking distance from residential zones; green coverage, and ratio of green buildings.[27] However, without access to more details on the indicator definition construction process, one cannot easily understand the theory and empirical evidence underlying these particular indicators.

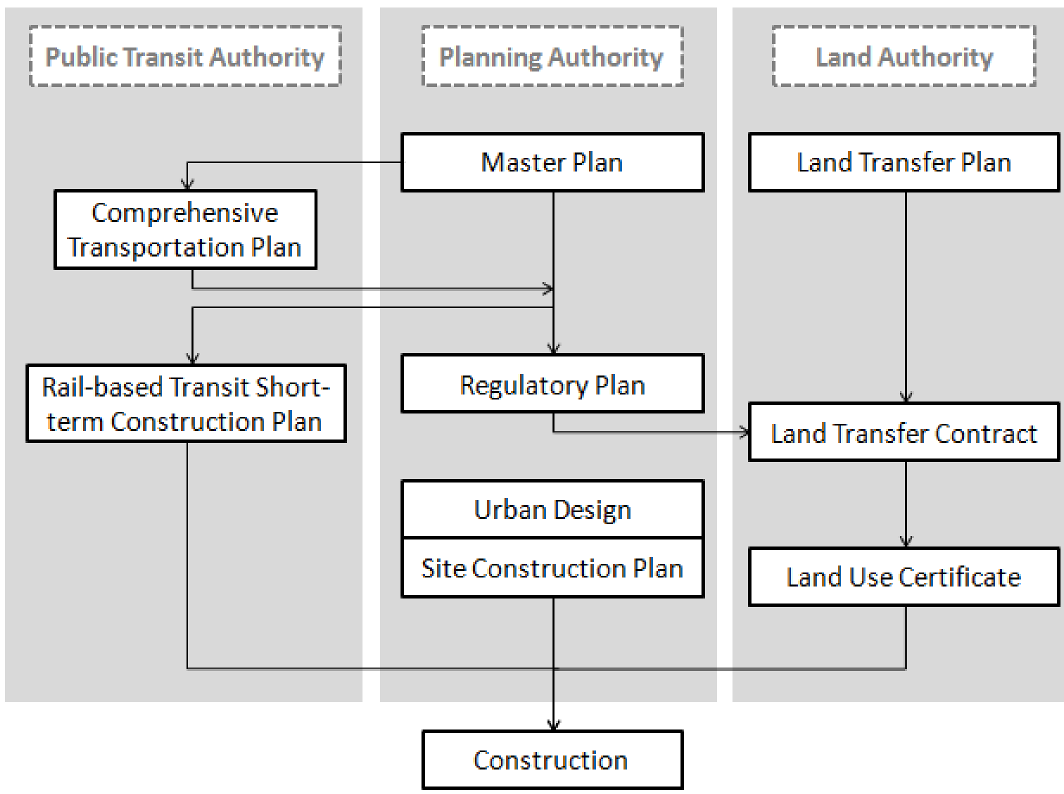


Figure 8.1 Flowchart of Planning Process in Chinese Cities

Adopted from Chen et al., 2008 with revisions

The normal planning process for a new development in Chinese cities usually involves the steps shown in Figure 8.1. The regulatory plan is the crucial step to get a land transfer contract and a land use certificate for construction. The regulatory plan specifies the land use (including mixed-use) functions, F.A.R., building height, building coverage, green coverage, infrastructure, and other amenities. So, while the recent master plans of many Chinese cities incorporate energy efficiency clauses as a guiding principle, the specific physical characteristics of neighborhood design that may importantly influence energy use are determined quantitatively

[27] Zheng, Ruishan's presentation on China Regulatory Plan and Eco-city Indicator System, MIT, 2012

in the regulatory plan. A relative lack of systematic research on the relationship between energy efficiency and the Chinese "eco-city" and related indicators makes it difficult to justify the selection of these indicators as well as their specified ranges of requirements.

The research in this dissertation offers a concrete step in that direction, providing theoretical and empirical justification for quantitative indicators that can help guide clean energy city development in China.

8.2.2 Policy Implications

As discussed in Chapter 1, demand side behavior changes are almost certainly needed in the residential and transportation sector to meet the national target of energy efficiency. Markowitz & Doppelt (2009) review studies, incentive programs, and behavioral experiments in Europe and Japan and show that not only are theoretical reductions in residential and travel energy use possible as a function of behavioral changes, actual reductions of between 5-30 percent have been achieved in these domains. Gardner and Stern (2008) assert that households could reduce energy consumption by at least 30% via behavioral changes that will not decrease their sense of well-being or comfort (citing Markowitz & Doppelt, 2009).

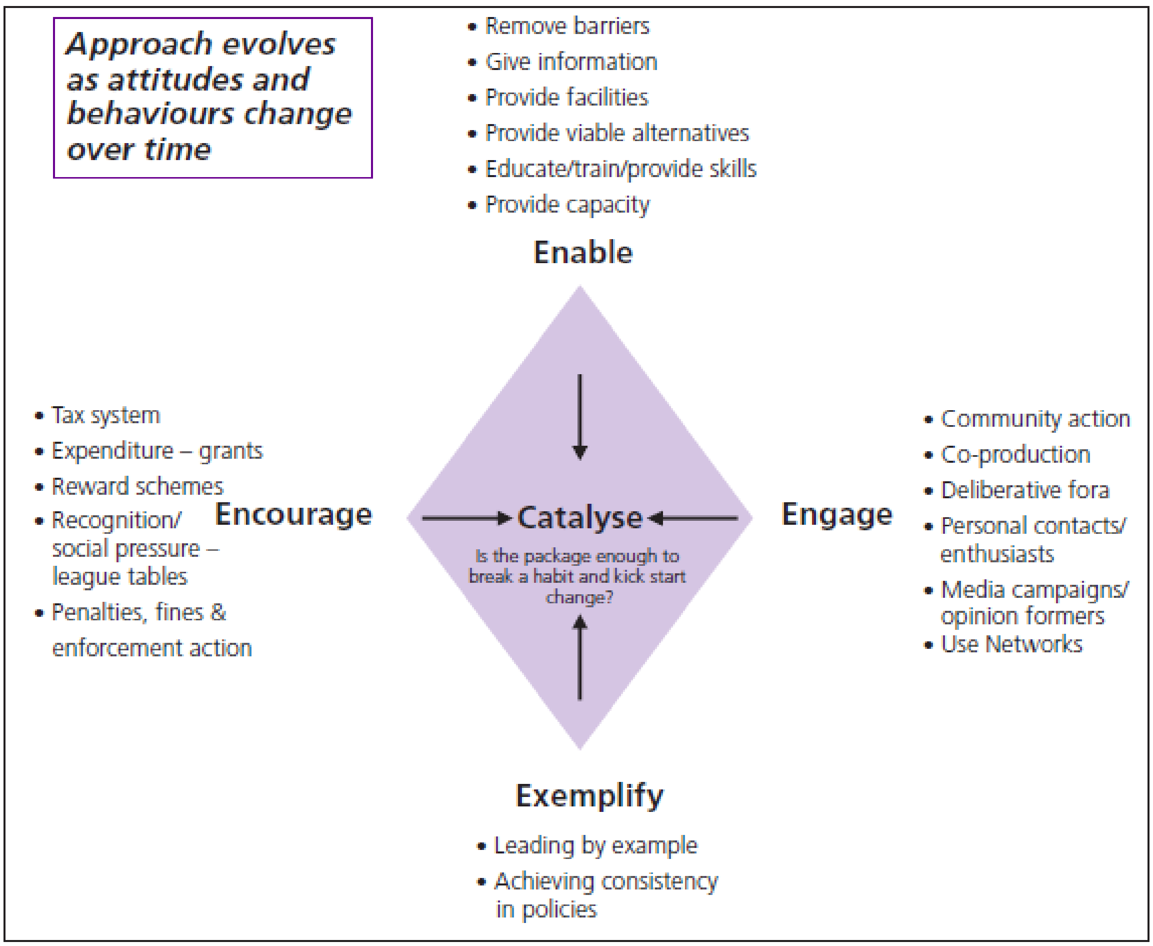


Figure 8.2 A Model for Lifestyle and Behavior Change Policy

Adopted from Securing the Future: Delivering the UK Sustainable Development Strategy[28]

[28] http://www.un.org/esa/sustdev/natlinfo/nsds/uk.pdf, © Crown Copyright 2005

This research suggests that neighborhood design could influence behaviors through changing household's lifestyle. Lifestyle change is more fundamental than short-term behavioral change. Tim Jackson, an expert in sustainable lifestyle, explores behavioral change strategies, and concludes that strategies for sustainable lifestyle include: (1) encouraging behavior through incentive structures and institutional rules; (2) enabling access to pro-environmental lifestyle choices; (3) engaging people; and (4) exemplifying the desired changes within policies and practices (Jackson, 2008). Details and examples of these strategies are illustrated in Figure 8.2. Energy-efficient neighborhood design plays essential role in (2), as it enables household access to alternative lifestyle choices, such as owning a smaller housing unit without losing the amenities they value or owning only non-motorized vehicles, due to living in a neighborhood where one can walk and bike safely and comfortably, get goods and services with little travel, and/or take public transit conveniently. Energy efficient neighborhood design can facilitate other strategies to exemplify policies (via, e.g., visual cues in the built environment) and/or to engage people (as physical form and social community may interact; e.g., Zegras et al., 2012). By enabling more lifestyle bundle choices and providing new experiences and feedback, facilitating the breaking of old habits and the creating of new habits – with attitudes, perceptions, and preferences adjusted accordingly – energy-efficient neighborhood design can "lock in" households' lifestyle for a longer period of time via the lifestyle bundle choice. Adding potential peer effects and social pressure, and the influence of lifestyle change has a larger and more robust impact in the long run than one-time or short-term incentives might. Over time, households might become more "budget-oriented" instead of "amenity-oriented," that is, pursuing more energy efficient lifestyles. Most likely, new lifestyle dimensions will be created over time by energy efficient neighborhood design, such as a "green amenity oriented" lifestyle by which households value future quality of life, equality, and a sense of community and sustainability more and treat sharing, recycling, and responsibility for society and the environment as amenities. Irrespective of household beliefs about working, child-rearing, saving, or enjoyment as the meaning of life, the emergence of a new energy efficient lifestyle would stand to increase a household's enjoyment of life with less external burdens on society.

In the context of the low-carbon city and the existing urban planning framework in China, the three main findings of this research have realistic implications. First, the interdependence of residential choice and vehicle ownership choice, i.e. the use of a lifestyle bundle choice analytical framework, makes the combined evaluation of both travel and residential energy use, little practiced at the moment, possible. And this combined analysis is essential for robust policy-making, as both energy end uses are important contributors to China's (and the rest of the world's) total energy consumption, and, thus, must be dealt with to meet the nation's energy efficiency targets.

Second, the heterogeneity of lifestyles, therefore different decision-making mechanisms, among urban households suggests the need and possibility for targeted designs and policies. With the help of the lifestyle classification in the bundle choice model, simple observations and descriptive statistics of "lifestyle indicators" can help identify lifestyle groups among neighborhood residents. For example, employees from large state owned enterprises and business owners tend to form job-oriented households, and families with babies and school-aged children tend to belong to the child-oriented group. Migrants, renters, singles, and retirees tend to be budget-oriented, while younger generations with affluent parents, descendants of local long-time urbanites, and households with luxury cars and furnishings tend to belong to the amenity-oriented group. Different policies, or different implementation schemes for the same policy, could be targeted at different lifestyle groups, who likely have different policy responsiveness or sensitivities, to improve the chances of good results. For example, job- and commuting-related amenities such as closeness to shuttle stops and bus/BRT stops are more attractive to job-oriented households. Child-oriented households are more responsive to provision of daycare, kindergarten, school quality, playground, indoor gym, swimming pool, and other amenities associated with children's livelihood and education. The budget-oriented group is the most price-sensitive, while the amenity-oriented households are more interested in quality improvements – e.g. underground parking, green coverage, architectural style, aesthetic elements, the brands and qualities of local shops, building materials, views – without caring too much about price. Consider, for example, a car pooling program; in neighborhoods with a large portion of job-oriented households, a scheme organized by employers and around commute time may be more efficient, while a car pooling program targeting drop-off/pickup for daycare, school, and extracurricular activities may be more welcome by the child-oriented group. Similarly, budget-oriented households might be very cost-sensitive to a car pooling program, while amenity-oriented households may care more about quality of service, such as the quality of the vehicle, the convenience of scheduling and routing, safety and liability concerns, waiting time, etc.

Third, what measurable characteristics exactly indicate energy efficient neighborhood design? Only a few neighborhood design indicators showed significant and substantial relationships with household energy consumption in the Jinan context. Specifically, continuity of street façades and the average building footprint have large elasticities estimated over the Jinan sample. Figure 8.3 shows the potential household energy reduction associated with various neighborhood design indicators (calculated using sample average elasticities).

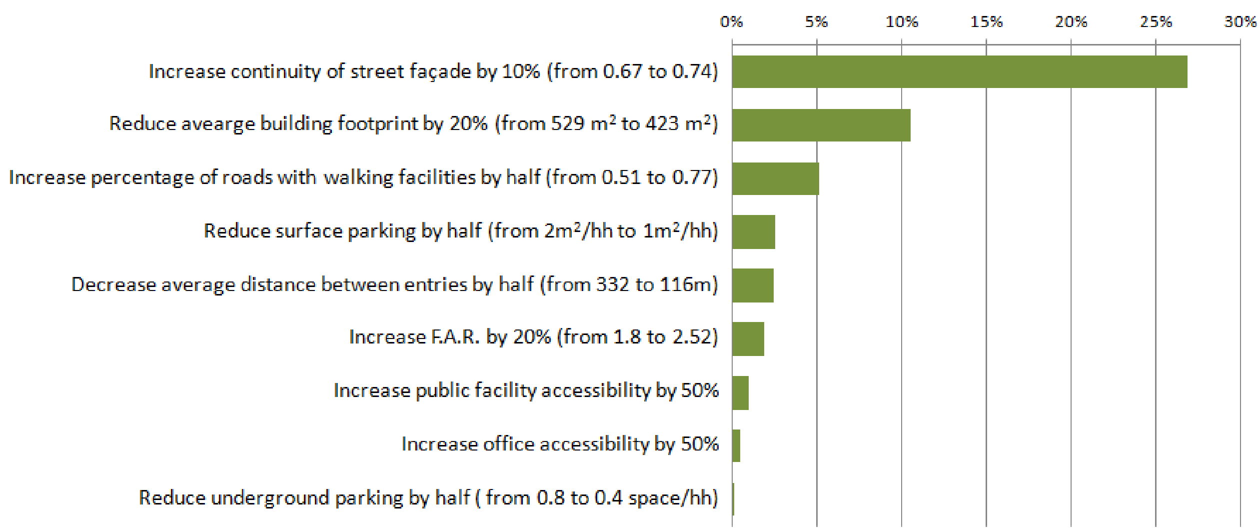


Figure 8.3 Household Energy Reduction Potential of Neighborhood Design Indicators

By increasing continuity of neighborhood street façades by 10%, total direct household energy consumption would be reduce by 27%. Using the average household energy consumption of 75.5 GJ/year in the Jinan household survey, the implied energy savings would be as much as 20 GJ per household per year. By reducing average building footprint by 20%, the reduction in household energy use would be 10.6%, or 8 GJ/year on average. Increasing the percentage of roads with walking facilities means more pedestrian paths and sidewalks, and effects on behavior will be greater when the existing conditions are worse. For example, if only half of the roads have walking facilities, then increasing this percentage to 77% will achieve a 5% energy reduction, or 4 GJ/year per household; but if starting from 75% of roads with walking facilities, increasing to 100% will only achieve 3.4% energy reduction, or 2.6 GJ/year per household. Other measures, although with likely modest relative energy use impacts, include decreasing surface parking and underground parking, shortening the distance between neighborhood entries, increasing F.A.R., and improving regional accessibility. The identified relationships between the indicators and energy consumption can serve as the foundation for selecting indicators as well as establishing their required/suggested values in the regulatory plan, especially for low-carbon cities or eco-cities.

However, focusing on individual indicators could be dangerous as most design indicators are interlinked together in an integrated neighborhood design. For example, one large building occupying the whole block will return a maximum value, 1, for continuity. However, this will also make much larger the area of the building footprint, not to mention changing the road, parking, and other indicators. The overall effect will still be ambiguous. For the most influential indicators, continuity and footprint, Figure 8.4 illustrates how different forms could have different combinations of these two indicators. Form (a) might be the thin tower type of building with a small footprint but low continuity; form (d) has high continuity but a large average footprint. The worst, from a household energy use perspective, would be form (c), with a large footprint building in the middle of the neighborhood. Form (a) seems to be the best in terms of energy efficiency as it has small building footprint and very high continuity. Note that, besides these two indicators, these forms probably imply differences in other indicators as well, e.g. building heights, average distance between entries, and all the solar and wind indices.

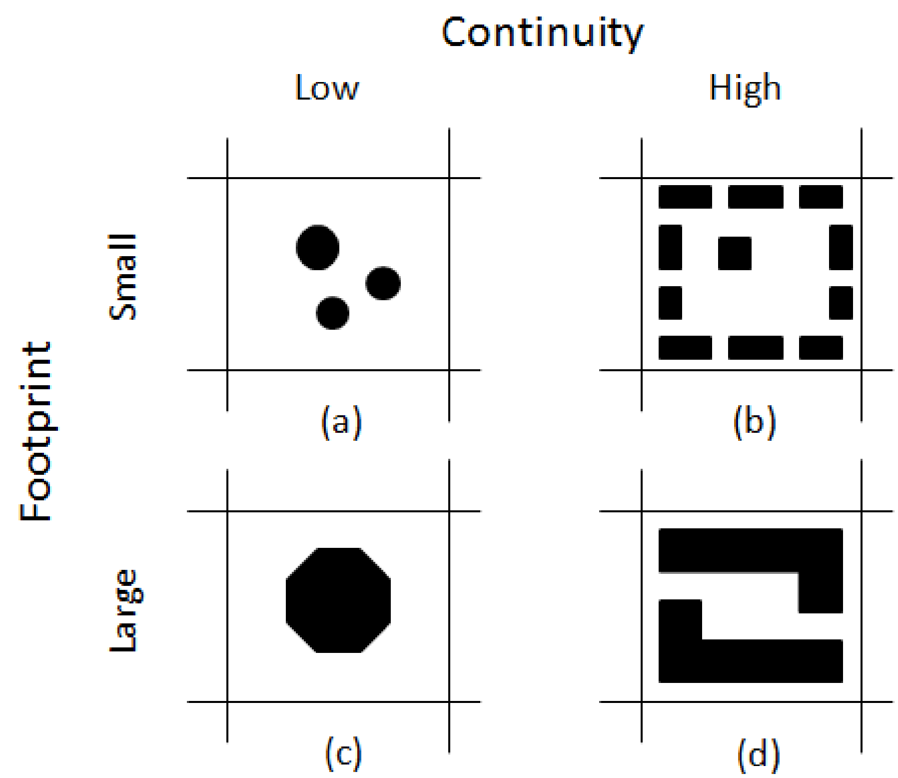


Figure 8.4 Forms with Different Continuity and Footprint

As another example, decreasing the average distance between neighborhood entries means adding more entries (if the neighborhood boundary is fixed). More neighborhood entries usually leads to a denser road network within the neighborhood, which will change the whole configuration of buildings, connections, and green spaces, therefore relevant indicators will all be quite different, including continuity, footprint, percentage of roads with walking facilities, surface parking, etc. Thus, we ultimately must consider the whole set of neighborhood design indicators together rather than focusing on single indicator values separately.

The methods and results piloted in this research have already been serving as part of the foundation to develop a design evaluation tool that calculates the expected residential energy consumption for different neighborhood designs: the "Energy Proforma," being developed and tested as part of the larger "Making the Clean Energy City in China" project (see Appendix A8 for sample input and output of the "Energy Proforma" tool). Testing the Proforma in a series of urban design studios, the project aims to derive a standards-based neighborhood "clean energy" policy framework that incentivizes design innovation for measurable energy outcomes. The Proforma tool offers a standardized way to estimate energy use during the design process, enabling realistic neighborhood energy consumption benchmarks (Neighborhood Energy Performance Standard, NEPS) to be set and allowing designers and developers to determine how to reach the performance standard (MIT, 2012).

8.3 Limitations and Future Work

8.3.1 On Data and Methods

Under the quantitative testing framework of this research, data improvements would support a more realistic model structure and/or help achieve more robust and reliable estimation results. For example, if detailed physical characteristics of more neighborhoods were available (ideally a representative sample of all neighborhoods in the city), neighborhood choice or neighborhood type choice could be modeled as part of lifestyle bundle choice. Even for the statistical models used in this research, data improvements could make a difference at several points. For example, the limited variation in neighborhood design variables (only 23 neighborhoods) constrains the number of neighborhood design variables that can enter the model, requiring compromises between the degree of multicollinearity and the possibility of missing variables. Missing variables that have a potential impact on household's lifestyle choice and energy consumption behaviors include: destination characteristics, employer subsidies for travel and residence, and more aspects of habits, attitudes, perceptions, preferences, and values. Also, more relevant physical attributes of the building and housing unit – such as building materials, year of construction, building surface to volume ratio, spacing, home insulation, room orientation, ventilation, etc. – should be included. Measurement errors may be problematic for important dependent variables, i.e. travel energy consumption and in-home energy consumption, as they were calculated from self-reported usage amounts or bills, rather than coming from objectively recorded usage (e.g. vehicle odometer reading, official electricity or gas usage/bill). The travel energy calculation relies on a simplified trip table, with some caveats (as explained in the data section in Chapter 3), and not accounting for long distance travel (e.g., flights). For in-home energy use, centralized heating takes up a big portion, however, individual meters for centralized heating in most neighborhoods in Jinan, and most other cities in China, are not used. So the energy use for centralized heating in this research is calculated using constructed area of the housing unit and a city-wide heat load index for residential buildings. As such, this portion of in-home energy consumption perfectly correlates with unit size, which is obviously not the reality as space heating varies with building characteristics as well as individual household behaviors. Finally, variations in the household surveys across the two years of implementation, resulting from different research needs of the various project partners, introduced some inconsistency in the indicators collected.

Therefore to enhance the empirical testing using the quantitative framework in this research, future data collection efforts should focus on: a larger number of neighborhoods in the sample; an expanded set of physical attributes, using GIS data collection, to cover the whole city; housing-unit level and building level characteristics; a more comprehensive attitudinal survey, personality survey, or lifestyle survey focusing on bundle choice and energy consumption to measure lifestyle; a more comprehensive travel survey, covering a longer time period and inter-city travel, possibly with help of mobile tracking devices; actual household energy consumption data from electricity and gas bills from official sources for all seasons. In addition, many more cities of the vast Chinese urban landscape should be examined similarly, to account for cultural, climatic, physical, and other differences of potential relevance.

With these additional data, a more comprehensive model structure could be tested, such as the structural equations model approaches (a) and (b) discussed in the method section of Chapter 3. In model estimation, more advanced techniques could be utilized to do simultaneous estimation of latent class, discrete choice, and SEM to ensure consistency and efficiency.

Furthermore, neighborhood design also influences energy consumption in the common areas (e.g., elevator, common space heating and cooling, public lighting) as well as embodied energy for the construction of the neighborhood (including building and infrastructure). Effects on non-residential energy use (e.g., neighborhood commercial, industrial, recreation, etc.) must also be included to gain a full picture of the role of the neighborhood. Analysis that incorporates these, embedded in a full lifecycle analysis framework, would ultimately enable a fully integrated approach to understand the complete spectrum of end user energy consumption effects.

In order to fully answer the question of how neighborhood design influences households' lifestyles and energy consumption, cross-sectional data are not sufficient to test hypotheses of a causal relationship since we can only observe attributes at one point in time. The ideal would be panel data covering a period of changes in household socio-economic status, employment, residential and vehicle choices, and other important life events over time. Although households seemingly make residential and vehicle ownership choices as a bundle that reflects the chosen lifestyle, the residential choice and vehicle ownership choice are not implemented at the same time therefore there is always a portion of a cross-sectional sample that has not "revealed" their full choice at certain point of time.

Last but not least, we need more qualitative research and analysis on the mechanisms of household energy consumption behavior and lifestyle, especially in China and other countries of the developing world, where energy demand is growing the quickest, and where households may think and behave in very different ways than their counterparts in the developed world due to different physical environments, resource availability, economic and political conditions, as well as social traditions and cultures.

8.3.2 On Policy Implication

The detailed policy implications for energy efficient neighborhood design from this research should also be viewed with caution. For example: the empirical model estimations do not account for potential changes in the implied behavioral mechanisms in the future; in evaluating neighborhood designs, all relevant variables should be examined at the same time instead of separately considering the indicators one by one; the selection and suggested values of neighborhood indicators (e.g. footprint, continuity, etc.) are not for new innovative forms or for context of other cities and other countries, as all estimates came from existing forms in Jinan. Local data will be needed to apply this approach (e.g., calibrate the model and use the "Energy Proforma" tool) in other cities to make viable policy suggestions.

8.4 Concluding Remarks

China and the rest of the world are facing the challenge of meeting energy demand sustainably. Household-level energy consumption is a large ultimate driving force of a nation's energy use. Realizing a sustainable energy future will require behavioral change on the consumption side. In this context, examining the role of neighborhoods is important since neighborhoods are the building blocks of China's urban growth and the neighborhoods we build now will have a long-lasting effect on households' lifestyles of energy consumption. This research uses Jinan as a context for Chinese cities, and tries to understand how neighborhood design influences households' direct energy consumption, including travel and in-home energy use, through the influence on urban households' lifestyle.

This research utilized an approach combining qualitative and quantitative methods, and finds that: (1) Household residential and vehicle ownership choice is made as a bundle reflecting the chosen lifestyle, making the combined evaluation of both travel and residential energy use possible; (2) Households belonging to different lifestyle groups have different decision-making mechanisms, suggesting the need for targeted design and policies; and, (3) Neighborhood design influences household direct energy consumption both through the ownership component choice and the usage component. By enabling more lifestyle bundle choices and providing new experiences and feedback, breaking old habits and creating new ones, energy-efficient neighborhood design can "lock in" households' lifestyles for a longer period of time via the lifestyle bundle choice effect. Design, therefore, likely has a larger and more robust impact in the long run than one-time or short-term incentives.

This qualitative-quantitative mixed-method study contributes to a bridging of the literatures on consumer behavior, lifestyle, built environment and travel behavior, residential energy consumption, and energy demand analysis. It also provides new insights into the interaction of residence and mobility as a lifestyle bundle, and enriches the empirical findings in the developing world. For policy makers and designers, this research presents a theoretical basis for the development of potential evaluation tools and a standard for energy efficient neighborhood design and offers a pilot method for the selection, and suggested range, of indicators for energy efficient neighborhood design.

Appendix

A1 Interview Protocol

Introduction, get consent for interview and tape recording, start!

Collect Basic information

Family size, structure, # of people working, household income
Personal information of each household member: age, education, occupation, years of working, etc.

About Home Purchase Decision

Current residence: housing tenure, years in this neighborhood, mortgage payment or rent
When did/will you start considering buying a home/moving to a new neighborhood? What factors come to your mind? What are the alternatives you have considered? Who made the decision? Is everyone satisfied with the decision? Any future plans?

About Vehicle Purchase Decision

Current vehicle portfolio: # of car, motorcycle, bicycle, years of ownership, model and make, purchase price and maintenance fee for each vehicle; which vehicle belongs to whom for what use; etc.
When? Why? Who made the decision? What factors are considered? Any future plans?

Ideal Lifestyle

Can you talk about what kind of life is ideal for you or your family?
- Home (including neighborhood), job, vehicle portfolio, family, leisure, daily activities, meaning of life, etc.

Which kind is your ideal home, without economic/price consideration?
- Apartment in busy urban center, quiet rural house, or villa in suburban area

Which neighborhood do you consider to be the best in Jinan?

Energy Using Habits

Awareness of the household's usage (do you know how much electricity your household consumes each month?); do you have a budget? measures to reduce usage?

Values and Attitudes

Attitudes and perceptions towards current trends, space, transportation modes, residence, job, income, environmental issues, culture, and social status, etc.

Reactions to Policies

Have you heard of …? What do you think of …? Will you change your behavior if…? (e.g. fuel tax, BRT, metro construction, congestion charging, TOD, parking provision of the neighborhood, traffic calming)

A2 Energy Calculation[29]

1. Travel Energy

$EN_i = \sum_m EN_i^m * 52 \quad m \in \{car,\ taxi,\ bus,\ BRT, motorcycle,\ ebike\}$[30]

$$EN_i^m = \sum_j \sum_k \left(FR_{i,j,k}^m * \frac{TD_{i,j,k}^m}{OC_{i,j,k}^m} \right) * EI^m$$

Where:

EN_i: Annual travel energy consumption (MJ) by household i

EN_i^m: Weekly transport-related energy consumption (MJ) by household i for trips with mode m

$FR_{i,j,k}^m$: Trip frequency (Trips/ Week), by mode m, for purpose k, by person j in household i

$TD_{i,j,k}^m$: Trip distance (Km), by mode m, for purpose k, made by person j in household i

$OC_{i,j,k}^m$: Occupancy rate, by mode m for purpose k, by person j in household i

EI^m: Energy Intensity factor per kilometer (MJ/km) of mode m

(1) Occupancy Rate (OC)

Occupancy rates of automobile, taxi, motorcycle and e-bike are associated with each trip, and thus estimated using reported person trip data. Specifically, person trips with exactly the same reported purpose, length and time among two or more household members are treated as one trip shared by all. For transit, the system-wide occupancy rate is estimated using empirical operation performance data in Jinan (Table A.0.1).

Table A.0.1 Jinan Public Transit Operation Performance Statistics[31]

Year	Annual Operating Distance (10,000 km/year)		Daily Passenger Volume (10,000 passenger-trips/year)		Average Trip Length (km/passenger-trip)	
	Total Transit	BRT	Total Transit	BRT	Total Transit	BRT
2008	18207		74566		4.04	
2009	19059		80393	7592		4.892
2010	18800		84500			

Therefore, the bus occupancy rate in Jinan for 2009 survey household is 16.55 (=74566×4.04/18207); the bus occupancy rate in Jinan for 2010 survey household is 17.04 (=80393×4.04/19059); BRT occupancy rate (for 2010 survey) = 11000*4.892/1420 = 37.9[32]

(2) Energy Intensity Factor (EI)

$$EI^m = FU^m * EC^m$$

Where:

[29] Adopted and updated from Jiang, 2010 and Zhang , 2010.
[30] Mode "car" include trips by private car and company car, mode "bus" include trips by company shuttle
[31] Source: Jinan Public Transit Development Report, 2010; Jinan Infrastructure and Public Utility Development Report, 2009
[32] To-date (1,000 days from opening in 2008 to Jan. 2011) operating distance and passenger volume data from Jinan Public Transit Cooperation, http://www.sd.xinhuanet.com/wq/2011-01/25/content_21950800.htm

FU^m: Fuel economy factor (L/km; kwh/km) associated with mode m
EC^m: Energy Content of each fuel type (MJ/L) of the fuel consumed in mode m

Table A.0.2 Energy Intensity Factors

Mode (m)	Vehicle Fuel Economy[a] (FU^m)	×	Fuel Energy Content[33] (EC^m)	=	Energy Intensity factor (EI^m)
Automobile	0.092L/km		32.2 MJ/L		2.962 MJ/km
Taxi	0.083L/km		32.2 MJ/L		2.673 MJ/km
Bus	0.266L/km[34]		35.6 MJ/L		9.470 MJ/km
BRT	0.5L/km[35]		35.6 MJ/L		17.80MJ/km
Motorcycle	0.019L/km		32.2 MJ/L		0.612 MJ/km
E-bike	0.021kwh/km[c]				0.076 MJ/km

a. Assume that all automobiles/taxis/motorcycles use gasoline, bus and BRT fleet uses diesel.
b. Cherry, C. R., J. X. Weinert, et al. (2009). "Comparative environmental impacts of electric bikes in China." Transportation Research Part D 14: 281-290.

2. In-home Energy

(1) Electricity

$$E_e = KWH * q_e \div (1 - \beta) \div \varepsilon \quad (MJ)$$

Electricity price = 0.5469 yuan/KWH[36]
q_e= 3.6 MJ/KWH
Electricity Transmission Loss rate: β= 7.08%[37]
Coal power plant conversion ε= 35.47%[38]

(2) Gas

$$E_m = G_m \times \alpha_m \times \gamma_m \qquad (MJ)$$

γ_m： Thermal value for gas m type （MJ/m^3）

Table A.0.3 Factor Values for Gas-related Energy Calculation

	Natural Gas	Coal Gas	LPG
α（%）	60	55	55
β	1.013	0.381	0.863
ρ（kg/m^3）	1.96		
γ（MJ/m^3）	36.4	16.74	118.2

[33] Energy content factors from MIT Energy Club (2007). Units & Conversions Fact Sheet. http://web.mit.edu/mit_energy/resources/factsheets/Units&ConvFactors.MIT%20EnergyClub%20Factsheet.v8.pdf
[34] http://www.jnjtj.gov.cn/info/display.jsp?ID=BF01L0DK50H
[35] BRT bus fuel economy figure (50L/100km) taking model Zhongtong LCK6180G
[36] Source: Jinan Electricity Provision Bureau, till April 2010, http://www.ql61.com/read.php?tid-11621.html
[37] National average
[38] Source: China Energy Yearbook 2009

Natural Gas:
Price = 2.4 yuan/m^3 ; Unit thermal Value = 36.4 MJ/ m^3
Coal Gas :
Price = 1.3 yuan/m^3 ; Unit thermal Value = 16.74 MJ/ m^3
Gas Pitcher (LPG):
Price = 13.9 yuan/m^3 ; Unit thermal Value = 118.2 MJ/ m^3

(3) Coal
Price = 876 yuan/ton [39]; Unit thermal Value = 26700 MJ/ton[40]

(4) Centralized Heating

$$E_h = N * \text{Unit\_Area} * qh * \frac{t_i - t_a}{t_i - t_{o,e,}} \div \mu_b \div \mu_p$$

N = heating days = 140 days, 1 day = 24 * 3600 seconds
q_h = 33.16 W/m^2 (jinan average)
Indoor designed temperature during heating period: t_i = 18°C[41]
Average outdoor temperature during heating period: t_a = -0.9°C [42]
Outdoor designed temperature during heating period: t_i = -7°C[43]
Cogeneration Boiler Efficiency: μ_b= 0.87[44]
Pipeline Network Efficiency: μ_p= 0.98[45]

39 Source: Jinan Price Bureau
40 Source: Jinan Bureau of Public Utilities
41 Source: Jinan Bureau of Public Utilities
42 Source: Jinan Bureau of Public Utilities
43 Source: Jinan Bureau of Public Utilities
44 Source: Jinan South Suburban Cogeneration Plant
45 Source: Jinan South Suburban Cogeneration Plant

A3 Regional Accessibility Calculation

Regional accessibility is calculated using gravity-based measure (Hansen, 1959). Other accessibility measures include isochronic or cumulative opportunity measure (Vickerman, 1974; Wachs and Kumagai, 1973); utility-based measure (Ben-Akiva and Lerman, 1977; Neuburger, 1971); and constraints-based or people-based measure (Wu and Miller, 2002). See El-Geneidy and Levinson (2006) for a review of different accessibility measures.

The regional accessibility index in this research is calculated using the following form:

$$RA_{im} = \sum_j A_j C_{ijm}{}^{-2}$$

Where:

RA_{im} is the regional accessibility index of neighborhood i of activity category m;

A_j is the attraction (or, opportunities) at point j (due to lack of scale or service level information, treated as one for each attraction point in this research);

C_{ijm} is the measure of travel cost (measured by distance in km in this research).

C_{ijm} is calculated using network analysis in GIS. Road network of Jinan and attraction points are provided by Beijing Normal University GIS, vectorized from Google Earth.

A4 Simulation-based Wind and Solar Indices

The geometric properties of neighborhood/clusters/building, which hypothetically influence the micro-climate therefore the demand for heating and cooling, and in turn in-home energy use, include Porosity, Orientation, Height Irregularity and Surface to Volume Ratio, are quantified using GIS maps (figure ground maps and the height information of buildings) and simulation programs, done by other team members in the MIT "Making the Clean Energy City in China" team.

For example, a cluster/neighborhood porosity is defined as the ratio of the total volume of open spaces to the total volume where the total volume of open spaces is equal to the area of open spaces multiplied by the average height of buildings, and the total volume is equal to the summation of the volume of open spaces and total volume of buildings. Solar gain index (summer and winter), and shadow ratio indices are measured as the average of three sample times in summer and three sample times in winter (10:30, noon and 13:30 on summer and winter solstice). The comparison between the measured in-shadow area of surfaces – using rendered site plans – and calculated geometric indices. For each individual façade the south orientation value is defined as the area of the projection of the façade onto the south plane and is equal to Cos (Q) X A, where Q is the angle between the normal vector of the wall and the south vector, and A is the area of wall. Please see MIT (2012) for detailed calculation.

A5 Summary of Interviewed Household Characteristics

Table A.4 Summary of Interviewee Household Characteristics

ID	Neighborhood Type	Location	HH Size	# of Employed	HH structure	Age	Education Level	Annual HH Income	Home Ownership	Private Car
1	superblock	north	5	2	three generations	40s	college	200k	mortgage	1
2	traditional	center	3	1	couple with kid	53	high school	20k	own	0
3	enclave	north	3	2	couple with kid	45	unknown	30k	own	0
4	superblock	northwest	4	1	couple with kid	36	high school	500k	own more than 1	2
5	superblock	northwest	2	2	couple	40	college	100k	mortgage	1
6	enclave	center	2	0	couple	74	college	60k	own	0
7	superblock*	northeast	2	2	couple	30s	master	100k	own	0
8	superblock*	northeast	3	1	couple with kid	29	college	30k	mortgage	0
9	enclave	northeast	3	2	couple with kid	45	college	100k	own more than 1	0
10	enclave	northeast	3	2	couple with kid	43	master	100k	own more than 1	0
11	enclave	northeast	3	2	couple with kid	46	unknown	150k	own	buying
12	enclave	south	3	1	couple	48	college	60k	own	1
13	enclave	east	3	1	couple with kid	30	college	100k	rent	0
14	superblock	east	3	2	couple with kid	30s	master, college	100k	mortgage	1
15	superblock	east	3	2	couple with kid	47	unknown	160k	own, buying 2nd	1
16	superblock	east	5	1	four generations	36	master	200k	own more than 1	1
17	superblock	east	3	2	couple with kid	41	college	250k	mortgage	2
18	superblock	east	3	2	couple with kid	40	college	200k	mortgage	2
19	superblock	east	3	2	couple with kid	35	master	500k	own	2
20	enclave	center	2	0	couple	60s	unknown	high income	own more than 1	1
21	superblock	east	4	2	three generations	30s	college	300k	own	1
22	superblock	east	4	3	three generations	47, 46	college	150k	own	0
23	enclave	east	4	1	three generations	32, 33	college, phd	70k	mortgage	0
24	enclave	east	3	1	couple with kid	41	junior high	25k	own	0
25	superblock	east	3	2	couple with kid	45, 44	college	200k	mortgage	2
26	enclave	center	1	1	single	28	college	100k	own	0
27	superblock*	center	2	2	couple	25	college	170k	mortgage	0
28	superblock	center	2	0	couple	64	college	70k	own	1
29	superblock	center	4	2	three generations	33	master	150k	own	1
30	superblock	center	3	1	couple with kid	43	college	250k	own more than 1	1
31	superblock	south	3	1	couple with kid	38, 35	phd, college	100k	own	1
32	superblock	south	3	2	couple with kid	35	master, college	150k	own	1, buying 2nd
33	enclave	east (~north)	11	3	three generations	80,75	elementary	low income	own	0
34	enclave	east (~north)	5	2	three generations	33,35	master	100k	mortgage	0
35	enclave	east	3	2	couple with kid	44	master	100k	own	0

* “Partial property” neighborhoods

A6 Correlation Matrix of OLS Model of Total Direct Energy

Table A.5 Correlation Matrix of Independent Variables in the OLS Model

	P(small unit with car)	P(medium unit without car)	P(medium unit with car)	P(large unit without car)	P(large unit with car)	renting
P(small unit with car)	1					
P(medium unit without car)	0.0307	1				
P(medium unit with car)	-0.4386	0.2043	1			
P(large unit without car)	-0.6091	-0.2169	0.2121	1		
P(large unit with car)	-0.5919	-0.4488	0.3862	0.6146	1	
renting	0.2821	-0.1912	-0.3647	-0.2005	-0.2574	1
single	-0.0616	-0.042	-0.2146	-0.0535	-0.1322	0.3277
couple	0.1158	-0.0026	-0.1666	-0.032	-0.1318	0.035
have_kid	-0.1678	0.0481	0.2515	0.1001	0.1878	-0.1163
have_old	0.0063	0.0282	-0.0225	-0.0183	-0.0001	-0.2266
no_employ	0.0155	0.0146	-0.2416	-0.0381	-0.1786	-0.1035
twoplus_employ	0.0011	-0.0091	0.3485	0.0927	0.2738	-0.1193
surface_to_volume	0.487	-0.1608	-0.4598	-0.3376	-0.4356	0.2294
height_irregularity	-0.4792	-0.09	0.3086	0.5015	0.5819	-0.2069
building_wind_summer	-0.1483	0.2994	0.3329	-0.0884	-0.0273	-0.0946
footprint	-0.4739	0.191	0.5051	0.2969	0.435	-0.2643
functin_mix	0.5358	-0.0021	-0.4611	-0.4126	-0.4784	0.1864
continuity	0.4922	-0.0922	-0.4643	-0.3091	-0.426	0.2554
underground parking (space/hh)	-0.6594	-0.1878	0.4251	0.6727	0.7573	-0.2071
surface parking per hh (sq.m/hh)	-0.3409	0.2603	0.5675	0.0528	0.1557	-0.157

	single	couple	have_kid	have_ old	no_ employ	twoplus employ	surface_ to_ volume
single	1						
couple	-0.143	1					
have_kid	-0.2488	-0.4397	1				
have_old	-0.0512	0.0673	-0.0486	1			
no_employ	0.0807	0.3401	-0.2435	0.3997	1		
twoplus_employ	-0.3163	-0.1372	0.2055	-0.1929	-0.5482	1	
surface_to_volume	0.1246	0.0943	-0.157	0.0778	0.1786	-0.203	1
height_irregularity	-0.0752	-0.0122	0.088	-0.0126	-0.0795	0.1492	-0.3731
building_wind_summer	-0.0499	-0.0169	0.0536	-0.0726	-0.0763	0.0682	-0.2674
footprint	-0.109	-0.0569	0.117	-0.0204	-0.1275	0.1803	-0.7166
functin_mix	0.0608	-0.0008	-0.0955	0.0197	0.0481	-0.1018	0.1702
continuity	0.1073	0.0528	-0.1434	0.0476	0.1076	-0.1526	0.6696
underground parking (space/hh)	-0.0754	-0.0367	0.1349	-0.0372	-0.1184	0.1817	-0.4873
surface parking per hh (sq.m/hh)	-0.0513	-0.0221	0.0572	-0.0469	-0.0757	0.1167	-0.2821

	height_ irregular ity	building _wind summer	footprint	function _mix	continui ty	Under- ground parking	surface parking
height_irregularity	1						
building_wind_summer	-0.0594	1					
footprint	0.4459	0.3156	1				
functin_mix	-0.3158	-0.1569	-0.298	1			
continuity	-0.397	-0.2528	-0.3793	0.5409	1		
underground parking (space/hh)	0.7351	-0.0187	0.414	-0.6046	-0.6098	1	
surface parking per hh (sq.m/hh)	0.2616	0.0912	0.259	-0.3409	-0.3783	0.4657	1

A7 More Information about the SEM of Energy Consumption

Table A.6 Standardized Coefficient Estimation

			Estimate
ln_t_mj_year	<---	no_employ	-0.20281
ln_t_mj_year	<---	twoplus_employ	0.04054
ln_t_mj_year	<---	have_kid	0.04241
ln_t_mj_year	<---	have_old	-0.05712
ln_o_mj_year	<---	have_kid	0.04319
ln_o_mj_year	<---	have_old	0.06609
ln_o_mj_year	<---	single	-0.08812
ln_o_mj_year	<---	renting	-0.1151
ln_t_mj_year	<---	single	-0.05404
ln_t_mj_year	<---	senior_hh	-0.04786
ln_t_mj_year	<---	functin_mix	0.06129
ln_t_mj_year	<---	footprint	0.08921
ln_o_mj_year	<---	footprint	0.10661
ln_o_mj_year	<---	continuity	-0.12134
ln_t_mj_year	<---	continuity	-0.09388
ln_t_mj_year	<---	street_level_shop	-0.04284
ln_o_mj_year	<---	surface_to_volume	0.07755
ln_t_mj_year	<---	p_l_car	0.21455
ln_o_mj_year	<---	p_s_car	0.0745
ln_o_mj_year	<---	p_m_nocar	0.08812
ln_t_mj_year	<---	a1_drive_prestige	-0.02914
ln_t_mj_year	<---	a2_bus_convenient	-0.02316
ln_t_mj_year	<---	p_l_nocar	0.03276
ln_o_mj_year	<---	p_l_car	0.15573
ln_t_mj_year	<---	p_m_car	0.17608
ln_o_mj_year	<---	p_m_car	0.09283
ln_t_mj_year	<---	p_m_nocar	0.0889
ln_t_mj_year	<---	p_s_car	0.11799
ln_t_mj_year	<---	a4_travel_time_waste	0.03236
ln_o_mj_year	<---	p_l_nocar	0.11029
ln_t_mj_year	<---	couple	-0.02961
ln_t_mj_year	<---	far	-0.03919
ln_o_mj_year	<---	building_wind_summer	-0.03863

Table A.7 Covariance Estimation for SEM

			Estimate	S.E.	C.R.	P
functin_mix	<-->	continuity	0.005	0.000	36.273	***
have_old	<-->	senior_hh	0.068	0.002	31.328	***
no_employ	<-->	senior_hh	0.059	0.002	34.242	***
no_employ	<-->	twoplus_employ	-0.078	0.003	-30.342	***
single	<-->	renting	0.032	0.002	20.986	***
twoplus_employ	<-->	single	-0.033	0.002	-19.669	***
footprint	<-->	continuity	-6.537	0.198	-33.066	***
have_old	<-->	renting	-0.040	0.003	-15.665	***
have_kid	<-->	single	-0.029	0.002	-14.303	***
no_employ	<-->	have_old	0.056	0.002	23.553	***
continuity	<-->	surface_to_volume	0.009	0.000	41.143	***
street_level_shop	<-->	surface_to_volume	-0.004	0.000	-14.661	***
have_kid	<-->	senior_hh	-0.030	0.002	-15.551	***
twoplus_employ	<-->	senior_hh	-0.041	0.002	-20.012	***
footprint	<-->	surface_to_volume	-35.224	0.761	-46.257	***
twoplus_employ	<-->	renting	-0.016	0.003	-6.189	***
twoplus_employ	<-->	have_old	-0.031	0.003	-9.910	***
renting	<-->	senior_hh	-0.018	0.001	-12.081	***
functin_mix	<-->	street_level_shop	0.007	0.000	24.415	***
renting	<-->	street_level_shop	0.008	0.001	12.551	***
have_old	<-->	single	-0.011	0.001	-7.331	***
have_kid	<-->	renting	-0.014	0.003	-5.471	***
no_employ	<-->	have_kid	-0.035	0.002	-14.333	***
no_employ	<-->	renting	-0.017	0.002	-10.074	***
twoplus_employ	<-->	have_kid	0.040	0.004	11.157	***
functin_mix	<-->	footprint	-7.541	0.369	-20.434	***
renting	<-->	footprint	-6.552	0.792	-8.276	***
p_s_car	<-->	p_l_nocar	-0.001	0.000	-32.666	***
p_l_car	<-->	p_m_car	0.005	0.000	21.427	***
p_s_car	<-->	p_m_car	-0.001	0.000	-26.468	***
p_m_nocar	<-->	p_m_car	0.005	0.000	18.728	***
p_l_car	<-->	p_s_car	-0.002	0.000	-37.394	***
p_l_car	<-->	p_m_nocar	-0.012	0.000	-35.278	***
p_m_nocar	<-->	p_l_nocar	-0.003	0.000	-20.039	***
footprint	<-->	p_l_nocar	1.409	0.196	7.193	***
footprint	<-->	p_m_nocar	8.143	0.418	19.461	***
renting	<-->	p_m_nocar	-0.010	0.001	-11.716	***
single	<-->	p_s_car	-0.001	0.000	-13.808	***
twoplus_employ	<-->	p_s_car	0.002	0.000	13.756	***
p_m_car	<-->	building_wind_summer	0.001	0.000	24.417	***

p_l_nocar	<-->	far	0.008	0.000	18.327	***
p_l_car	<-->	far	0.025	0.001	28.053	***
senior_hh	<-->	couple	0.047	0.002	26.751	***
surface_to_volume	<-->	far	-0.045	0.001	-38.964	***
no_employ	<-->	couple	0.044	0.002	21.232	***
far	<-->	building_wind_summer	0.002	0.000	12.211	***
p_m_nocar	<-->	building_wind_summer	0.001	0.000	21.060	***
p_s_car	<-->	building_wind_summer	0.000	0.000	-13.715	***
surface_to_volume	<-->	p_m_nocar	-0.006	0.000	-16.131	***
street_level_shop	<-->	p_l_car	-0.006	0.000	-25.819	***
footprint	<-->	far	88.365	2.219	39.817	***
surface_to_volume	<-->	p_s_car	0.002	0.000	27.817	***
p_l_car	<-->	p_l_nocar	0.006	0.000	34.241	***
p_l_car	<-->	a2_bus_convenient	-0.015	0.002	-8.937	***
single	<-->	couple	-0.020	0.001	-13.283	***
functin_mix	<-->	p_l_car	-0.011	0.000	-33.222	***
have_kid	<-->	couple	-0.087	0.003	-25.103	***
twoplus_employ	<-->	p_m_car	0.014	0.001	18.280	***
p_s_car	<-->	couple	0.001	0.000	9.896	***
surface_to_volume	<-->	p_m_car	-0.009	0.000	-25.804	***
renting	<-->	p_m_car	-0.014	0.001	-19.999	***
twoplus_employ	<-->	p_l_car	0.009	0.001	13.377	***
no_employ	<-->	p_m_car	-0.006	0.001	-11.657	***
no_employ	<-->	p_l_car	-0.002	0.000	-6.285	***
a1_drive_prestige	<-->	a4_travel_time_waste	0.147	0.024	6.237	***
street_level_shop	<-->	p_m_car	-0.004	0.000	-17.725	***
single	<-->	p_m_car	-0.005	0.000	-11.575	***
have_kid	<-->	p_m_car	0.010	0.001	12.610	***
have_old	<-->	p_m_car	0.002	0.001	2.808	0.005
a2_bus_convenient	<-->	p_m_car	-0.016	0.002	-8.902	***
street_level_shop	<-->	far	0.007	0.001	11.404	***
footprint	<-->	p_m_car	14.022	0.469	29.898	***
functin_mix	<-->	p_s_car	0.002	0.000	32.741	***
p_s_car	<-->	a2_bus_convenient	0.003	0.000	7.175	***
street_level_shop	<-->	p_s_car	0.001	0.000	23.482	***
renting	<-->	p_s_car	0.002	0.000	13.351	***
single	<-->	p_l_car	-0.003	0.000	-8.422	***
street_level_shop	<-->	p_l_nocar	-0.003	0.000	-21.959	***
renting	<-->	p_l_car	-0.011	0.001	-13.008	***
have_old	<-->	p_l_car	0.006	0.001	11.363	***
p_m_car	<-->	couple	-0.007	0.001	-11.441	***
functin_mix	<-->	p_l_nocar	-0.004	0.000	-26.655	***
have_kid	<-->	p_l_car	0.008	0.001	10.652	***

no_employ	<-->	p_s_car	0.000	0.000	-6.245	***
p_l_car	<-->	couple	-0.005	0.001	-10.140	***
a2_bus_convenient	<-->	a4_travel_time_waste	-0.120	0.024	-5.111	***
functin_mix	<-->	p_m_car	-0.008	0.000	-27.716	***
renting	<-->	p_l_nocar	-0.004	0.000	-10.205	***
have_kid	<-->	p_s_car	-0.001	0.000	-5.361	***
functin_mix	<-->	building_wind_summer	-0.001	0.000	-11.605	***
renting	<-->	building_wind_summer	0.000	0.000	-3.528	***
footprint	<-->	building_wind_summer	2.030	0.083	24.376	***
senior_hh	<-->	p_m_car	-0.004	0.000	-8.195	***
footprint	<-->	p_s_car	-2.746	0.092	-29.837	***
have_kid	<-->	street_level_shop	-0.003	0.001	-5.005	***
surface_to_volume	<-->	building_wind_summer	-0.001	0.000	-22.617	***
p_l_nocar	<-->	building_wind_summer	0.000	0.000	-14.137	***
footprint	<-->	p_l_car	13.236	0.494	26.799	***
continuity	<-->	p_s_car	0.001	0.000	29.821	***
continuity	<-->	p_m_car	-0.004	0.000	-28.811	***
p_s_car	<-->	far	-0.003	0.000	-18.794	***
continuity	<-->	p_l_car	-0.003	0.000	-23.153	***
surface_to_volume	<-->	p_l_car	-0.008	0.000	-22.605	***
continuity	<-->	building_wind_summer	-0.001	0.000	-21.686	***
continuity	<-->	p_m_nocar	-0.002	0.000	-11.853	***
renting	<-->	continuity	0.003	0.000	12.143	***
have_old	<-->	a2_bus_convenient	0.033	0.007	4.717	***
renting	<-->	functin_mix	0.010	0.001	11.136	***
p_m_car	<-->	far	0.008	0.001	10.213	***
continuity	<-->	street_level_shop	0.001	0.000	12.591	***
twoplus_employ	<-->	couple	-0.020	0.003	-6.817	***
twoplus_employ	<-->	a4_travel_time_waste	0.034	0.007	4.872	***
p_l_car	<-->	a4_travel_time_waste	0.008	0.002	4.585	***

A8 More on the Energy Proforma

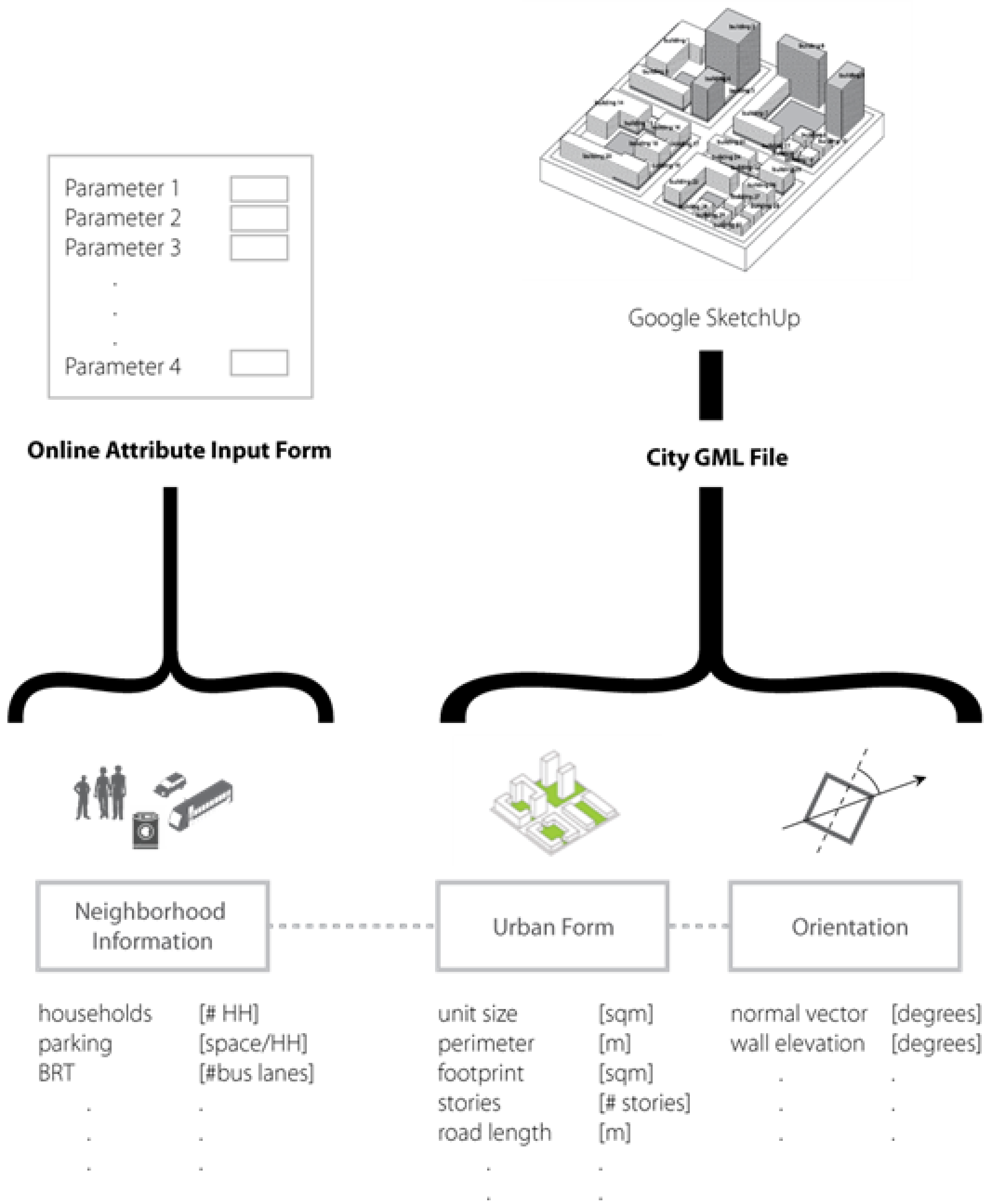


Figure A.1 Input of the "Energy Proforma" Tool

Adopted from "Making Clean Energy City in China" Project Year 2 Presentation, MIT, 2012

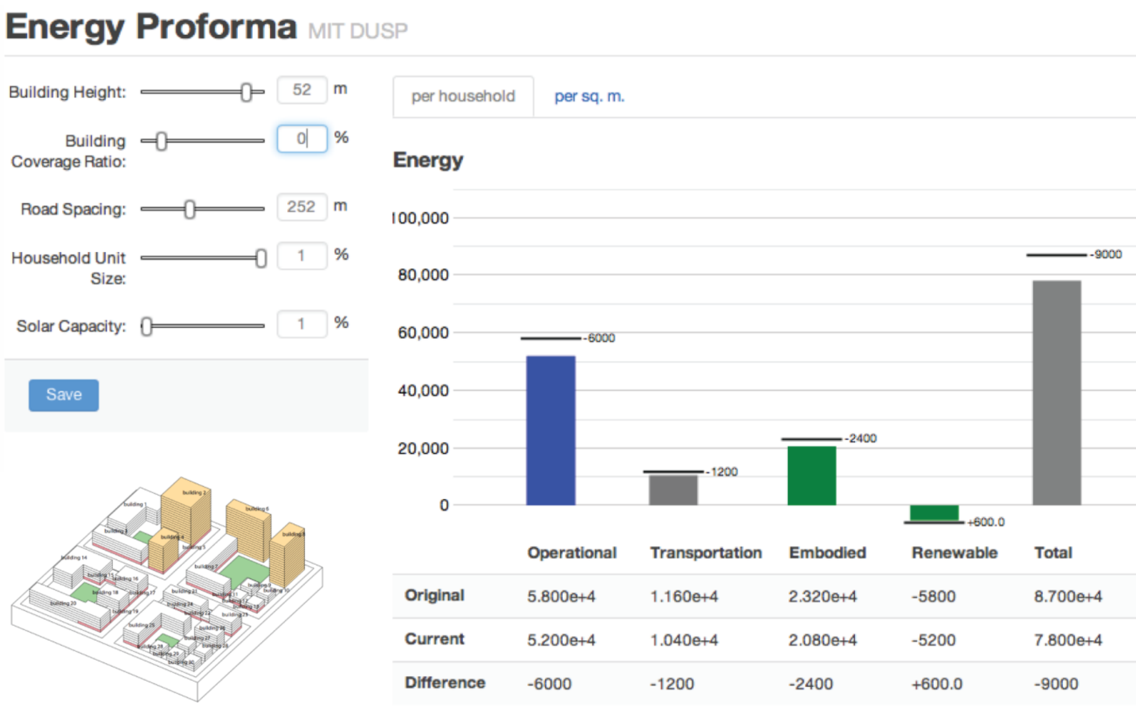


Figure A.2 Sample Output of the "Energy Proforma" Tool

Adopted from "Making Clean Energy City in China" Project Year 2 Presentation, MIT, 2012

References

Aeroe, T. (2001). *Residential preferences, choice of housing, and lifestyle*. PhD dissertation (English summary), Aalborg University.

Alonso, W. (1967). A reformulation of classical location theory and its relation to rent theory. *Papers in Regional Science*, *19*(1), 22–44.

Alonso, William. (1964). *Location and land use: toward a general theory of land rent*. Harvard University Press.

Andrews, C. J. (2008). Greenhouse gas emissions along the rural-urban gradient. *Journal of Environmental Planning and Management*, *51*(6), 847–870. doi:10.1080/09640560802423780

Andrews, C. J. (2008). Greenhouse gas emissions along the rural-urban gradient. *Journal of Environmental Planning and Management*, *51*(6), 847–870. doi:10.1080/09640560802423780

Axhausen, K. W. (2008). Social networks, mobility biographies, and travel: survey challenges. *Environment and Planning B: Planning and Design*, *35*(6), 981 – 996. doi:10.1068/b3316t

Bagley, M. N., & Mokhtarian, P. L. (2002). The impact of residential neighborhood type on travel behavior: A structural equations modeling approach. *The Annals of Regional Science*, *36*(2), 279–297.

Bagley, M. N., Mokhtarian, P. L., & Kitamura, R. (2002). A methodology for the disaggregate, multidimensional measurement of residential neighborhood type. *Urban Studies*, *39*(4), 689.

Bagley, M. N., Mokhtarian, P. L., Center, U. of C. (System). T., & University of California, D. I. of T. S. (1999). *The role of lifestyle and attitudinal characteristics in residential neighborhood choice*. University of California Transportation Center, University of California.

Bartholomew, K., & Ewing, R. (2009). Land Use-Transportation Scenarios and Future Vehicle Travel and Land Consumption: A Meta-Analysis. *Journal of the American Planning Association*, *75*(1), 13–27. doi:10.1080/01944360802508726

Becker, G. S. (1965). A Theory of the Allocation of Time. *The economic journal*, *75*(299), 493–517.

Beige, S., & Axhausen, K. (2012). Interdependencies between turning points in life and long-term mobility decisions. *Transportation*, *39*(4), 857–872. doi:10.1007/s11116-012-9404-y

Ben-Akiva, M., & Lerman, S. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press.

Ben-Akivai, M., Bowman, J., & Gopinath, D. (1996). Travel demand model system for the information era. *Transportation*, *23*(3). doi:10.1007/BF00165704

Bhat, C. R., & Guo, J. Y. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. *Transportation Research Part B: Methodological*, *41*(5), 506–526. doi:10.1016/j.trb.2005.12.005

Bhat, C.R., & Sen, S. (2006). Household vehicle type holdings and usage: an application of the multiple discrete-continuous extreme value (MDCEV) model. *Transportation Research Part B: Methodological*, *40*(1), 35–53.

Bhat, Chandra R., & Guo, J. Y. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. *Transportation Research Part B: Methodological*, *41*(5), 506–526. doi:10.1016/j.trb.2005.12.005

Bhat, Chandra R., & Pulugurta, V. (1998). A comparison of two alternative behavioral choice mechanisms for household auto ownership decisions. *Transportation Research Part B: Methodological*, *32*(1), 61–75. doi:10.1016/S0191-2615(97)00014-3

Bin, S., & Dowlatabadi, H. (2005). Consumer lifestyle approach to US energy use and the related CO 2 emissions. *Energy Policy*, *33*(2), 197–208.

Boarnet, Marlon G., & Sarmiento, S. (1998). Can Land-Use Policy Really Affect Travel Behaviour? A Study of the Link Between Non-Work Travel and Land-Use Characteristics. *Urban Studies*, *35*(7), 1155–1169. doi:10.1080/0042098984538

Boarnet, Marlon Gary, & Crane, R. (2001). *Travel by design: the influence of urban form on travel*. Oxford University Press US.

Bourdieu, P., & Nice, R. (1984). *Distinction: A social critique of the judgement of taste*. Harvard Univ Pr.

Boxall P. C, & Adamowicz W. L. (n.d.). Understanding Heterogeneous Preferences in Random Utility Models: A Latent Class Approach.

Brownstone, D. (2008). Key relationships between the built environment and VMT. *Transportation Research Board*, 7.

Brownstone, D., & Golob, T. F. (2009). The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics*, *65*(1), 91–98. doi:10.1016/j.jue.2008.09.002

Burnard, P. (1991). A method of analysing interview transcripts in qualitative research. *Nurse education today*, *11*(6), 461–466.

Cao, X. (Jason), Mokhtarian, P. L., & Handy, S. L. (2009). Examining the impacts of residential self-selection on travel behaviour: A focus on empirical findings. *Transport Reviews*, *29*(3), 359–395.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2006). Neighborhood design and vehicle type choice: Evidence from Northern California. *Transportation Research Part D: Transport and Environment*, *11*(2), 133–145. doi:10.1016/j.trd.2005.10.001

Cervero, R., & Day, J. (2008). Suburbanization and transit-oriented development in China. *Transport Policy*, *15*(5), 315–323. doi:10.1016/j.tranpol.2008.12.011

Cervero, R., Sarmiento, O. L., Jacoby, E., Gomez, L. F., & Neiman, A. (2009). Influences of Built Environments on Walking and Cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, *3*(4), 203–226. doi:10.1080/15568310802178314

Chiou, Y.-C., Wen, C.-H., Tsai, S.-H., & Wang, W.-Y. (2009). Integrated modeling of car/motorcycle ownership, type and usage for estimating energy consumption and emissions. *Transportation Research Part A: Policy and Practice*, *43*(7), 665–684. doi:10.1016/j.tra.2009.06.002

Chliaoutakis, J. E., Koukouli, S., Lajunen, T., & Tzamalouka, G. (2005). Lifestyle traits as predictors of driving behaviour in urban areas of Greece. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(6), 413–428. doi:10.1016/j.trf.2005.05.003

Choo, S., & Mokhtarian, P. L. (2004). What type of vehicle do people drive? The role of attitude and lifestyle in influencing vehicle type choice. *Transportation Research Part A: Policy and Practice*, *38*(3), 201–222. doi:10.1016/j.tra.2003.10.005

Cockerham, W. C., Rütten, A., & Abel, T. (1997). Conceptualizing Contemporary Health Lifestyles: Moving beyond Weber. *The Sociological Quarterly*, *38*(2), 321–342.

Crane, R. (1996). On Form versus Function: Will the New Urbanism Reduce Traffic, or Increase It? *Journal of Planning Education and Research*, *15*(2), 117 –126. doi:10.1177/0739456X9601500204

Crane, R. (2000). The Influence of Urban Form on Travel: An Interpretive Review. *Journal of Planning Literature*, *15*(1), 3 –23. doi:10.1177/08854120022092890

Delucchi, M. (2004). Conceptual and methodological issues in lifecycle analyses of transportation fuels. Retrieved from http://escholarship.org/uc/item/8n77n6z7.pdf

Depecker, P., Menezo, C., Virgone, J., & Lepers, S. (2001). Design of buildings shape and energetic consumption. *Building and Environment*, *36*(5), 627–635. doi:10.1016/S0360-1323(00)00044-5

Dieleman, F. (1996). Editorial: Modeling housing choices. *Journal of Housing and the Built Environment*, *11*(3), 201–207. doi:10.1007/BF02496588

Doppelt, B. (2008). *The Power of Sustainable Thinking: How to Create a Positive Future for the Climate, the Planet, Your Organization and Your Life* (First ed.). Routledge.

Doppelt, B. (2008). *The power of sustainable thinking: how to create a positive future for the climate, the planet, your organization and your life*. Earthscan/James & James. Retrieved from http://books.google.com/books?hl=en&lr=&id=8FFbKr1hPRQC&oi=fnd&pg=PR5&dq=doppelt+power+of+sustainable&ots=RkKT05LDG2&sig=yGJHk2E9hVoc2Yze-g_tKqHkF58

Doppelt, B., Markowitz, E. M., & Initiative, C. L. (2009). Reducing Greenhouse Gas Emissions through Behavioral Change: an assessment of past research on energy use, transportation and water consumption. Retrieved from https://scholarsbank.uoregon.edu/xmlui/handle/1794/8373

Droege, P. (Ed.). (2008). *Urban Energy Transition: From Fossil Fuels to Renewable Power* (1st ed.). Elsevier Science.

Dykstra, P. A., & Wissen, L. J. G. (1999). Introduction: The Life Course Approach as an Interdisciplinary Framework for Population Studies. In L. J. G. Wissen & P. A. Dykstra (Eds.), *Population Issues*, The Springer Series on Demographic Methods and Population Analysis (pp. 1–22). Springer Netherlands. Retrieved from http://www.springerlink.com/content/u75441j405u14272/abstract/

Earl, P. E. (1986). *Lifestyle Economics: Consumer Behaviour in a Turbulent World*. Palgrave Macmillan.

El-Geneidy, A. M., & Levinson, D. M. (2006). *Access to destinations: Development of accessibility measures*. Retrieved from http://trid.trb.org/view.aspx?id=789631

Ewing, R., & Cervero, R. (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, *1780*(-1), 87–114. doi:10.3141/1780-10

Ewing, R., & Rong, F. (2008). The impact of urban form on U.S. residential energy use. *Housing Policy Debate*, *19*(1), 1–30. doi:10.1080/10511482.2008.9521624

Ewing, R., & Rong, F. (2008). The impact of urban form on US residential energy use. *Housing Policy Debate*, *19*(1), 1–30.

Ewing, Reid, & Cervero, R. (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, *1780*(-1), 87–114. doi:10.3141/1780-10

Fang, H. A. (2008). A discrete–continuous model of households' vehicle choice and usage, with an application to the effects of residential density. *Transportation Research Part B: Methodological*, *42*(9), 736–758. doi:10.1016/j.trb.2008.01.004

Featherstone, M. (1987). Lifestyle and Consumer Culture. *Theory, Culture & Society*, *4*(1), 55 –70. doi:10.1177/026327687004001003

Feng, D., Sovacool, B. K., & Minh Vu, K. (2010). The barriers to energy efficiency in China: Assessing household electricity savings and consumer behavior in Liaoning Province. *Energy Policy*, *38*(2), 1202–1209. doi:10.1016/j.enpol.2009.11.012

Flamm, B. (2009). The impacts of environmental knowledge and attitudes on vehicle ownership and use. *Transportation Research Part D: Transport and Environment*, *14*(4), 272–279. doi:10.1016/j.trd.2009.02.003

Ford, L. (2005). *Metropolitan San Diego: how geography and lifestyle shape a new urban environment*. Univ of Pennsylvania Pr.

Fujita, M. (1989). *Urban economic theory: Land use and city size*. Cambridge Univ Pr.

Giddens, A. (1991). *Modernity and self-identity: self and society in the late modern age*. Stanford University Press.

Giuliano, G., & Dargay, J. (2006). Car ownership, travel and land use: a comparison of the US and Great Britain. *Transportation Research Part A: Policy and Practice*, *40*(2), 106–124. doi:10.1016/j.tra.2005.03.002

Greening, L., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption — the rebound effect — a survey. *Energy Policy*, *28*(6–7), 389–401. doi:10.1016/S0301-4215(00)00021-5

Guerra Santin, O. (2011). Behavioural Patterns and User Profiles related to energy consumption for heating. *Energy and Buildings*, *43*(10), 2662–2672. doi:10.1016/j.enbuild.2011.06.024

Guerra Santin, O., Itard, L., & Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings*, *41*(11), 1223–1232. doi:10.1016/j.enbuild.2009.07.002

Guerra-Santin, O., & Itard, L. (2010). Occupants' behaviour: determinants and effects on residential heating consumption. *Building Research & Information*, *38*(3), 318–338. doi:10.1080/09613211003661074

Guevara, C., & Ben-Akiva, M. (2006). Endogeneity in Residential Location Choice Models. *Transportation Research Record: Journal of the Transportation Research Board*, *1977*(-1), 60–66. doi:10.3141/1977-10

Hakim, C. (2000). *Work-lifestyle choices in the 21st century: preference theory*. Oxford University Press US.

Handy, S. (1996). Methodologies for exploring the link between urban form and travel behavior. *Transportation Research Part D: Transport and Environment*, *1*(2), 151–165.

Handy, S. L., & Clifton, K. J. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation*, *28*(4), 317–346.

Handy, S., Cao, X., & Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment*, *10*(6), 427–444.

Hanemann, W. M. (1984). Discrete/Continuous Models of Consumer Demand. *Econometrica*, *52*(3), 541–561. doi:10.2307/1913464

Hankey, S., & Marshall, J. D. (2010). Impacts of urban form on future US passenger-vehicle greenhouse gas emissions. *Energy Policy*, *38*(9), 4880–4887. doi:10.1016/j.enpol.2009.07.005

Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D., & Haas, P. (2002). Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use-Studies in Chicago, Los Angeles and San Francisco. *Transportation Planning and Technology*, *25*(1), 1–27.

IEA, 2010, http://www.iea.org/index_info.asp?id=1479, last accessed on October 28, 2010

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative science quarterly*, *24*(4), 602–611.

Kamakura, W. A., & Wedel, M. (1995). Life-Style Segmentation with Tailored Interviewing. *Journal of Marketing Research*, *32*(3), 308–317.

Kaza, N. (2010). Understanding the spectrum of residential energy consumption: A quantile regression approach. *Energy Policy*, *38*(11), 6574–6585. doi:10.1016/j.enpol.2010.06.028

KENWORTHY, J. R. (2008). Energy use and CO2 production in the urban passenger transport systems of 84 international cities: findings and policy implications. *Urban energy transition: from fossil fuels to renewable power*, 211.

Kitamura, R. (2010). The effects of added transportation capacity on travel: a review of theoretical and empirical results. *Transportation*, *36*(6), 745–762. doi:10.1007/s11116-009-9245-5

Knowles, R. (1985). *Sun Rhythm Form*. The MIT Press.

Knowles, R. (2006). *Ritual House: Drawing on Nature's Rhythms for Architecture and Urban Design* (1st ed.). Island Press.

Knowles, R. L. (1978). *Energy and Form: An Ecological Approach to Urban Growth*. The MIT Press.

Kockelman, K. M., Thompson, M. R., & Whitehead-Frei, C. A. (2011). Americans' Contributions to Climate Change: Opportunities for Meeting Carbon Targets. *Journal of Urban Planning and Development*, *137*, 91.

Krizek, K. J. (2003). Residential Relocation and Changes in Urban Travel. *Journal of the American Planning Association*, *69*(3), 265.

Krizek, K. J., & Waddell, P. (2002). Analysis of lifestyle choices: Neighborhood type, travel patterns, and activity participation. *Transportation Research Record: Journal of the Transportation Research Board*, *1807*(-1), 119–128.

Kvale, S., & Brinkmann, S. (2008). *Interviews: Learning the craft of qualitative research interviewing*. Sage Publications, Inc. Retrieved from http://books.google.com/books?hl=en&lr=&id=bZGvwsP1BRwC&oi=fnd&pg=PR1&dq=qualitative+methods+interview+coding&ots=q5GLuhxwLg&sig=xj9Nw-QjlfGzEHktcPQA5hLHzxk

Lancaster, K. (1971). *Consumer demand : a new approach / Kelvin Lancaster*. Columbia studies in economics ; 5. New York :: Columbia University Press.

Lanzendorf, M. (2003). *Mobility biographies: A new perspective for understanding travel behaviour, paper presented at the 10th International Conference on Travel Behaviour Research*. Lucerne, August.

Lazer, W. (1965). Lifestyle concepts and marketing. *Dimensions of consumer behavior*, 185.

Lee, B., & Waddell, P. (2010). Residential mobility and location choice: a nested logit model with sampling of alternatives. *Transportation*, *37*(4), 587–601. doi:10.1007/s11116-010-9270-4

Lenzen, M., Dey, C., & Foran, B. (2004). Energy requirements of Sydney households. *Ecological Economics*, *49*(3), 375–399. doi:10.1016/j.ecolecon.2004.01.019

Lewis, A. (Ed.). (2008). *The Cambridge Handbook of Psychology and Economic Behaviour* (illustrated ed.). Cambridge University Press.

Lin, H.-Z., Lo, H.-P., & Chen, X.-J. (2009). Lifestyle classifications with and without activity-travel patterns. *Transportation Research Part A: Policy and Practice*, *43*(6), 626–638. doi:10.1016/j.tra.2009.04.002

Lindén, A.-L., Carlsson-Kanyama, A., & Eriksson, B. (2006). Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change? *Energy Policy*, *34*(14), 1918–1927. doi:10.1016/j.enpol.2005.01.015

Litman, T. (2005). Land use impacts on transport. *Victoria Transport Policy Institute (www. vtpi. org)*.

Litman, T. (2005). Land use impacts on transport. *Victoria Transport Policy Institute (www. vtpi. org)*. Retrieved from http://www.vtpi.org/landtravel.pdf

Maat, K., van Wee, B., & Stead, D. (2005). Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories. *Environment and Planning B: Planning and Design*, *32*(1), 33–46.

Madigan, R., & Munro, M. (1996). `House Beautiful': Style and Consumption in the Home. *Sociology*, *30*(1), 41 –57. doi:10.1177/0038038596030001004

Marshall, J. D. (2008). Energy-Efficient Urban Form. *Environ. Sci. Technol.*, *42*(9), 3133–3137. doi:10.1021/es0870471

Marshall, S., & Banister, D. (2000). Travel reduction strategies: intentions and outcomes. *Transportation Research Part A: Policy and Practice*, *34*(5), 321–338. doi:10.1016/S0965-8564(99)00034-8

Martinez, F., & Araya, C. (2000). Transport and land-use benefits under location externalities. *Environment and Planning A*, *32*(9), 1611–1624.

Mayer, K. U., & Tuma, N. B. (1990). *Event History Analysis in Life Course Research*. Univ of Wisconsin Press.

Michael, R. T., & Becker, G. S. (1973). On the new theory of consumer behavior. *The Swedish Journal of Economics*, 378–396.

Michman, R. D. (1991). *Lifestyle market segmentation*. Praeger.

Miron, J. R. (2004). Housing demand, coping strategy, and selection bias. *Growth and Change*, *35*(2), 220–261.

MIT. (2012). "Making Cleaning Energy City in China" Year 2 Report.

Mitchell, A. (1984a). Nine American Lifestyles: Values and Societal Change. *Futurist*, *18*(4), 4–14.

Mitchell, A. (1984b). *The nine American lifestyles: Who we are and where we're going* (Warner Books ed.). Warner Books.

Mokhtarian, P. L., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological*, *42*(3), 204–228. doi:10.1016/j.trb.2007.07.006

Mokhtarian, P. L., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological*, *42*(3), 204–228.

Mokhtarian, P. L., & Chen, C. (2004). TTB or not TTB, that is the question: a review and analysis of the empirical literature on travel time (and money) budgets. *Transportation Research Part A: Policy and Practice*, *38*(9–10), 643–675. doi:10.1016/j.tra.2003.12.004

Muellbauer, J. (1974). Household Production Theory, Quality, and the" Hedonic Technique." *The American Economic Review*, *64*(6), 977–994.

Mulder, C. (1996). Housing choice: Assumptions and approaches. *Journal of Housing and the Built Environment*, *11*(3), 209–232. doi:10.1007/BF02496589

Murphy, P. E., & Staples, W. A. (1979). A Modernized Family Life Cycle. *The Journal of Consumer Research*, *6*(1), 12–22.

Muthukrishnan, S. (2010). Vehicle ownership and usage charges. *Transport Policy*, *17*(6), 398–408. doi:10.1016/j.tranpol.2010.04.007

Næss, P., & regionforskning, N. institutt for by-og. (2007). *Residential location and travel in Hangzhou Metropolitan Area*. Norwegian Institute for Urban and Regional Research.

Næss, P. (2006). *Urban Structure Matters: Residential Location, Car Dependence and Travel Behaviour* (annotated ed.). Routledge.

Næss, P. (2009). Residential Self-Selection and Appropriate Control Variables in Land Use: Travel Studies. *Transport Reviews*, *29*(3), 293–324. doi:10.1080/01441640802710812

National Bureau of Statistics. (2009) Special report –Introduction of Jinan, in Jinan Statistical Yearbook 2009

Nelson, C., & Wake, N. (2005). Geodemographic Segmentation: Do Birds of a Feather Flock Together. *Retrieved August*, *25*, 2005.

Ni, M. C. (2008). *Motorization, vehicle purchase and use behavior in China: A Shanghai survey*. University of California, Davis. Retrieved from http://escholarship.org/uc/item/9kn849h1.pdf;origin=repeccitec

Noorman, K. J., & Uiterkamp, T. S. (1998). *Green Households?: Domestic Consumers, Environment, and Sustainability*. Earthscan.

Norman, J., MacLean, H. L., Kennedy, C. A., & others. (2006). Comparing high and low residential density: life-cycle analysis of energy use and greenhouse gas emissions. *Journal of Urban Planning and Development*, *132*, 10.

Novshek, W., & Sonnenschein, H. (1979). Marginal Consumers and Neoclassical Demand Theory. *Journal of Political Economy*, *87*(6), 1368–1376.

O'brien, R. M. (2007). A Caution Regarding Rules of Thumb for Variance Inflation Factors. *Quality and Quantity*, *41*(5), 673–690. doi:http://dx.doi.org.libproxy.mit.edu/10.1007/s11135-006-9018-6

Ouyang, J., J. Gao, X. Luo, Et al. (2007). A Study on the Relationship between Household Lifestyles and Energy Consumption of Residential Buildings in China. *Journal of South China University of Technology (Natural Science Edition)*, 10:171-174

Pan, H., Shen, Q., & Zhang, M. (2009). Influence of Urban Form on Travel Behaviour in Four Neighbourhoods of Shanghai. *Urban Studies*, *46*(2), 275–294. doi:10.1177/0042098008099355

Parshall, L., Hammer, S., & Gurney, K. (2009). Energy consumption and CO2 emissions in urban counties in the United States with a case study of the New York Metropolitan Area. *Fifth Urban Research Symposium, Cities and Climate Change: Responding to an Urgent Agenda* (pp. 28–30).

Pope, C., & Mays, N. (1995). Qualitative research: reaching the parts other methods cannot reach: an introduction to qualitative methods in health and health services research. *Bmj*, *311*(6996), 42–45.

Potoglou, D. (2008). Vehicle-type choice and neighbourhood characteristics: An empirical study of Hamilton, Canada. *Transportation Research Part D: Transport and Environment*, *13*(3), 177–186. doi:10.1016/j.trd.2008.02.002

Prettenthaler, F. E., & Steininger, K. W. (1999). From ownership to service use lifestyle: the potential of car sharing. *Ecological Economics*, *28*(3), 443–453. doi:10.1016/S0921-8009(98)00109-8

Prillwitz, J., Harms, S., & Lanzendorf, M. (2007). Interactions Between Residential Relocations, Life Course Events, and Daily Commute Distances. *Transportation Research Record: Journal of the Transportation Research Board*, *2021*(-1), 64–69. doi:10.3141/2021-08

Reddy, B. S., & Balachandra, P. (2010). Dynamics of Urban Mobility: A Comparative analysis of megacities of India. *Governance Working Papers*.

Reisch, L. A., & Ropke, I. (Eds.). (2005). *The Ecological Economics Of Consumption* (illustrated ed.). Edward Elgar Pub.

Roberts, P., Ravetz, J., & George, C. (2009). *Environment and the City* (New Ed.). Routledge.

Saldaña, J. (2009). *The coding manual for qualitative researchers*. Sage Publications Ltd.

Salomon, I., & Ben-Akiva, M. (1983). The use of the life-style concept in travel demand models. *Environment and Planning A*, *15*(5), 623 – 638. doi:10.1068/a150623

Salomon, I., & Ben-Akiva, M. (1983). The use of the life-style concept in travel demand models. *Environment and Planning A*, *15*(5), 623 – 638. doi:10.1068/a150623

Schipper, L., Bartlett, S., Hawk, D., & Vine, E. (1989). Linking Life-Styles and Energy Use: A Matter of Time? *Annual Review of Energy*, *14*(1), 273–320. doi:10.1146/annurev.eg.14.110189.001421

SENBIL, M., Hiroshima, H., FUJIWARA, A., & ZHANG, J. (2005). Residential and Travel Mode Choices in the Developing World: A Comparative Study of Eleven Developing Cities. *Proceedings of the Eastern Asia Society for Transportation Studies* (Vol. 5, pp. 2463–2469).

Sobel, M. E. (1981). *Lifestyle and Social Structure: Concepts, Definitions, Analyses*. Quantitative studies in social relations. New York: Academic Press.

Sorrell, S., & Dimitropoulos, J. (2007). The rebound effect. *An assessment of the evidence for economy-wide energy savings from improved energy efficiency, London*. Retrieved from http://www.blakealcott.org/pdf/LaunchSteveReboundPresentation.pdf

State Council of China. (1998) http://www.law110.com/law/guowuyuan/2025.htm, last access: March 6, 2012

Stone, B. (2005). Urban Heat and Air Pollution: An Emerging Role for Planners in the Climate Change Debate. *Journal of the American Planning Association*, *71*(1), 13–25. doi:10.1080/01944360508976402

Swait, J. (1994). A structural equation model of latent segmentation and product choice for cross-sectional revealed preference choice data. *Journal of Retailing and Consumer Services*, *1*(2), 77–89. doi:10.1016/0969-6989(94)90002-7

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819–1835. doi:10.1016/j.rser.2008.09.033

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819–1835. doi:10.1016/j.rser.2008.09.033

Train, K. (2003). *Discrete Choice Models with Simulation*. Cambridge University Press.

Van Acker, V., & Witlox, F. (2010). Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. *Journal of Transport Geography*, *18*(1), 65–74. doi:10.1016/j.jtrangeo.2009.05.006

Van Raaij, W. F., & Verhallen, T. M. M. (1983). A behavioral model of residential energy use. *Journal of Economic Psychology*, *3*(1), 39–63. doi:10.1016/0167-4870(83)90057-0

Van Raaij, W. F., & Verhallen, T. M. M. (1983). Patterns of residential energy behavior. *Journal of Economic Psychology*, *4*(1–2), 85–106. doi:10.1016/0167-4870(83)90047-8

Vance, C., & Hedel, R. (2007). The impact of urban form on automobile travel: disentangling causation from correlation. *Transportation*, *34*(5), 575–588. doi:10.1007/s11116-007-9128-6

Veal, A. J. (1993). The concept of lifestyle: a review. *Leisure Studies*, *12*(4), 233–252. doi:10.1080/02614369300390231

Waddell, P. (2001). Towards a Behavioral Integration of Land Use and Transportation Modeling.

Walker, J. L., & Li, J. (2007). Latent lifestyle preferences and household location decisions. *Journal of Geographical Systems*, *9*(1), 77–101.

Wang, D., & Chai, Y. (2009). The jobs–housing relationship and commuting in Beijing, China: the legacy of Danwei. *Journal of Transport Geography*, *17*(1), 30–38. doi:10.1016/j.jtrangeo.2008.04.005

Weber, C., & Perrels, A. (2000). Modelling lifestyle effects on energy demand and related emissions. *Energy Policy*, *28*(8), 549–566. doi:10.1016/S0301-4215(00)00040-9

Weber, M. (1968). *Economy and Society; an Outline of Interpretive Sociology*. New York: Bedminster Press.

Wei, Y.-M., Fan, Y., Han, Z.-Y., & Wu, G. (Eds.). (2009). *Energy Economics: Modeling and Empirical Analysis in China* (1st ed.). CRC Press.

Wei, Y.-M., Liu, L.-C., Fan, Y., & Wu, G. (2007). The impact of lifestyle on energy use and CO2 emission: An empirical analysis of China's residents. *Energy Policy*, *35*(1), 247–257. doi:10.1016/j.enpol.2005.11.020

Wei, Y.-M., Liu, L.-C., Fan, Y., & Wu, G. (2007). The impact of lifestyle on energy use and CO2 emission: An empirical analysis of China's residents. *Energy Policy*, *35*(1), 247–257. doi:10.1016/j.enpol.2005.11.020

Wei, Y.-M., Liu, L.-C., Fan, Y., & Wu, G. (2007). The impact of lifestyle on energy use and CO2 emission: An empirical analysis of China's residents. *Energy Policy*, *35*(1), 247–257. doi:10.1016/j.enpol.2005.11.020

Weiss, M. J. (1989). *The clustering of America*. Harper & Row New York.

Wu, G., Yamamoto, T., & Kitamura, R. (1999). Vehicle Ownership Model That Incorporates the Causal Structure Underlying Attitudes Toward Vehicle Ownership. *Transportation Research Record: Journal of the Transportation Research Board*, *1676*(-1), 61–67. doi:10.3141/1676-08

Xie, Y., N. Li, S. Chen, et al. (2007). Survey and Partial Correlation Analysis of Energy Consumption of Residential Buildings in Changsha City, *Gas and Heat*, 5: 85-88

Xinyu Cao, Patricia Lyon Mokhtarian, Susan L Handy, & Xinyu Cao, P. L. M. and S. L. H. (2007). Cross-sectional and quasi-panel explorations of the connection between the built environment and auto ownership.

Zahavi, Y., & Talvitie, A. (1980). REGULARITIES IN TRAVEL TIME AND MONEY EXPENDITURES. *Transportation Research Record*, (750).

Zegras, C. (2010). The Built Environment and Motor Vehicle Ownership and Use: Evidence from Santiago de Chile. *Urban Studies*, *47*(8), 1793 –1817. doi:10.1177/0042098009356125

Zegras, C., Lee, J. S., & Ben-Joseph, E. (2012). By Community or Design? Age-restricted Neighbourhoods, Physical Design and Baby Boomers' Local Travel Behaviour in Suburban Boston, US. *Urban Studies*, 49(10), 2169-2198

Zhao, J. (2009). Preference accommodating and preference shaping : incorporating traveler preferences into transportation planning. Thesis. Retrieved December 7, 2010, from http://dspace.mit.edu/handle/1721.1/54221

Zhou, N. (2010). Energy for 500 Million Homes: Drivers and Outlook for Residential Energy Consumption in China.

Zukin, S. (1990). Socio-Spatial Prototypes of a New Organization of Consumption: The Role of Real Cultural Capital. *Sociology*, *24*(1), 37 –56. doi:10.1177/0038038590024001005