The Pennsylvania State University

The Graduate School

College of Agricultural Sciences

ESSAYS ON LAND DEVELOPMENT, HOUSING MARKETS, AND ENVIRONMENT

A Dissertation in

Agricultural, Environmental and Regional Economics & Operations Research

by

Haoying Wang

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

December 2014

The dissertation of Haoying Wang was reviewed and approved* by the following:

Spiro E. Stefanou
Professor of Agricultural Economics
Faculty in Operations Research
Dissertation Co-Adviser
Chair of Committee

Richard Ready
Professor of Agricultural and Environmental Economics
Dissertation Co-Adviser
Graduate Program Coordinator

James Shortle
Distinguished Professor of Agricultural and Environmental Economics
Faculty in Operations Research

Michael Akritas
Professor of Statistics

H. Allen Klaiber
Associate Professor of Agricultural, Environment and Development Economics
The Ohio State University
Special Member

*Signatures are on file in the Graduate School.

ABSTRACT

This dissertation research takes three different approaches to study the urban land development process, mainly from a supply side perspective. The three approaches are organized into different essay chapters. Each chapter has its independent framework and methodology. Chapter 2 uses numerical optimization methods to explore how residential households allocate across space with introduction of distance related amenity/disamenity, as well as under non-monocentric urban spatial structure. Chapter 3 proposes an agent-based simulation of housing market and land development to understand the role of home improvement as part of housing supply. An important feature of the proposed agent-based simulation model is that it allows for neighborhood spillover effects among home improvement activities. Chapter 4 assembles a micro panel data to empirically investigate the relationship between manufacturing decline and increased residential land development in Allegheny county, PA. One policy implication of the results is that, there might be a significant underestimate of household willingness to pay (WTP) for better air quality, due to the supply side effect of manufacturing decline induced air quality change.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

It is impossible for me to finish my dissertation without the guidance of my advisors and committee members, help from peer-graduate students in AEREC program and friends, and support from my dear wife.

First of all, I would like to express my deepest gratitude to my advisors, Dr. Spiro Stefanou and Dr. Richard Ready, for their excellent mentoring, advices, patience, and providing me with a very supportive environment for study and research. I would also like to express my appreciation to Dr. Allen Klaiber, who led me to the area of land use change and urban economics. I have had too many fruitful conversations with Dr. James Shortle, who is a great thinker. I am glad we can continue working on the same project. Special thanks goes to Dr. Michael Akritas, a great statistician, who was willing to participate in my dissertation committee at the last moment.

Without the first three years of coursework at Penn State, I would not know how to start my dissertation research. There are too many great teachers I want to say thank you. Dr. Herman Bierens from economics, Dr. Edward Jaenicke, Dr. Karen Fisher-Vanden, and Dr. James Shortle from AEREC, Dr. David Hunter and Dr. Debashis Ghosh from statistics, among many others, Thank You!

Research can never be isolated from life. I have enjoyed the past four and half years at Penn State. I love the campus and the town. But I love my friends there more. Truong Chau, a globalized Asian boy, a good mechanic, gardener, runner, biker. Oh, you deserve too many titles. And yes, I have enjoyed our conversations, neighborship, and friendship. I believe our friendship will go forever. Minghao Li, we have too many things in common. Let's continue our friendship and collaboration. Yuan Huang, a friend who is always ready to help. Too many names in my mind, and my research and life have benefited from our friendship in many ways.

I would also like to say thank you to Dr. Alan Ker and Dr. Satheesh Aradhyula back to University of Arizona, as well as Dr. Minshu Lin (林民书) at Xiamen University. In my early stage of graduate studies, these three mentors prepared me well for beginning the journey of Ph.D. Studies.

Finally, I would like to thank my wife Si (Lucy) Luo (骆思), who was always there cheering me up and stood by me through the good times and bad; my father Dongwang Wang (王东旺), my mother Huirong Xie (颉会荣), who never had chance to complete even their basic education, but they have taught me well in becoming an honest and confident person.

Haoying Wang
November 5, 2014

I: Introduction

1. Motivation and Overview

A city is a combination of physical and human environments in a compact and dense form. From a structural point of view, a city consists of three fundamental activities: housing production, non-housing production, and transportation system. The non-housing production usually consists of vast range of goods and services. But still, the real estate market is of the first importance not only because it represents the most valuable asset to the city, but also because it defines the spatial structure and land use pattern of the city to a great extent. This simplification of urban activities was first summarized in Mills (1967). From a consumer's perspective, the three categories also contribute to almost all of the household expenditure. A common feature of these three activities is that they all require land inputs. Land is a scarce resource to cities. If more land is used to build freeways in a metropolitan area, then less land will be allocated to residential development and therefore residents have to bear higher housing price or a smaller living space. On the other hand, indeed, more freeways can reduce commuting time (cost) and congestion cost. Trade-offs in such fashion can be interpreted from alternative perspectives. From an urban planning perspective, the optimal allocation of land to different uses defines an urban structure which reflects the spatial equilibrium outcome of location choices. From a market perspective, the trade-off is about factor (land, capital, labor, and etc.) substitution - the most important characteristic of urban structure, and the underlying driver of location choices. In the long run, the observed configuration of a city should always tend to reveal the best use of its most valuable resource - land, and the substitution effects of its factors. The scope of this dissertation research is to understand the role of land in urban development from both perspectives.

Since the very first day when city was born to the planet, it has been planned, managed, and regulated. At the end of the stone age, for the first time in human history cities appeared in response to population pressure, as well as to meet the organizational requirement of agriculture and the need of barter. Even the smallest city has a non-random location and designed architecture and it evolves over time, which makes it different from even the largest shelter in the stone age. From a purely structural point of view, a city is an efficient combination of location, architecture, and resources which largely determine its function and destiny. The efficiency arises from the fact that cities have greatly improved the productivity of society. In economics' theoretical definition, cities are more about density and proximity - the absence of physical space between people and firms (Glaeser, 2007). Modern cities have become more and more complex than ancient cities, and it is no longer a place to manage irrigation water or trade agricultural products only. But it still reflects the dense relationship between human habitation and physical environment, only in an intricate format and with likely higher efficiency. On the other hand, precise planning, proper management, and detailed regulations become more necessary than ever to sustain the operation and development of modern cities. The questions are: how to do it, and who should do it?

The modern city is an arrangement between its residents and governments from both an institutional and a financial perspective. It is very different from a country, in the sense that it is more open while it is also more dense and compact. The involvement of governments spreads to every corner of every street in the city. For all urban affairs in which governments are involved, land use and housing markets are among the most common and sensitive. Mayer and Somerville (2000) find that metropolitan areas with more extensive regulation can have up to 45 percent fewer starts and housing price elasticities that are more than 20 percent lower than those in less-regulated markets with a panel data of 44 U.S. metropolitan areas between 1985 and 1996. Ihlanfeldt (2007) further suggests that greater regulation restrictiveness tends to increase housing price and decrease land price by studying more than 100 Florida cities. The mode of government involvement has evolved over time as well. The way that governments participate in urban development nowadays goes far beyond its traditional roles. Garreau (1991) defines the new form of government involvement in urban development as shadow government [1]. These shadow governments, or the derivatives of governments, are highly organized and locally involved. But still, the most important role of city governments until today is to provide comfortable living space and environment to its residents, while they often fail to do so.

The value (or profit to the monopolistic developer in the case of edge cities) of a city depends on its resources, functions, and structure. To maintain the value and keep it growing, the first tool that is necessary is urban planning. The primary characteristic of a city is its density (and therefore proximity and externalities) which is something that urban planning and urban political economy

[1] Garreau (1991) named the sixth chapter of his bestselling book <Edge City: Life on the New Frontier> as Shadow Government, and the chapter is about some fascinating stories in Phoenix - the fastest growing large metropolitan area in United States within last several decades. He writes: "These shadow governments (forms of private-enterprise governments) have powers far beyond those ever granted rulers in this country before. Not only can they prohibit the organization of everything from a synagogue to a Boy Scout troop; they can regulate the color of a person's living room curtains."

should take into consideration first. The importance of density lies not only on the fact that city residents' quality of life depends on the amount of space they occupy, but also on how the city's functions are efficiently integrated together. Therefore, even at a purely technical dimension, urban planning is a task about density, integrity, and efficiency. These technical dimensions form the foundation for higher dimensions of a city - welfare, culture, and the spatial political economy.

Since early 20th century, economists and urban planners have been searching for structural understanding of the technical dimension of cities, and further linking it to the socio-economic concerns of urban and regional studies. The early stage of the theory focuses mostly on the productivity origin of urban areas. In other words, cities arise on the ground of the economic advantages of large-scale activities and market forces (Mills and Hamilton, 1989). Christaller (1933) argues that it is the population threshold and the geographic range that facilitates the emergence a system of central places with regular hierarchy based on scale economies. The central place theory was further developed by Lösch (1954) into a more general theory of locations. Around the middle of the 20th century, economists and regional scientists started paying attention on the demand side of cities. Research topics related to land use, efficiency of transportation system, housing markets became popular topics in the literature.

There are several reasons for this transition. First, there was no particular tradition of urban and regional economics studies in United States until the World War II. August Lösch's book titled <The Economics of Location> was first published in 1941 in Germany, and translated into English in 1954. The most influential book <Location and Space-Economy: A General Theory Relating to Industrial Location, Market Areas, Land Use, and Urban Structure> in regional science by Walter Isard was published in 1956. The first United States version of a comprehensive urban economics book was written by William Alonso and published in 1964.

The contextual reason for the rise of urban economics is the postwar socio-economic status of Americans. There were three important elements to urban economy during that age: baby boom, subdivision, and automobile. From 1950 to 1980, the American population increased by 50%, while the number of automobiles increased is four times of which. The improvement of transportation tools and road conditions had largely changed how Americans chose to live[2].

[2]During that time, as Jackson (1985) described, "the best symbol of individual success and identity was a sleek, air-conditioned, high-powered, personal statement on wheels."

In the meantime, it was an age of expansive optimism, low inflation, affordable energy, and subsidies. Only within two decades after the World War II ended, new subdivisions and new towns quickly sprawled from coast to coast. Urban economists started paying analytical attention on the new subdivision and town development phenomenon in 1970s (e.g., Ottensmann, 1977).

The development of optimization tools was the driving force for the rise of urban economics as a discipline. During and after the World War II, the development of operations research has made unprecedented progress on optimization tools, especially the programming methods which was very soon found to be useful in solving urban planning problems. An early example on using programming methods in land use modeling is Schlager (1965). Brill (1979) gave a comprehensive and critical review on the early stage of applying optimization tools in urban planning and public-sector planning. The use of optimization tools has evolved over time as well. As summarized by Keirstead and Shah (2013), in recent literature researchers often combine optimization routines with other techniques, as part of a more complex behaviour-based interactive system.

In modern age, the objective of urban planners and policy makers is to ensure the sustainable growth of their cities in both economic and environmental measures, as well as the maximization of the welfare of their residents. A city's economic and environmental performance is related to but beyond its architecture form, and the measures of economic and environmental performance can be very quantitatively involved. The complexity arises, as pointed out by Keirstead and Shah (2013), in part because more active forms of urban planning are often required in response to the limitations intrinsic in urban system, such as transportation and public health constraints. Modern cities come into shape as system planning and technology become essential parts of urban evolution process along with other factors (e.g., religion, culture, and politics). However, the planning and development of modern cities are still subject to natural resources, demographics, finance, and regulatory factors. The economics approach to urban planning and development problem puts main emphasis on people instead of places (Glaeser, 2007). Therefore, the economics style urban policies always have a flavor of cost-benefit analysis and welfare maximization, which is different from place-based policies and architecturally oriented policies. The potential conflicts with other disciplines can lead to profound challenges in practice. But one distinction with economics approach is that it always conveys a clear equilibrium structure which has the advantage of being able to make more precise inference from.

Looking into future, several trends have become more and more clear as the tool set of economists and urban planners gets richer and more powerful. First, even though the optimization-based models can still be used as benchmark models, more realistic behaviour models based on a disaggregated view of urban activities will be dominating the practice, as Keirstead and Shah (2013) pointed out. As argued at the very beginning, a city is a combination of people and their living environment. The combination is not just some simple additive relations, but more towards a sustainable system. To explore the structure of this system and the feedback mechanism between a city and its residents, we have to start with the heterogeneous individual behaviours of each agent from the bottom.

The second trend is that the scale and dimension of problems faced by economists and urban planners have fundamentally changed overall last two decades. Cities are much closer to each other now. With exponentially expanding internet resources, emails, instant messages, and so on, the fact is that communication has reshaped everything. Cities are no longer isolated from each other by any metrics, even just for one day. Residents now can easily learn from each other without making friends first. The revolution of communication technologies has created knowledge-based cities, while it has also substantially increased the density of the modern city. Jacobs (1970) argued that dense urban areas make intellectual cross fertilization easier in combining old ideas and generating new innovations. Undoubtedly, modern communication technologies have made this cross fertilization even easier and more effective. The classic urban economics models to date have focused on a snapshot equilibrium in one urban area. But the evolving world approaches to a well connected network of cities, which calls for urban economics models capable of solving large scale network problems. The temporal dimension in traditional structural modeling is often ignored. Now, as cities evolve faster and faster, their residents interact more and more frequently, multidimensional modeling becomes necessary to support city planning and management.

Lastly, the importance of the environmental dimension of urban life is emerging with greater public interests. This is a direct consequence of increasing density, which demands more and more concerns in urban planning. The urban environmental issues had never been a serious concern until early 1960s in the United States. The first U.S. urban environmental initiative is dealing with air pollution. The first practitioner is the state of California who were struggling against their unique photo-chemical smog issue. Beginning with the 1964 model year, all new automobiles sold in California had to equip with a crankcase control device certified by the Motor Vehicle Pollution Control Board. Then quickly, California's motor vehicle exhaust standards for new cars went into effect in 1966. The regulations were very effective, and housing markets tended to be very responsive. According to the report submitted to California Air Resources Board by Trijonis et al. (1985), air quality as measured by light extinction, was a significant determinant of home sale price. According to their estimates, the annual basin-wide benefits of a hypothetical 10% improvement in air quality in the Los Angeles Area range from approximately $ 250 million to $ 617 million. In short, environmental concern has become another significant force that shapes the pattern of urban development. The current research of urban economics still has more to explore beyond its conventional framework. A broad question left to answer is, how the regulations on environmental dimension have shaped land use and urban development across major metropolitan areas. In the literature, the focus of attention has been on the demand side and the capitalization of environmental qualities into property values using hedonic pricing models (e.g., Smith and Huang, 1995; Chay and Greenstone, 2005). From the supply side, however, we still lack solid investigations.

2. Literature

Why do so many people cluster next to each other in cities? What are the environmental and social cost of density? How does living close to others change us? As summarized in questions by Glaeser (2007), answers to these questions, theoretically and empirically, converge together and emerge into a rich literature on urban economics to related urban issues. The early stage of the urban economics literature had a self-evident structural appearance. Analysis was usually confined within a simplified framework, such as the Alonso-Mills-Muth, Herbert-Stevens, Centre-Periphery, and Rosen-Roback models. Most of these models have a footprint of the monocentric city framework. The popularity of structural style models has a lot to do with the mathematical tools available. The results of these structural models are analytical (often in the forms of comparative statics). In practice, their results have limitations. The first limitation is that the empirical applications of these models require calibration of parameters, which can be imprecise and lead to wrong inferences. Another limitation is that the comparative static analysis is often ambiguous. Therefore, the implications of the results largely depends on the model setup and the interpretation of parameters. In Ross and Yinger (1995), for example, change in the transportation cost has an ambiguous effect on population size while it is of great concern to urban policy makers. Zhang and Sasaki (2000) demonstrate some unambiguous results but only under the assumptions of no land input into production and exogenous wage rate.

In the neoclassical framework, the basic characteristics of aggregative urban structure models is the market responses to opportunities for production and income (Mills, 1967). Therefore, properties of utility functions and production functions play crucial roles in all analytical urban economics models. As argued by Glaeser (2007), most of urban economics theories can be defined as a set of spatial equilibrium models. Among which, two are the standing pillars: Alonso-Mills-Muth model and Rosen-Roback model. The Alonso-Mills-Muth model focuses on trade-off among different costs of living in urban area given income level fixed in a metropolitan area (Alonso, 1964; Mills, 1967; Muth, 1969). The Rosen-Roback model focuses on the trade-off among income level, amenities and housing costs across metropolitan areas (Rosen, 1979b; Roback, 1982). The conclusions from these aggregative models can be different from disaggregated models. For example, the Alonso-Mills-Muth model predicts that population density is a decreasing function of distance to urban center, which is not necessarily the case in the Herbert-Stevens model.

A common feature of these analytical urban economics models is the ignorance of network effects. The early central place theory (Christaller, 1933; Lösch, 1954) did have some elements of network effects built in, though not in a rigorous fashion. Modeling of network effects is not an easy exercise, as described by Boyce (2007):

"Formulation, estimation, validation and application of a large-scale location and travel model involve many compromises pertaining to the representation of spatial and temporal detail, the number of market segments, and the transportation network itself, as well as the constraints of data. Once estimated and solved computationally, the detail of the forecast is often quite overwhelming, and the reasons for the overall pattern of location and travel choices represented in the solution may be more murky than transparent."

Therefore, the difficulty in mathematical representation does not fit the goal of seeking rigorous analytical results in classic structural modeling. As computational techniques and new algorithms being developed, however, large-scale urban economics modeling with network effects should be a fruitful direction for future research.

The empirically oriented urban economics studies emerged in 1980s and 1990s. At that moment, the traditional optimization approach and comparative static analysis seems heading an end. Urban planners and policy markers faced a coming urban era of information and technology, which in many ways has changed both the demand and supply for urban and regional studies. Another sufficient condition for empirically oriented research to emerge is the development of statistics and econometrics tools. Even though econometrics methods were developed around the same time as urban economics and regional science, it was until 1980s and 1990s major journals started publishing econometric analysis papers on urban issues. Some of the empirical works in very early stage are Steinnes and Fisher (1974), Straszheim (1975), Rosen (1979a), and Goodman (1988). Since 1990s, the empirical study of urban (and regional) economics has moved forward to a new transition. The development of computation power and software packages, as well as the possibility of collecting vast amount of micro level land use and household data, have greatly facilitated the empirical studies in the literature. Models like hedonic pricing model, duration model, discrete choice model, sorting model (Bayer and Timmins, 2005) are among popular choices. For example, Smith and Huang (1995) gave an early review on using hedonic pricing models to value air quality. Cunningham (2006) studied the timing of land development using a duration model. Carrión-Flores and Irwin (2004) studied the determinants of residential land conversion and rural-urban fringe sprawl using probit model.

In either forms, theoretical or empirical, land values and land use pattern have been a major theme through the urban economics literature. And it also inspires the spirit of this dissertation research.

3. Objective

The research of this dissertation stands on the classic monocentric city framework and looks forward into the future of urban economics research. The scope of the series of research proposed in this dissertation is on how cities use their most valuable resource - land, and on factors affecting land use hence the urban spatial structure. The main body of this research consists of three essays, from Chapter 2 to Chapter 4.

The first essay takes a bottom-up aggregative perspective to explore an ideal scenario under which a city optimally allocates land to its residents. In this study, both the spatial variation of amenities and inter-urban structure are modeled endogenously. The objective of this study is to extend the conventional optimization-based approach and make it more flexible in evaluating the efficiency of urban land use. To demonstrate the feasibility and applicability of the model, numerical examples are designed with different artificial scenarios. In addition, the monocentric city framework is extended to a duocentric city framework which is more realistic in describing modern urban structure, as one step forward towards modeling urban spatial structure as a network.

The next two essays focus on a more specific urban economics issue - housing supply. In the literature, much more attention has been placed on the demand side of housing markets. The lack of deep understanding of housing supply has limited our valuation on land use policies, housing policies, and even the efficiency of entire urban system. The task of these two essays is to contribute some alternative observations to the supply side of urban housing markets. The second essay studies the land development and housing supply mechanism at micro level using agent-based simulation models. The goal of the simulation study is to understand how home improvement acts as a part of housing supply and alters land development pattern. The simulated model also highlights the importance of neighborhood spillover effects from home improvement activities.

The third essay establishes an empirical strategy to investigate the relationship between manufacturing decline and increased residential land development in Allegheny County, Pennsylvania. The study particularly focuses on local air pollution level which serves as a proxy for manufacturing decline. The results of this study have important implications for evaluating household willingness to pay for better air quality through housing market.

Reference

1. Alonso, W. 1964. *Location and Land Use*. Cambridge, MA: Harvard University Press.
2. Bayer, P., and C. Timmins. 2005. "On the equilibrium properties of locational sorting models." Journal of Urban Economics 57(3): 462-477.
3. Boyce, D. 2007. "Future research on urban transportation network modeling." Regional Science and Urban Economics 37(4):472-481.
4. Brill, E. D. 1979. "The Use of Optimization Models in Public-Sector Planning." Management Science 25(5): 413-422.
5. Carrión-Flores, C., and E. G. Irwin. 2004. "Determinants of Residential Land-Use Conversion and Sprawl at the Rural-Urban Fringe." American Journal of Agricultural Economics 86(4): 889-904.
6. Chay, K. Y., and M. Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market." Journal of Political Economy 113(2): 376 - 424.
7. Christaller, W. 1933. Die zentralen Orte in Süddeutschland. Gustav Fischer, Jena.
8. Cunningham, C. R. 2006. "House Price Uncertainty, Timing of Development, and Vacant Land Prices: Evidence for Real Options in Seattle." Journal of Urban Economics 59(1): 1-31.
9. Garreau, J. 1991. Edge City: Life on the New Frontier. New York: Doubleday.
10. Glaeser, E. L. 2007. "The Economics Approach to Cities." NBER Working Paper Series, No. 13696.
11. Goodman, A. C. 1988. "An econometric model of housing price, permanent income, tenure choice, and housing demand." Journal of Urban Economics 23(3): 327-353.
12. Ihlanfeldt, K. R. 2007. "The effect of land use regulation on housing and land prices." Journal of Urban Economics 61(3): 420-435.
13. Jackson, K. T. 1985. Crabgrass Frontier: The Suburbanization of the United States. New York: Oxford University Press.
14. Jacobs, J. 1970. The Economy of Cities. New York: Vintage Books Press.
15. Keirstead, J., and N. Shah. 2013. "The Changing Role of Optimization in Urban Planning." in A. Chinchuluun et al. (eds.) *Optimization, Simulation, and Control*, Springer Optimization and Its Applications 76: 175-193.
16. Lösch, A. 1954. The Economics of Location, 2nd Revised Edition. New Haven: Yale University Press.
17. Mayer, C. J., and C. T. Somerville. 2000. "Land use regulation and new construction." Regional Science and Urban Economics 30(6): 639-662.

18. Mills, E. S. 1967. “Transportation and Patterns of Urban Development: An Aggregative Model of Resource Allocation in a Metropolitan Area.” The American Economic Review 57(2): 197-210.
19. Mills, E. S., and B. W. Hamilton. 1989. Urban Economics, 4th Edition. Scott, Foresman and Company.
20. Muth, R. 1969. Cities and Housing. Chicago: University of Chicago Press.
21. Ottensmann, J. R. 1977. “Urban Sprawl, Land Values and the Density of Development.” Land Economics 53(4): 389-400.
22. Roback, J. 1982. “Wages, Rents, and the Quality of Life", Journal of Political Economy 90(4): 1257-1278.
23. Rosen, H. S. 1979a. “Housing decisions and the U.S. income tax: An econometric analysis.” Journal of Public Economics 11(1): 1-23.
24. Rosen, S. 1979b. “Wage-Based Indexes of Urban Quality of Life." In *Current Issues in Urban Economics*, edited by P. Mieszkowski and M. Straszheim. Baltimore: Johns Hopkins University Press.
25. Schlager, K. J. 1965. “A Land Use Plan Design Model.” Journal of the American Institute of Planners 31(2): 103-111.
26. Smith, V. K., and J. Huang. 1995. “Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Models." Journal of Political Economy, 103 (2): 209 - 27.
27. Steinnes, D. N., and W. D. Fisher. 1974. “An Econometric Model of Intraurban Location.” Journal of Regional Science 14: 65-80.
28. Straszheim, M. R. 1975. “An Econometric Analysis of the Urban Housing Market.” NBER Books, National Bureau of Economic Research, No. stra75-1.

II: Herbert-Stevens Model Revisited: Monocentric City and Duocentric City

1. Introduction

The rise of urban and regional economics can be dated back to the nineteenth and early twentieth centuries, due to the work by Johann Heinrich von Thünen, Walter Christaller, Henry George, August Lösch, among others. More recently, the contemporary work by William Alonso, Richard F. Muth, Edwin S. Mills, and Water Isard has become standing pillars to the field. A classic theme of these early stage urban economics modeling is to integrate transportation with land use and search for equilibria between two. Later on, environment becomes another critical component to be integrated into the agenda of urban economics modeling and policy making. The notion of amenities in the seminal work by Rosen (1979) and Roback (1982) is one of the earliest attempts to incorporate environmental components into urban economics modeling. Moore and Kim (1995) proposed a conceptual model framework to integrate environment (pollution control) into transportation and land use modeling basing on Mills (1967, 1972) and Guldmann (1979). Yang and Fujita (1983) studied the welfare properties of spatial equilibrium models with open space considered as a local public good. A recent example of incorporating environment into urban spatial structure modeling is Wu and Plantinga (2003). Geerlings and Stead (2003) provided a critical review and rich documentary evidence on the need for integrating transportation, land use, and environment into research programs and policy regimes.

There are two different perspectives regarding the modeling of urban spatial structure, the aggregative perspective and the disaggregated perspective. A key feature of the aggregative approach is that households are assumed to have identical income levels and preferences, i.e., location decisions are made by a representative household. Most of the Alonso-Mills-Muth (Alonso, 1964; Mills, 1967, 1972 ; Muth, 1969) style models and applications take the aggregative approach (e.g., Brueckner, 1983; Arnott et al., 1999; Timothy and Wheaton, 2001; Wu and Plantinga, 2003). Among the large body of empirical studies with hedonic pricing models, urban households and residents also tend to be characterized by a common underlying utility function that only tells something about the marginal resident. As Glaeser (2007) pointed out, however, the marginal resident's willingness to pay on housing attributes and environmental amenities may not represent the average willingness to pay across the population.

In disaggregated models, households are allowed to have different income levels and heterogeneous preference structure. Herbert and Stevens (1960) is the first model of urban spatial structure that has the flavor of disaggregated perspective, where households are grouped into different household strata instead of being represented by one representative household. However, the household preference structure is not explicitly established in the original model. Schweizer et al. (1976) is among the first set of studies where households are explicitly modeled into different classes with heterogeneous preferences and different endowments. In Yang and Fujita (1983), similar household structure is adopted. In recent literature, Magliocca et al. (2011) incorporated heterogeneous households into a spatially disaggregated, economic agent-based model of urban land use. Among other recent studies taking the disaggregated perspective on urban spatial structure, theoretical development and empirical applications on locational sorting models are good examples (e.g., Bayer and Timmins, 2005; Klaiber and Phaneuf, 2010; Kuminoff and Jarrah, 2010). An alternative way to look at the difference between aggregative models and disaggregated models is through the treatment of space. Aggregative models tend to use continuous representation for space, while disaggregated models more likely use discrete space (Pagliara and Wilson, 2010)[1]. The discrete space, more generally the zone system, can provide a more tractable platform for interaction-based urban modeling (e.g., Chang and Mackett, 2006).

In this paper, the urban residential land use model of Herbert and Stevens (1960) is revisited with heterogeneous households and spatially disaggregated environmental amenities. The Herbert-Stevens model was originally constructed for the Penn-Jersey Transportation Study as part of a larger model designed to locate all types of land use activities (Herbert and Stevens, 1960). The goal of the model is to determine the equilibrium location pattern of an urban residential land market using linear programming (LP). There are two major issues in the original formulation of the Herbert-Stevens model, lack of economic interpretation on market equilibria, and computation difficulty. The core of Wheaton (1974) and Anderson (1982)'s development on the original Herbert-Stevens model is to incorporate the theory of competitive land bidding which was formally developed by Alonso (1964). In these models, implicitly, landowners (take the role of urban planner) auction their land parcels to those households offering the highest net return to the land. The general mechanism to

[1]Interestingly, as pointed out by Pagliara and Wilson (2010), the Herbert-Stevens model can be considered as the translation of Alonso (1964)'s model into discrete space. Also, the Herbert-Stevens model was actually proposed later than Alonso's monocentric model. The early version of Alonso's model appeared in 1960 as well, but it was considered to be difficult to apply. The Herbert-Stevens model was developed to provide an analogous approach that is more workable given the tools available to economists in 1960s.

achieve equilibrium is to allocate discrete land zones in a rent-maximizing manner. However, in both Wheaton (1974) and Anderson (1982) households are assumed to be identical. This aggregative treatment also appeared in other following studies (e.g., Timothy and Wheaton, 2001). Among recent developments to the original Herbert-Stevens model, Chang and Mackett (2006) developed the model into a non-cooperative game framework in which heterogeneous household classes compete (bid) for locations. Kuminoff and Jarrah (2010) built their model upon Wheaton (1974)'s framework but with households differentiated through income and preferences.

The task of this paper is to develop the Herbert-Stevens model into a solvable disaggregated model which integrates transportation, residential land use, and environment using numerical tools. Basing on which, there are two research questions to be addressed in this paper. First it is interesting to explore what is the difference between disaggregated models and aggregative models in predicting and interpreting urban landscape. Another more policy relevant question is that, what further insights can a non-monocentric model bring to urban planners and policy makers regarding urban spatial structure.

The paper is organized in the following structure. Section 2 sets up the basic monocentric model. Section 3 proceeds with algorithm and a numerical example for the monocentric model. Section 4 incorporates spatial disamenity as an extension to the model. Section 5 develops the monocentric model into a non-monocentric model - the duocentric model. Economic interpretation of the models and results is discussed in section 6, and section 7 concludes the paper.

2. The Monocentric Model

The modern city comes into shape as economic planning and technology become essential parts of urban evolution process along with other forces (e.g., religion, culture, and politics). On the other hand, the planning and development of modern cities are indeed subject to land, financial resources, demographics, and regulatory factors. As pointed out by Keirstead and Shah (2013), more active forms of urban planning are often required in response to the limitations of urban growth, e.g., transportation and public health constraints. One of the basic ideas of this paper is to introduce additional constraints beyond land resources into the Herbert-Stevens model.

According to Herbert and Stevens (1960), the model formulation begins with the following set of parameters:

(1) The demand for housing is given by a population of n household strata (i), and each household stratum consists of N_i members;

(2) The supply of land is given by an urban area which can be divided into m zones (j), and each has an area of L_j;

(3) The technology of housing industry makes it feasible to choose among p housing types (k), and each with a unique construction cost C_k attached. The construction cost covers any nominal profit to land developers or home builders if different from land owners;

(4) Each housing type (k) requires a net use of land associated with it, l_k;

(5) Members within each household stratum share identical income level and preferences which determine the amount they are willing to pay for house type k at location j, R_{ijk};

(6) The equilibrium residential land market problem is to determine how many members of household stratum i will live at location j with housing type k chosen, and the decision variable is defined as x_{ijk}.

Using all notations and definitions specified above, the optimal configuration of residential land market is given by solving the following LP problem:

$$\max_{x_{ijk}} \sum_i \sum_j \sum_k (R_{ijk} - C_k) x_{ijk}$$
$$s.t. \begin{cases} \sum_i \sum_k l_k x_{ijk} = L_j & j = 1, \ldots, m \\ \sum_j \sum_k x_{ijk} = N_i & i = 1, \ldots, n \\ x_{ijk} \geq 0 & k = 1, \ldots, p \end{cases} \tag{1}$$

As it has been pointed out in Wheaton (1974) that, the formulation in (1) is not a pure/ordinary transportation problem in LP, but rather a generalized transportation problem[2]. The generalized transportation problem is more com-

[2]Transportation problem is one of the classic applications of LP models. The basic problem is to schedule a transportation route or network among the demand and supply of one single commodity at different locations, while the total transportation cost is minimized. The main difference between a pure/ordinary transportation problem and a generalized transportation problem is on the structure of constraints. In a generalized transportation problem, there is

plicated and may not be solved with algorithms for pure transportation problems. Instead, Wheaton (1974) proposed a two-step model to convert the problem in (1) to a pure transportation problem. The first step is to expand the formulation regarding optimal rent level for each household stratum i and land zone j combination to incorporate Alonso's micro-theory of bid rents. The second step is to solve a pure transportation problem by LP to determine the optimal allocation of land to each household stratum i and in all land zones.

2.1. Step 1: Optimal Net Return to Land

Following Wheaton (1974), a circular city where all commuting is made to the city center is given. Urban land zones are therefore rings, located at distance t from the city center, with associated transportation costs $k(t)$. Available housing types are characterized by H attributes $q_1,...,q_H$ and a cost function similar as in the original Herbert-Stevens model, $C(q_1,...,q_H)$. $C(q_1,...,q_H)$ represents the cost of residential bundle exclusive of a site (Herbert and Stevens, 1960). Without loss of generality, the first housing attribute, q_1, is defined as lot size. For simplicity, utility functions take the Cobb-Douglas form, depending on the characteristics of housing and residual consumption on non-locational items M. Then the utility function (u_i) for a household belonging to household stratum i in land zone j is given by:

$$u_i = M^{\alpha} \prod_h q_{ih}^{\alpha_h}, \qquad h = 1,...,H \tag{2}$$

where q_{ih} is the variable that measures the housing attribute h chosen by household stratum i. Note that the utility function in (2) is invariant by locations (measured by the distance to the city center), which is different from Wheaton (1974). The distance to the city center will be used as a measure for disamenity later on. As pointed out by Glaeser (2007), urban development reflects millions of individual choices to live in cities, to understand urban spatial structure it is necessary to understand the relative importance of the different urban attributes. The utility function in (2) presents a simplified way to capture the relative importance of a set of location exclusive attributes. The household's budget constraint is given by:

a linear combination constraint on the decision variables, such as the first constraint in LP problem (1).

$$Y = R + M + k(t) \tag{3}$$

Given utility level as a parameter, then the rent (household's willingness to pay for house), R, can be written as a function of income, transportation cost, housing attributes, and utility level:

$$R_{ij} = Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} \tag{4}$$

where income Y only varies by household stratum. At each land zone j, by maximizing the rent in (4) net of construction costs a combination of q_h is selected, which yields the highest net return per unit of land (net rent is divided by lot size - q_1):

$$max_{q_{i1},\dots,q_{iH}} \left[Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - C(q_{i1},\dots,q_{iH}) \right] q_{i1}^{-1} \tag{5}$$

The objective function in (5) represents the rent-paying ability, which can be summed up to the total social net return from land and housing markets. The maximization problem in (5) is essentially an unconstrained problem. If the construction cost function is sufficiently simple though unlikely in reality, the rent-maximizing housing attributes can be determined from the first-order conditions of (5). Wheaton (1974)'s suggested solution is that, given a discrete number (p) of home types and each is attached with a fixed set of attributes (i.e., $\left[q_1^k,\dots,q_H^k\right]$, $k = 1,\dots,p$), in which case p values of objective functions are computed and the maximum value is then selected by comparison. An alternative way to solve the maximization problem in (5) is to convert it into a constrained optimization problem with a nonlinear objective function. Assuming that construction cost $C(q_1,\dots,q_H)$ reflects the property value to land owner or developer up to a scale factor, we can specify the cost following a hedonic pricing framework:

$$C(q_1,\dots,q_H) = c_0 \prod_h q_h^{\gamma_h} \qquad h = 1,\dots,H \tag{6}$$

where c_0, γ_h are constant parameters, which becomes coefficients in the logarithm form of (6):

$$lnC(q_1,...,q_H) = lnc_0 + \sum_{h=1}^{H} \gamma_h lnq_h \tag{7}$$

Inserting (6) into (5), an explicit form of the optimization problem is given by:

$$max_{q_{i1},...,q_{iH}} \left[Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0 \prod_h q_{ih}^{\gamma_h} \right] q_{i1}^{-1} \tag{8}$$

Furthermore, without loss of generality, we can standardize the housing attributes into a continuous $[Q_h^L, Q_h^U]$ interval through scaling or mapping. The constrained choice set can then reflect both the natural (e.g., geographical and environmental) boundaries and social regulatory regimes. Now given the distance t we have a constrained optimization problem which is equivalent to (8):

$$\begin{aligned} & max_{q_{i1},...,q_{iH}} \left[Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0 \prod_h q_{ih}^{\gamma_h} \right] q_{i1}^{-1} \\ & s.t. \qquad Q_h^L \le q_{ih} \le Q_h^U \qquad h = 1,...,H \end{aligned} \tag{9}$$

Note that, to solve (9) we need to specify transportation cost function $k(\cdot)$, income level Y_i, household desired utility level u_i, and other parameters in the objective: $\alpha, \alpha_h, c_0, \gamma_h$.

2.2. Step 2: Optimal Land Allocation

After solving the optimization problem in (9), the maximum value of objective function is then the highest net return per unit of land for households belonging to household stratum i in zone j (j is defined by t in the circular city case). Letting this optimal value to be b_{ij}, and the land consumption of all the chosen housing units for stratum i in zone j (given the optimal attributes level determined from (9)) is labeled as y_{ij}. Now the original Herbert-Stevens model can be revised into a maximization problem which is also a pure transportation problem:

$$\max_{y_{ij}} \sum_{i=1}^{n+1} \sum_{j=1}^{m} b_{ij} y_{ij}$$

$$s.t. \begin{cases} \sum_i^{n+1} y_{ij} = L_j & j = 1, \ldots, m \\ \sum_j^m y_{ij} = H_i & i = 1, \ldots, n, n+1 \\ y_{ij} \geq 0 \end{cases} \tag{10}$$

Following Wheaton (1974)'s formulation, an $n+1th$ household stratum is included whose bid rent is uniformly equal to the opportunity price of urban land in the given zone. This hypothetical household stratum will be used to absorb all unallocated vacant land. The first set of constraints balances land demand and supply, by assuring that all land in a zone (L_j) is used by either urban households or the $n+1th$ stratum. The second set of constraints requires that the total land used by each household stratum equals to some predetermined amount H_i. Note that the predetermined H_i does not necessarily ensure all households in stratum i being located. By iteratively computing H_i, however, it is possible to ensure that the second set of constraints equivalently requires that all households be located. Letting s denote an iteration number, define H_i^s as:

$$\begin{cases} H_i^s & = N_i(\sum_{j=1}^m y_{ij}^{s-1}) / \sum_{j=1}^m \left(\frac{y_{ij}^{s-1}}{l_{ij}} \right), \quad i = 1, \ldots, n \\ H_{n+1}^s & = \sum_{j=1}^m L_j - \sum_{i=1}^n H_i^s \end{cases} \tag{11}$$

where l_{ij} denotes the identical land consumption of each household from household stratum i in zone j, therefore $\sum_{j=1}^m \left(\frac{y_{ij}^{s-1}}{l_{ij}} \right)$ represents the total number of located households from stratum i in $s-1th$ iteration. H_{n+1}^s represents all unallocated land. If the process in (11) is converged, then the following conditions should be satisfied:

$$\begin{cases} H_i^s & = H_i^{s-1} \\ y_{ij}^s & = y_{ij}^{s-1} \end{cases} \tag{12}$$

By combining conditions in (11) and (12) and then inserting into the second set of constraints in (10), it becomes two set of constraints:

$$\begin{cases} \sum_{j=1}^{m} \left(\frac{y_{ij}}{l_{ij}}\right) & = N_i, \qquad i = 1, \dots, n \\ \sum_{j=1}^{m} y_{n+1,j} & = \sum_{j=1}^{m} L_j - \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij} \end{cases} \tag{13}$$

The first set of constraints in (13) guarantees that the optimal solutions to (10) allocate just enough land for household stratum i to locate all of its N_i members. The second constraint simply provides that all unallocated land is occupied by the $n+1th$ hypothetical household stratum. Replacing the second set of constraints in (10) with (13), the optimization problem becomes:

$$\begin{aligned} & \max_{y_{ij}} \sum_{i=1}^{n+1} \sum_{j=1}^{m} b_{ij} y_{ij} \\ & s.t. \begin{cases} \sum_{i}^{n+1} y_{ij} = L_j & j = 1, \dots, m \\ \sum_{j=1}^{m} \left(\frac{y_{ij}}{l_{ij}}\right) = N_i & i = 1, \dots, n \\ \sum_{j=1}^{m} y_{n+1,j} = \sum_{j=1}^{m} L_j - \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij} \\ y_{ij} \geq 0 \end{cases} \end{aligned} \tag{14}$$

The constraints in (14) are exactly the set of constraints derived by Wheaton (1974). In (14), however, it can be shown that the first set of constraints directly imply the third equality constraint. Therefore, the optimization problem in (14) can be simplified into a more concise form:

$$\begin{aligned} & \max_{y_{ij}} \sum_{i=1}^{n+1} \sum_{j=1}^{m} b_{ij} y_{ij} \\ & s.t. \begin{cases} \sum_{i}^{n+1} y_{ij} = L_j & j = 1, \dots, m \\ \sum_{j=1}^{m} \left(\frac{y_{ij}}{l_{ij}}\right) = N_i & i = 1, \dots, n \\ y_{ij} \geq 0 \end{cases} \end{aligned} \tag{15}$$

Note that the optimization problem in (15) is still a pure transportation problem and can be solved by LP methods. Now, solving the Herbert-Stevens Model becomes a two-step optimization problem, which is easier to implement than solving the generalized transportation problem for the original Herbert-Stevens Model. Therefore, the optimal residential land use pattern will be given by solving the nonlinear programming (NLP) problem in (9) and the LP problem in (15) sequentially.

3. Algorithm and Numerical Example

To solve the two-step optimization problem, ideally, the parameters of the system need to be calibrated with real observational data. In Wheaton (1974), a test problem of 50 zones (m) and 10 household strata (n) is solved. In this section, to illustrate the model depicted in section 2, a designed small scale numerical example is solved. The parameterization for the numerical example based on a circular city framework is summarized in Table 2.1. One thing to note is the utility function parameter α_1 which is defined as an increasing function of income level. Similar preference structure has been used in Wilson (2010), where consumers have heterogeneous preference on the size of retail centres. The economic rationale behind is that households and communities with higher income prefer to living in bigger houses (Glaeser 2007). Preferences over other housing attributes are assumed stable over time and invariant across income levels. Differences in location choice are simply the results of differences in budget opportunity sets and changes in these sets. Therefore, the outcome is mainly driven by the trade-off between income and distance at a disaggregated level.

Parameter	Definition	Value	Note
n	number of household strata (i)	5	$N_1 = ... = N_5 = 20$
m	number of land zones (j)	10	$L_1 = ... = L_{10} = 20$
l_{ij}	land demand by stratum and zone	1	$l_{ij} = 1$
H	number of housing attributes	2	lot size, amenity level
$k(\cdot)$	transportation cost function	$k_0 t^\beta$	$k_0 = 1,\ \beta = 0.5$
Y_i	household income by stratum		$Y_i = 20, 30, 40, 50, 60$
u_i	desired utility by stratum	$Y_i/2$	increase with income
α	utility function parameter	0.75	
α_1	utility function parameter	$\alpha_1(Y_i)$	$1 + \frac{(Y_i - min(Y))}{(max(Y) - min(Y))}$
α_2	utility function parameter	0.75	
γ_h	cost function parameter	1	$h = 1, 2$
c_0	cost function constant	2	
t	distance to city center	$t = j$	defined by index of land zones
Q_h	constraint bounds		$Q_h^L = 1,\ Q_h^U = 10$

Table 2.1: Parameterization of a numerical example for the monocentric model

Given the parameterization in Table 2.1, the optimal net return is obtained by solving the NLP problem in (9) with the Frank - Wolfe algorithm[3]. The Frank - Wolfe algorithm is very efficient in solving NLP problems with convex objective functions, and it solves them as minimization problems. In the case of the net return maximization in (9), we need to multiply the objective by -1. The algorithm decomposes the NLP problem into a LP problem and a line search problem, which makes it feasible for various optimization problems and computationally efficient. In solving the NLP problem in (9), note that the objective function is not global concave therefore it is necessary to try with different set of starting values. The numerical example is programmed in MATLAB and implemented on a 64-bit Windows 7 operating system, with a 3.40 GHz Intel Core i7-2600 processor and 12.0 GB RAM. The CPU time consumption is 3.61 minutes. Table 2.2 shows the optimal net return for each household stratum i in land zone j:

		Zones (j)									
Net Return		1	2	3	4	5	6	7	8	9	10
Strata (i)	1	5.58	5.17	4.84	4.58	4.34	4.12	3.92	3.74	3.57	3.40
	2	11.50	11.08	10.77	10.50	10.26	10.05	9.86	9.67	9.50	9.33
	3	17.88	17.46	17.14	16.88	16.64	16.43	16.23	16.05	15.88	15.72
	4	24.82	24.40	24.08	23.82	23.58	23.37	23.17	22.99	22.82	22.65
	5	31.69	31.28	30.96	30.69	30.46	30.24	30.05	29.86	29.69	29.53

Table 2.2: Optimal net return to land by household strata and land zones

			Zones (j)									
		Income	1	2	3	4	5	6	7	8	9	10
Strata (i)	1	20	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	30	0.0	0.0	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0
	3	40	0.0	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0
	4	50	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	60	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	6	0	0.0	0.0	0.0	0.0	0.0	**20.0**	**20.0**	**20.00**	**20.0**	**20.0**

Table 2.3: Optimal residential land allocation by household strata and land zones

[3]The Frank - Wolfe algorithm is a numerical optimization method for solving NLP problems based on linearization. In 1960s and 1970s, a lot of previously unsolved transportation and planning problems were solved with the Frank - Wolfe algorithm (e.g., Evans, 1973; LeBlanc, 1973). The Matlab code for one of the numerical examples in this paper is attached in the Appendix, all other examples are implemented based on similar algorithm.

The land zones are indexed from city center to outside, zone $j = 1$ is the closest zone to city center and zone $j = 10$ is the zone furthest from city center. Note that, in the numerical example shown, the index for land zones is also used as a measure of travel distance (Table 2.1). The index for household strata is not associated with any locational factor, and it can be considered as randomly assigned. The results in Table 2.2 shows consistency with the classic monocentric urban models. As a household moves away from the city center (index j gets larger), the net return to land declines due to the increasing transportation cost. The optimal net return in Table 2.2 gives the coefficients for the objective function of the LP problem in (15), and the solution of which gives the optimal residential land development structure. Table 2.3 shows the optimal residential land allocation given the optimal net return to land, population constraint, and land resource constraint.

In Table 2.3, the first column shows the income level for each household stratum, and the stratum 6 is the hypothetical stratum to absorb all unallocated land. In the numerical example, desired utility level is set as half of the income instead of being independently assigned. This can be interpreted as that households with higher income also have higher expectation on the quality of life. The results in Table 2.3 clearly show that no households want to live in the land zones ($j > 5$) too far from the city center, and therefore all land is left as undeveloped (unallocated). Note that l_{ij} is set to 1 for all household strata and land zones, therefore the actual land allocation becomes an ineger 20 for all land zones.

The function forms used in this numerical example satisfy the conditions implicit in the Alonso-Mills-Muth monocentric model, but results show different pattern. This illustrates the importance of the spatial variation of income and amenity levels. If the land zones 4 and 5 are considered as suburban area, then we can see that it is the middle income class who lives in the suburban area. This actually matches with what we observe in the real world where most of the middle class groups commute long distance to work. Low income groups and high income groups tend to live closer to the city center.

4. Location and Disamenity

In urban economics, a basic principle of urban spatial structure is that transportation cost differences must be compensated for by the differences in housing prices and spatial distribution of amenities. The utility function in (2) captures the amenities exclusive of a given location. However, some other (dis)amenities may depend on the entire urban spatial structure rather than the given location. For example, crime rate and racial tensions are usually much higher in large cities than in small cities. Within a city, these social disamenities tend to be higher near the city center and it can become a self-enforcing process. As Mieszkowski and Mills (1993) pointed out, these disamenities lead affluent central city residents to migrate to the suburbs, which leads to further deterioration of the quality of life in the city center. Given the monocentric city framework, in this paper the distance to the city center is used as an approximate measure for disamenities which is not specific to any sites. Being further from the city center, higher utility level can be achieved due to lower disamenities holding other factors constant.

Note that the disamenity here does not reflect the disutility related to residential density. Given the setup of our model, the residential density at each developed land zone equals to 1. In this case, disamenity acts like a reduction in transportation costs, but nonlinearly. Therefore the utility function in (2) can be expanded to:

$$u_i = M^{\alpha} t^{\alpha_t} \prod_h q_{ih}^{\alpha_h}, \qquad h = 1, \ldots, H \tag{16}$$

where t is used as an aggregated measure of amenities and disamenities related to distance. α_t is positive and is a relative measure of the importance of distance related amenity/disamenity in total household utility. In Wheaton (1974), the power of distance (equivalent to α_t) is negative and is being used to reflect the disutility from long distance commuting. Actually, the disutility from long distance commuting is already accounted for through income effect in the household budget constraint[4]. Higher expenditure on commuting will suppress the expense on living necessities given income level, as being implicit in (3). With the new utility structure, the maximum willingness to pay for rent becomes:

$$R_i = Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} t^{\frac{-\alpha_t}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} \tag{17}$$

[4]In Wheaton (1974), the long distance commuting has both an income effect through transportation cost in the budget constraint and a substitution effect in household utility structure. In this paper, the income effect of long distance commuting is explicit. The substitution effect of commuting is implicit in the new aggregated measure t.

The optimization problem in (9) then becomes:

$$
\begin{aligned}
&max_{q_{i1},\ldots,q_{iH}} \left[Y_i - k(t) - (u_i)^{\frac{1}{\alpha}} t^{\frac{-\alpha_t}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0 \prod_h q_{ih}^{\gamma_h} \right] q_{i1}^{-1} \\
&s.t. \qquad Q_h^L \leq q_{ih} \leq Q_h^U \qquad h = 1, \ldots, H
\end{aligned}
\tag{18}
$$

In the optimization problem (9) the trade-off is mainly between the third part (non-housing expense) and the last part (construction cost). In the optimization problem (18) above, another trade-off is incorporated and which is between the transportation cost and the savings from lower disamenity level in the further suburban area. A similar numerical example is implemented for the NLP problem in (18), and the only extra parameter α_t is set to 0.1. Similarly, the numerical example is programmed in MATLAB and implemented on a 64-bit Windows 7 operating system, with a 3.40 GHz Intel Core i7-2600 processor and 12.0 GB RAM. The CPU time consumption is 4.28 minutes. The optimal land allocation outcome is reported in Table 2.4.

			Zones (j)									
		Income	1	2	3	4	5	6	7	8	9	10
Strata (i)	1	20	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	30	0.0	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0	0.0	0.0
	3	40	0.0	0.0	0.0	0.0	0.0	**20.0**	0.0	0.0	0.0	0.0
	4	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**20.0**	0.0	0.0
	5	60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**20.0**
	6	0	**20.0**	**20.0**	0.0	0.0	**20.0**	0.0	**20.0**	0.0	**20.0**	0.0

Table 2.4: Optimal residential land allocation with disamenity

From the results in Table 2.4 it is clear that no households now want to live near the city center due to the disamenity. However, the monocentric relationship between income level and location choice is very clear. All of the high income strata choose to live in the further suburban area, and low income strata stay closer to the city center. The economic reason for this pattern is that the disamenities associated with distance now partially offset the transportation cost which is obviously driven by distance as well. Therefore the entire spatial structure of residential land use is dominated more by the income level now. High income households now are more willing to live in the suburban area because higher transportation cost is partially compensated for through lower disamenity level. Another interesting result emerged in Table 2.4 is the pattern of leapfrog development - a major explanation for urban sprawl. Between land zone 3 and 10, land zone 5, 7, and 9 are left undeveloped. The technical reason for this is that the distance is measured with discontinuity (integers in this paper). In the real world, both geographical barriers and regulatory constraints can cause discontinuity in developable land space. In some cases, strategic behaviors (e.g., holding land to arbitrage) can also cause discontinuity.

5. The Duocentric Model

The monocentric city framework is the foundation of urban economics studies within last several decades. A recent tendency in the literature is to develop it into more realistic models of urban spatial structure that explain the pattern and regularities in the urban landscape (Fujita and Ogawa, 1982; Ogawa and Fujita, 1989; Yinger, 1992; Alperovich and Deutsch, 1996; Henderson and Mitra, 1996; Zhang and Sasaki, 2000; Wilson, 2010). A straightforward development to the monocentric framework is the duocentric city framework where two urban centers coexist within a larger urban area (Figure 2.1). The two urban centers can simply be employment centers as in Yinger (1992), or more generally multi-functional central business districts (CBD).

One of the key questions in modeling a duocentric city is how the distance between two urban centers is being determined. If two urban centers have been developed independently from the beginning, then it is more likely that the inter-city distance is determined exogenously (e.g., by geography or historical factors). On the other hand, if one city came into shape after the other city has been developed into certain stage, then it is more likely that the inter-city distance is endogenous to the evolution of the entire urban area. For instance, the population increase as a result of urban development may have forced people with certain demographics to move to the suburb and form another subcenter, as Jackson (1985, pp. 20) described: "... the enormous growth to metropolitan size was accompanied by rapid population growth on the periphery, by a leveling of the density curve, by an absolute loss of population at the center, and by an increase in the average journey to work, as well as by a rise in the socioeconomic status of suburban residents. This shift was not sudden, but it was no less profound for its gradual character. Indeed, the phenomenon was one of the most important in the history of society, for it represented the most fundamental realignment of urban structure in the 4500-year past of cities on this planet." In this section, I focus on the second scenario where the inter-city distance is endogenously determined.

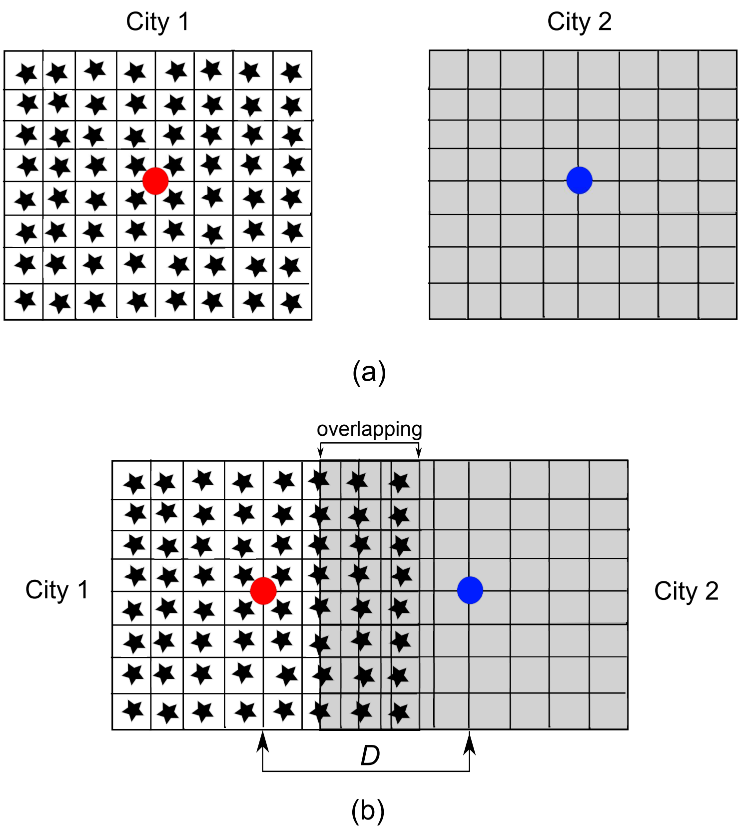


Figure 2.1: The duocentric city model

In the literature, the inter-city distance is usually treated as fixed (e.g., Yinger 1992, Zhang and Sasaki 2000). If this distance is exogenously given, the resulted urban spatial structure should not be qualitatively different from the monocentric case. Assuming that households can travel to both cities, then what changes is just the transportation cost and disamenity levels given income still being same as in the monocentric case. If the urban transportation system consists of spoke-roads, the distance to one urban center is directly related to the inter-city distance and the distance to another urban center. In the case of exogenous inter-city distance, the same model we have for the monocentric case can be used to solve for the optimal land allocation.

If the inter-city distance is endogenous to the urban development process, then the resulted urban spatial structure is unknown from the model we have so far. As argued in Henderson and Mitra (1996), however, the inter-city distance is a critical choice variable. At micro level, if the inter-city distance becomes a decision variable, then every household stratum has its own preferred distance between two cities given its residential location. This preferred distance balances the additional transportation cost occurred and the potential congestion cost generated between two urban areas (the overlapping area shown in Figure 2.1). At macro level, the urban planner faces the same problem that the optimal inter-city distance has to balance the additional commuting cost and congestion cost of all residents.

In practice, the governments who usually take the role of urban planner, to large extent, can decide the location of a new urban center. Zoning is one of the policy instruments which can achieve such goal. One good example is the edge cities which are usually the product of decisions by a single large agent with monopolistic power in the land and housing markets (see Garreau (1991)). Most of these agents are large private development companies, often reflecting the vision of one person or a small group of people (Henderson and Mitra, 1996). Of course, the rise of a new urban center also heavily depends on infrastructure development, which goes beyond the scope of this paper.

Given this observation, it is necessary to modify the Herbert-Stevens model to solve for the optimal inter-city distance. The modification is based on the following conjecture. The urban planner estimates the inter-city distance (therefore the location of the new urban center) first by taking into consideration of all individual preferences on the distance. The preference of each household stratum reflects the balance between additional transportation cost and congestion cost. Then given the socially optimal inter-city distance, the optimal net return to land and optimal residential land allocation are calculated by household strata and land zones, which is similar to the Herbert-Stevens model in monocentric case. To simplify the model, the inter-migration process is ignored for the moment. In other words, households who are willing to live in the original city and who are willing to live in the new city are given. But it is assumed that, as mentioned above, households can draw utility by traveling to both cities. As shown in Figure 2.1, the inter-city distance is denoted as D. The distance from any given location to urban center 1 and urban center 2 is denoted as t_1 and t_2, respectively. Thus, the utility function in (16) for a household belonging to household stratum i in zone j is rewritten as:

$$u_{ij} = M^{\alpha} \left(\frac{t_1 + t_2}{2} \right)^{\alpha_t} \prod_h q_{ih}^{\alpha_h}, \qquad h = 1, ..., H \tag{19}$$

where the disamenity is measured by the average distance to both city centers. Note that households are assumed to be indifferent between two cities. If the transportation cost is further assumed to be additive, then a household's transportation cost can be given as $k(t_1, t_2) = (k(t_1) + k(t_2))/2$. The new transportation cost function implies that the household's total commuting time does not change much from monocentric case to duocentric case. Different from the circular city in monocentric case, we assume a square urban area in duocentric case. As illustrated in Figure 2.1, each small square in the grid represents a land zone. All land zones are connected through spoke-roads to urban centers. All households bear some congestion cost when they travel through the congested area (overlapping area shown in Figure 2.1). The congestion cost is assumed to be proportional to the square of the length of congested area. Let the length (in the direction along with two urban centers) of congested area be L, then L can be written as a function of the inter-city distance D, and the side length of two urban areas (denoted as $2d_1$ and $2d_2$, respectively), i.e., $L = d_1 + d_2 - D$ if $0 \leq D \leq d_1 + d_2$, and $L = 0$ otherwise. Given that d_1 and d_2 are fixed parameters, as D gets larger the congestion cost is smaller but with increasing transportation cost. Now a household's new budget constraint can be written as:

$$Y = R + M + \frac{1}{2} (k(t_1) + k(t_2)) + \delta L^2 \tag{20}$$

where δ is the constant parameter in the congestion cost function. Without loss of generality, we can further set $d_1 = d_2 = d$ which gives two cities of equal size. When $D \geq 2d$, the congestion cost becomes zero, which is no longer an interesting case. Therefore, D is restricted to be between zero and $2d$ (i.e., $D \in [0, 2d)$), and now the budget constraint can be rewritten as:

$$Y = R + M + \frac{1}{2} (k(t_1) + k(t_2)) + \delta (2d - D)^2 \tag{21}$$

Then the first step optimization problem in (9) becomes:

$$
max_{q_{i1},\ldots,q_{iH},D_i}\left[Y_i - \frac{1}{2}\left(k(t_1)+k(t_2)\right) - \delta(2d-D_i)^2 - (u_i)^{\frac{1}{\alpha}}\prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0\prod_h q_{ih}^{\gamma_h}\right] q_{i1}^{-1}
$$
$$
\begin{aligned}
s.t. \quad & Q_h^L \le q_{ih} \le Q_h^U \qquad h = 1,\ldots,H \\
& 0 \le D_i < 2d
\end{aligned} \tag{22}
$$

If the disamenity is further incorporated, the first step optimization problem in (18) becomes:

$$
\begin{aligned}
max_{q_{i1},\ldots,q_{iH},D_i} & \left[Y_i - \frac{1}{2}\left(k(t_1)+k(t_2)\right) - \delta(2d-D_i)^2 - \right. \\
& \left. (u_i)^{\frac{1}{\alpha}} 2^{\frac{\alpha_t}{\alpha}} (t_1+t_2)^{\frac{-\alpha_t}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0\prod_h q_{ih}^{\gamma_h}\right] q_{i1}^{-1} \\
s.t. \quad & Q_h^L \le q_{ih} \le Q_h^U \qquad h = 1,\ldots,H \\
& 0 \le D_i < 2d
\end{aligned} \tag{23}
$$

where it is assumed that the disamenity level depends on the average distance to both urban centers given other attributes. Note that for any household stratum i, given D_i, and the distance to one urban center (t_1), then the distance to the other urban center (t_2) is implicitly determined. As illustrated in Figure 2.2, t_2 can be written as a function of D_i, and coordinates of t_1. Without loss of generality, letting the City 1 centers at the origin and t_2 can be expressed as: $t_2 = \sqrt{t_{1,y}^2 + (D_i - t_{1,x})^2}$, where $t_{1,x}$ and $t_{1,y}$ are the horizontal and vertical coordinates of t_1, respectively. By substituting t_2 into (22), we have a new form of the NLP problem:

$$
\begin{aligned}
max_{q_{i1},\ldots,q_{iH},D_i} & \left[Y_i - \frac{1}{2}\left(k(t_1)+k\left(\sqrt{t_{1,y}^2+(D_i-t_{1,x})^2}\right)\right) - \delta(2d-D_i)^2 - \right. \\
& \left. (u_i)^{\frac{1}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0\prod_h q_{ih}^{\gamma_h}\right] q_{i1}^{-1} \\
s.t. \quad & Q_h^L \le q_{ih} \le Q_h^U \qquad h = 1,\ldots,H \\
& 0 \le D_i < 2d
\end{aligned} \tag{24}
$$

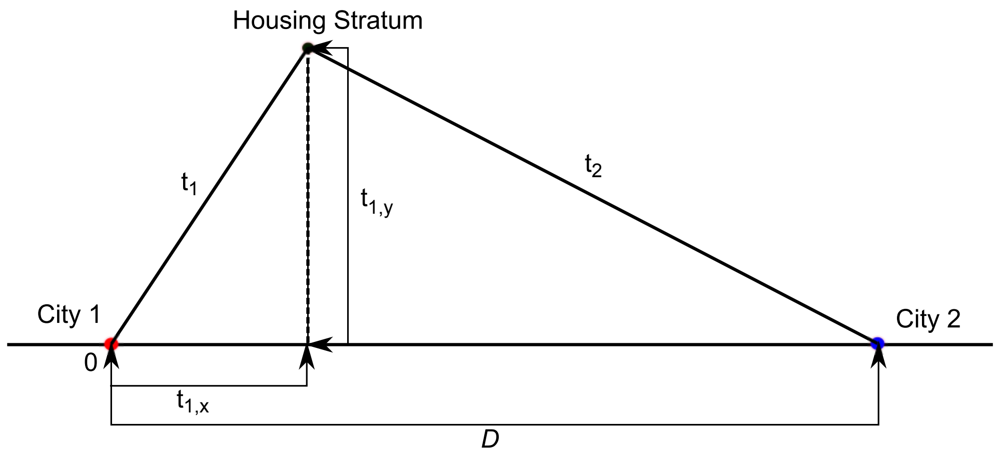


Figure 2.2: Inter-city distance in the duocentric model

The first order condition with respect to D_i is (given that $k(t) = k_0 t^\beta$ as specified in Table 2.1):

$$2\delta(2d - D_i) - k_0\beta \left(t_{1,y}^2 + (D_i - t_{1,x})^2\right)^{\frac{\beta}{2}-1} (D_i - t_{1,x}) = 0 \tag{25}$$

Realized from the first order condition above that D_i is separable from other choice variables, therefore in the case without disamenity the individually preferred inter-city distance can be solved directly from the first order condition in (25). The optimal distance is only a function of household location and the side length of cities in this case. With disamenity further incorporated, the final version of the NLP problem for optimal net return to land in the duocentric Herbert-Stevens model is given as:

$$\begin{aligned} max_{q_{i1},\ldots,q_{iH},D_i} \Bigg[& Y_i - \frac{1}{2}\left(k(t_1) + k\left(\sqrt{t_{1,y}^2 + (D_i - t_{1,x})^2}\right)\right) - \delta(2d - D_i)^2 - \\ & (u_i)^{\frac{1}{\alpha}} 2^{\frac{\alpha_t}{\alpha}} \left(t_1 + \sqrt{t_{1,y}^2 + (D_i - t_{1,x})^2}\right)^{\frac{-\alpha_t}{\alpha}} \prod_h q_{ih}^{\frac{-\alpha_h}{\alpha}} - c_0 \prod_h q_{ih}^{\gamma_h} \Bigg] q_{i1}^{-1} \\ s.t. \quad & Q_h^L \le q_{ih} \le Q_h^U \qquad h = 1, \ldots, H \\ & 0 \le D_i < 2d \end{aligned} \tag{26}$$

After solving the constrained NLP problem in (26), we can get the preferred inter-city distance and optimal net return to land by household strata and land zones. Given all of these individually preferred inter-city distance, in this paper the urban planner's decision is made by taking weighted average of all individual choices. The weighted average here can be considered as a voting system. The urban planner's decision on the inter-city distance (D^*) is given by:

$$D^* = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{s=1}^{m} \frac{b_{ijs}D^*_{ijs}}{\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{s=1}^{m} b_{ijs}} \tag{27}$$

where j and s are used to index horizontal and vertical coordinates, respectively; b_{ijs}, the optimal net return to land solved from (26), is used as weight. D^*_{ijs} represents the individually preferred inter-city distance by household strata and land zones. By substituting the D_i in (26) with the D^* calculated from (27) and re-solving the constrained NLP problem in (26), a new set of optimal net return to land can be obtained. Since the households who are willing to live in the original city and who are willing to live in the new city are given, the next step is to solve the second stage of the Herbert-Stevens model as in (15) for each city independently.

$$\begin{aligned} &\max_{y_{ijs}} \sum_{i=1}^{n+1}\sum_{j=1}^{m}\sum_{s=1}^{m} b_{ijs}y_{ijs} \\ &s.t. \begin{cases} \sum_{i}^{n+1} y_{ijs} = L_{js} & j,s = 1,...,m \\ \sum_{j=1}^{m}\sum_{s=1}^{m}\left(\frac{y_{ijs}}{l_{ijs}}\right) = N_i & i = 1,...,n \\ y_{ijs} \geq 0 \end{cases} \end{aligned} \tag{28}$$

The duocentric model without disamenity (i.e., $\alpha_t = 0$) is only a special case of the model with disamenity incorporated. Therefore the numerical example for the model with disamenity is implemented only. There are several new parameters to be specified, and the values of few others have been changed. All new parameters and changed parameters are summarized in Table 2.5, and other unspecified parameters are kept same as in Table 2.1.

Parameter	Definition	Value	Note
n	number of household strata (i)	5	$N_1 = ... = N_5 = 60$
m	number of land zones (j, s)	7	$L_{1,1} = L_{1,2} = ... = L_{10,9} = L_{10,10} = 10$
α_t	utility function parameter	0.1	
δ	congestion function parameter	0.2	
d	half side length of each city	3	$d = (m-1)/2$
t_1	distance to city center 1	$[t_{1,x}, t_{1,y}]$	measured by geometry distance

Table 2.5: Parameterization of a numerical example for the duocentric model

The numerical example for the duocentric model is also programmed in MATLAB and implemented on a 64-bit Windows 7 operating system, with a 3.40 GHz Intel Core i7-2600 processor and 12.0 GB RAM. The CPU time consumption is 112.77 minutes[5]. The optimal land allocation outcome for each household stratum is reported in Table 2.6. The two cities are of equal size by design ($d_1 = d_2 = d$), so Table 2.6 only shows the outcome for City 1. City 2 is located on the right hand side of City 1. For each city the landscape is symmetric, and the city center (CBD) is at the coordinate ($j = 4$, $s = 4$). The optimal inter-city distance (D^*) in this case is 5.81. Note that the sub-table of stratum 6 at the bottom right of Table 2.6 is for unallocated land. This spatial configuration simplifies the problem, but the pattern of urban spatial structure is still very clear.

From the optimal land allocation shown in Table 2.6, we can observe: (1) Low income households choose to live in the fringe between two cities which can be considered as further suburban area for both cities. This is a result different from the previous two cases of the monocentric model. (2) Middle income households tend to live in the suburban area of City 1, while the high income households stay closer to the city center. This is a result similar to the results in Table 2.2 - the monocentric model without disamenity, but two models are not directly comparable.

There are two changes made from the monocentric model to the duocentric model, which drives the differences in the outcome. The first change is the introduction of congestion cost between two cities. The sources of congestion are not limited to traffic. It can also be the congestion due to higher living density in the overlapping area, for example, hygiene and public health issues. Mathematically, this congestion cost comes into the model as an adjustment to the transportation cost. The main determinant of congestion cost is the optimal inter-city distance, and the change of which has opposite effects on transportation cost and congestion cost. The other change made to the monocentric model is on the utility structure. In the duocentric model, the optimal inter-city distance affects household utility through the average distance to city centers which is employed as an approximate measure for disamenity.

[5]The Matlab code for this numerical example is attached in the Appendix.

Stratum = 1		Zones (j)						
Income = 20		1	2	3	4	5	6	7
	1	0	0	0	0	0	0	**10**
	2	0	0	0	0	0	0	**10**
	3	0	0	0	0	0	0	**10**
Zones (s)	4	0	0	0	CBD	0	0	0
	5	0	0	0	0	0	0	**10**
	6	0	0	0	0	0	0	**10**
	7	0	0	0	0	0	0	**10**

Stratum = 2		Zones (j)						
Income = 30		1	2	3	4	5	6	7
	1	0	0	0	0	**5**	**10**	0
	2	0	0	0	0	0	**10**	0
	3	0	0	0	0	0	0	0
Zones (s)	4	0	0	0	CBD	0	0	**10**
	5	0	0	0	0	0	0	0
	6	0	0	0	0	0	**10**	0
	7	0	0	0	0	**5**	**10**	0

Stratum = 3		Zones (j)						
Income = 40		1	2	3	4	5	6	7
	1	0	0	0	**5**	**5**	0	0
	2	0	0	0	0	**5**	0	0
	3	0	0	0	0	0	**10**	0
Zones (s)	4	0	0	0	CBD	0	**10**	0
	5	0	0	0	0	0	**10**	0
	6	0	0	0	0	**5**	0	0
	7	0	0	0	**5**	**5**	0	0

Stratum = 4		Zones (j)						
Income = 50		1	2	3	4	5	6	7
	1	0	0	0	0	0	0	0
	2	0	0	0	**10**	**5**	0	0
	3	0	0	0	0	**10**	0	0
Zones (s)	4	0	0	0	CBD	**10**	0	0
	5	0	0	0	0	**10**	0	0
	6	0	0	0	**10**	**5**	0	0
	7	0	0	0	0	0	0	0

Stratum = 5		Zones (j)						
Income = 60		1	2	3	4	5	6	7
	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0
	3	0	0	**10**	**10**	0	0	0
Zones (s)	4	0	**10**	**10**	CBD	0	0	0
	5	0	0	**10**	**10**	0	0	0
	6	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0

Stratum = 6		Zones (j)						
Income = NA		1	2	3	4	5	6	7
	1	**10**	**10**	**10**	0	0	0	0
	2	**10**	**10**	**10**	0	0	0	0
	3	**10**	**10**	0	0	0	0	0
Zones (s)	4	**10**	0	0	CBD	0	0	0
	5	**10**	**10**	0	0	0	0	0
	6	**10**	**10**	**10**	0	0	0	0
	7	**10**	**10**	**10**	0	0	0	0

Table 2.6: Optimal residential land allocation with disamenity in the duocentric model

As Boyce (2007) noted, achieving balance among spatial and temporal details, representation of bundles of location and transportation choices, and computation capacity will still remain a challenge to researchers for a long time. Basing on numerical examples in this paper, we have demonstrated that how urban economics models and numerical optimization tools can be integrated for identifying an optimal urban spatial structure from a land development perspective. But the parameterization in the models still needs to be calibrated when it comes to real world problems, which is certainly a challenge in practice.

6. Economic Interpretation

The Herbert-Stevens model takes the urban planner's perspective and optimally determines a urban spatial structure which maximizes the total social net return to residential land. In the setting of this paper, households are mainly differentiated by income levels (and preference over lot size which depends on income as well). Assuming that the income levels and desired utility levels (i.e., the minimum desired living standard) of each household stratum can be observed, then for each combination of household stratum and land zone the maximum net return to land can be obtained by choosing housing attributes. This corresponds to the constrained NLP problem in the first step of the Herbert-Stevens model.

In reality, a household stratum can be considered as a community which shares similar demographics. A land zone can be considered as an area at the scale of subdivision, census tract, or school district. For each combination of household stratum and land zone, the maximum net return to land that can be reached represents an ideal scenario - the most efficient urban spatial structure given the socio-economic profile of its residents. In a real urban area, it is almost always impossible to realize all of these ideal scenarios. However, the maximum net return to land under ideal scenarios provides a series of references for the urban planner to match household strata with land zones simultaneously while the total social net return to land is maximized. This leads to the LP problem in the second step of the Herbert-Stevens model.

In the second step, the only objective of the urban planner is to maximize the social net return to land by allocating all land to households. The net return solved from the first step represents a series of bids from all household strata on all land zones. And the urban planner accepts the set of bids which maximizes the objective of the entire city. In the first step, given the location of land zones, each household stratum chooses a set of housing attributes which is best for them. This is the decision at the micro level. In the second step, the urban planner's decision variable is the amount of land to allocate among household strata, which constitutes the macro level of the planning problem. Therefore, the Herbert-Stevens model presents a framework containing both micro and macro layers of the urban spatial structure problem.

Methodologically, the mechanism of the Herbert-Stevens model is similar to the goal programming approach in multi-criteria optimization. The similarity mainly comes from the fact that households within a stratum are assumed to have homogeneous preference on housing and other non-locational goods, which also simplifies the structure of the problem. Each household stratum can be treated as a representative household, and the maximum net return to land of that household stratum becomes a criterion to meet in the urban planner's planning goal. Homogeneous preference is indeed a strong assumption. If heterogeneous preference is introduced at individual household level in the Herbert-Stevens model, however, it is less likely to have the model fundamentally changed in methodology. More parameterization will be required in the numerical procedure as the size of problem increases, but the same model setup and algorithm can still be used.

When the model is developed to the duocentric case, one additional decision variable - the inter-city distance - is introduced. In the case considered in this paper where the inter-city distance is endogenous to the urban spatial structure, the optimal distance balances the benefits and costs from having two co-existing urban centers. The new urban center and expanded urbanized area can provide new employment opportunity and more affordable living space. On the other hand, the costs may come as longer commuting time and potential congestion cost along with urban population growth. Urban development and land use policies always play a big role in the rise of a new urban center, as well as in the suburbanization movement across United States in the last half century. To urban planners, the decision of inter-city distance in the duocentric city and more generally the network size in the polycentric city (e.g., corridor cities, network of cities) is crucial to the efficiency of resource use in the urban society. Of course, this is not an easy problem given the fact that the urban development process is the evolution of a multidimensional complex system. The Herbert-Stevens model and its development in this paper, in simplified forms, can shed some light on solutions to the problem.

Model is always a simplification of the real world problem, so does the model in this paper. There are at least four simplifications imposed regarding economic activities and markets in this paper. The first simplification is the income level which is exogenously given. A further elaboration of income level Y can potentially lead to the incorporation of labor markets in the model. For example, in the duocentric model two urban centers can represent different types of labor markets and therefore households can be differentiated through income structure as well.

The second simplification is the transportation system. In the current model, all residents use the same transportation system and travel on spoke-roads at uniform cost. In reality, residents can make choice over transportation modes and travel routes, which will lead to heterogeneity in transportation costs. The structure of congestion cost can also be changed based on the changes of transportation modes and travel routes.

The third simplification is that the current model is static in the sense that it only captures a long run equilibrium. One way to develop it into a dynamic model is allowing for migration on the urban landscape over time. In the current duocentric model, internal migration between two cities is not allowed. However, there are at least two motivations for internal migration to happen: (1) the wage rates at different cities evolve differently over time; (2) uneven infrastructure investment due to inter-jurisdictional fiscal competition and it may lead to, for example, more efficient transportation system in one city and therefore lower transportation costs.

The last simplification is the ignorance of environmental externalities of land development and the need for environmental planning. The importance of the environmental dimension of urban life has never been emphasized more than today. This is a direct consequence of increasing density, and it demands more and more concerns in urban planning and public policy. Glaeser (2007) argued that the desire of the rich to own more land does not seem to be great enough to justify their decisions to live on the urban edge. As explicitly modeled in this paper, the desire to avoid disamenity near the city center can be one explanation. But more elaborate treatment on the environmental dimension of urban development is more than necessary.

7. Concluding Remarks

In this paper, I reinterpret the Herbert-Stevens model and propose a general procedure to solve the two-step residential land allocation problem via numerical optimization. In the first step, I convert Wheaton (1974)'s unconstrained optimization problem into a constrained NLP problem which is then solved by the Frank - Wolfe algorithm. Through numerical examples, I show that the Frank - Wolfe algorithm can solve the first step NLP problem within a small number of iterations, and the algorithm is applicable to large scale problem as well. In the second step, I solve the LP problem of the Herbert-Stevens model, and obtain the optimal residential land allocation for the urban area. The solution presents the best that the urban planner can achieve, which itself is a Pareto equilibrium[6]. The monocentric Herbert-Stevens model is further developed into the duocentric city framework. In the duocentric Herbert-Stevens model, the inter-city distance is endogenized to the urban spatial structure. The determination of the optimal inter-city distance is demonstrated through a numerical example. Methodologically, the model framework and algorithm proposed in this paper offer an effective technique for identifying the limits of feasible urban performance.

The key observation of the spatial equilibrium based urban economics models is that the differences in transportation costs within an urban area must be balanced by the quality of living at any given location, i.e., individuals must be indifferent across all locations. In an aggregative single (homogenous) agent model, the balance can be easily reached. In a disaggregated model where the population consists of heterogeneous households or communities, however, the balance between transportation costs and location specific quality of living only implies a series of ideal scenarios. The socially optimal spatial structure in an urban area may not guarantee the most preferred combination between transportation costs and quality of living for each household. In classic spatial equilibrium based models, for example the Alonso-Muth-Mills model, population density is a decreasing function of distance to the city center. The monotonic decreasing relationship between population density and distance, however, may only be a special case in disaggregated models, which has been numerically shown in this paper.

The duocentric model makes two essential changes to the monocentric model,

[6]It does not necessarily imply a first-best optimal outcome, most likely a second-best outcome instead.

the congestion cost between two cities and the endogenized inter-city distance. The inter-city distance directly affects transportation cost and congestion cost. It also affects household utility through the average distance to city centers which is used as an approximate measure for disamenity. The numerical illustration of the duocentric model shows that low income households choose to live in the fringe between two cities further from both urban centers, which is consistent to observations in the literature, such as Anderson (2008). This is a result different from the two cases of the monocentric model. A major implication of the results to urban planners and policy makers is that the economic planning of a multi-city urban area requires potentially different transportation, environment, and land use policies. Especially, the income effect of transportation policies on low income households should be considered. A development plan that solves the deterioration issues in inner urban area may lead to new deterioration in suburban area. A policy that is proper in a monocentric city may have opposite results in a non-monocentric city.

The model framework and examples proposed in this paper provide a benchmark for modeling of corridor cities and network of cities. But they are in their purely simplified form. A valuable improvement to this study would be obtaining the parameters of the system through calibration with real observational data, especially for the parameters in the utility functions and cost functions. The observational data can also be used as information to determine the starting values (for large scale problems) or bounds of constraints in numerical implementation. Given the constrained NLP problem in (9), for example, there could be some other constraints imposed on q_{i1} and q_{i2} due to external conditions. Let q_{i1} be lot size and q_{i2} be amenity level as specified in Table 2.1, say the city has a regulation which limits the residential lot size from being too small to protect local open space (which corresponds to high amenity level therefore a larger q_{i2}), then assuming both q_{i1} and q_{i2} are standardized another constraint like $q_{i1} \geq cq_{i2}(c > 0)$ may be realistic and necessary. The constant c can be estimated directly from the observational data.

Another interesting improvement to this study is to incorporate the transportation mode choice and travel pattern, which will change the structure of transportation and congestion costs in the model. Eliasson and Mattsson (2000) constructed a model to analyze the interactions between infrastructure, household location choice, and travel pattern, which can be a good starting point to integrate the disaggregated urban economics models as in this study with detailed representation of transportation behaviors. The need for integrated land use and detailed transportation behavior modeling is also emphasized in Waddell et al. (2007). Using a simulation approach, Waddell et al. (2007) show that accounting for feedback between land use and regional transportation planning may lead to significant changes in key transportation system performance measures. An interesting alternative to explore is how accounting for the feedback between land use and transportation system will change the urban spatial structure in urban development and planning. These directions are the focus for future research.

Reference

1. Alonso, William. 1964. Location and Land Use. Cambridge: Harvard University Press.
2. Alperovich, G. and J. Deutsch. 1996. "Urban Structure with Two Coexisting and Almost Completely Segregated Populations: The Case of East and West Jerusalem." Regional Science and Urban Economics 26(2): 171-187.
3. Anderson, A. S. 1982. "A Linear Programming Model of Housing Market Equilibrium." Journal of Urban Economics 11(2): 159-168.
4. Anderson, M. W. 2008. "Cities Inside Out: Race, Poverty, and Exclusion at the Urban Fring." UCLA Law Review 55, 1095-1160.
5. Arnott, R., R. Braid, R. Davidson, and D. Pines. 1999. "A General Equilibrium Spatial Model of Housing Quality and Quantity." Regional Science and Urban Economics 29(3): 283-316.
6. Bayer, P. and C. Timmins. 2005. "On The Equilibrium Properties of Locational Sorting Models." Journal of Urban Economics 57(3): 462-477.
7. Boyce, D. 2007. \Future Research on Urban Transportation Network Modeling." Regional Science and Urban Economics 37(4):472-481.
8. Brueckner, J. K. 1983. "The Economics of Urban Yard Space: An \Implicit-Market" Model for Housing Attributes." Journal of Urban Economics 13(2): 216-234.
9. Chang, J. S. and R. L. Mackett. 2006. "A Bi-level Model of The Relationship Between Transport and Residential Location." Transportation Research Part B: Methodological 40(2): 123-146.
10. Eliasson, J. and L. G. Mattsson. 2000. "A Model for Integrated Analysis of Household Location and Travel Choices." Transportation Research Part A: Policy and Practice 34(5): 375-394.
11. Evans, S. P. 1973. Some Applications of Optimisation Theory in Transport Planning. Ph.D. thesis, Civil Engineering, University College London, London.
12. Fujita, M. and H. Ogawa. 1982. "Multiple Equilibria and Structural Transition of Non-monocentric Urban Configurations." Regional Science and Urban Economics 12(2): 161-196.
13. Geerlings, H. and D. Stead. 2003. "The Integration of Land Use Planning, Transport and Environment in European Policy and Research." Transport Policy 10(3): 187-196.
14. Glaeser, E. L. 2007. \The Economics Approach to Cities." NBER Working Paper Series, No. 13696.
15. Guldmann, J. M. 1979. "Urban Land Use Allocation and Environmental

Pollution: An Inter-temporal Optimization Approach." Socio-Economic Planning Science 13: 71-86.

16. Henderson, V. and A. Mitra. 1996. "The New Urban Landscape: Developers and Edge Cities." Regional Science and Urban Economics 26: 613-643.
17. Herbert, J. D. and B. H. Stevens. 1960. "A Model for The Distribution of Residential Activity in Urban Areas." Journal of Regional Science 2(2): 21-36.
18. Jackson, K. T. 1985. Crabgrass Frontier: The Suburbanization of the United States. New York: Oxford University Press.
19. Keirstead, J. and N. Shah, 2013. "The Changing Role of Optimization in Urban Planning." In A. Chinchuluun, P. M. Pardalos, R. Enkhbat, and S. Pistikopoulos (Eds.), Optimization, Simulation and Control, 175-193, Springer.
20. Klaiber, A. H. and D. J. Phaneuf. 2010. "Valuing Open Space in A Residential Sorting Model of The Twin Cities." Journal of Environmental Economics and Management 60(2): 57-77.
21. Kuminoff, N. V. and A. S. Jarrah. 2010. "A New Approach to Computing Hedonic Equilibria and Investigating the Properties of Locational Sorting Models." Journal of Urban Economics 67(3): 322-335.
22. LeBlanc, L.J. 1973. Mathematical Programming Algorithms for Large Scale Network Equilibrium and Network Design Problems. Ph.D. thesis, Industrial Engineering and Management Sciences, Northwestern University, Evanston, IL.
23. Magliocca, N., E. Safirova, V. McConnell, and M. Walls. 2011. \An Economic Agent-Based Model of Coupled Housing and Land Markets (CHALMS)." Computers, Environment and Urban Systems 35 (3): 183- 191.
24. Mieszkowski, P. and E. S. Mills. 1993. \The Causes of Metropolitan Suburbanization." Journal of Economic Perspectives 7(3): 135-147.
25. Mills, E. S. 1967. \Transportation and Patterns of Urban Development: An Aggregative Model of Resource Allocation in a Metropolitan Area." The American Economic Review 57(2): 197-210.
26. Mills, E.S. 1972. Studies in the Structure of the Urban Economy. Baltimore: Johns Hopkins Press.
27. Moore, J. E. and T. J. Kim. 1995. "Mills' Urban System Models: Perspective and Template for LUTE (Land Use/Transport/Environment) Applications." Computers, Environment and Urban Systems 19(4): 207-225.
28. Muth, Richard F. 1969. Cities and Housing. Chicago: University of Chicago Press.

29. Ogawa, H. and M. Fujita. 1989. “Nonmonocentric Urban Configurations in a Two-dimensional Space.” Environment and Planning A 21(3): 363-374.
30. Pagliara, F. and A. Wilson. 2010. “The State-of-the-Art in Building Residential Location Models.” In Residential Location Choice - Models and Applications, edited by F. Pagliara, J. Preston, and D. Simmonds. Berlin Heidelberg: Springer.
31. Roback, J. 1982. \Wages, Rents, and the Quality of Life." Journal of Political Economy 90(4): 1257-1278.
32. Rosen, S. 1979. \Wage-Based Indexes of Urban Quality of Life." In Current Issues in Urban Economics, edited by P. Mieszkowski and M. Straszheim. Baltimore: Johns Hopkins University Press.
33. Schweizer, U., P. Varaiya, and J. Hartwick. 1976. \General Equilibrium and Location Theory." Journal of Urban Economics 3: 285-303.
34. Waddell, P., G. F. Ulfarsson, J. P. Franklin, and J. Lobb. 2007. “Incorporating Land Use in Metropolitan Transportation Planning.” Transportation Research Part A: Policy and Practice 41(5): 382-410.
35. Wheaton, W. C. 1974. “Linear Programming and Locational Equilibrium - The Herbert-Stevens Model Revisited.” Journal of Urban Economics 1(3): 278-287.
36. Wilson, A. 2010. “The General Urban Model: Retrospect and Prospect.” Papers in Regional Science 89(1): 27-42.
37. Wu, J. and A. J. Plantinga. 2003. “The Influence of Public Open Space of Urban Spatial Structure.” Journal of Environmental Economics and Management 46(2): 288-309.
38. Yang, C. H. and M. Fujita. 1983. “Urban Spatial Structure with Open Space.” Environment and Planning A 15(1): 67-84.
39. Yinger, J. 1992. “City and Suburb: Urban Models with More Than One Employment Center.” Journal of Urban Economics 31: 181-205.
40. Zhang, Y. and K. Sasaki. 2000. “Spatial Structure in An Open City with A Subcenter.” The Annals of Regional Science 34(1): 37-53.

III: A Simulation Model of Home Improvement with Neighborhood Spillover

1. Introduction

Improvement on existing housing stock is an important alternative to the production of new housing. In the U.S., the household expenditures on home improvement have increased substantially in recent decades. According to the Survey of Residential Improvements and Repairs from the U.S. Census, in 1966, out of 46,500 million dollars of total expenditures on residential improvements and repairs by U.S. households, 58.9% was spent on home improvements. In 1996, the corresponding number is 69.4% out of 527,900 million dollars, and 75.8% out of 908,400 million dollars in 2007. However, the literature has only recently started paying attention on the fact that home improvement has been a substantial source of housing supply. Dipasquale (1999) points out that homeowners' decision on rehabilitation and home improvement are substantial adjustments to the existing housing stock. On the other hand, the improving decisions are also very complicated since the homeowners play the roles of both suppliers and consumers of housing. An early literature review on household home improvement decisions is given in Bogdon (1992). Her research also suggests that the classic modeling approach to home improvement decisions based on maximizing the value of the net benefit from the housing unit may be inadequate, and home improvement expenditures tend to be inelastic to income level. Lately, Gyourko and Saiz (2004) urge urban scholars and policy makers to start paying attention to the supply side of housing market, especially the reinvestment and redevelopment of existing housing stock. Their analysis suggests that physical costs are a very important determinant of improving effort, and when home values go below replacement cost households' effort in reinvestment is found to be substantially reduced.

Home improvement can be simply defined as any construction activities which significantly increase the stock of housing capital (therefore the housing service provided) without developing new dwellings. In other words, home improvement is more about increasing the density of housing service produced on developed residential land. Examples of home improvement can be putting a recreation room in an unfinished basement, converting a garage into a room, adding another bathroom or bedroom, putting on a new roof, or even paving the driveway to increase parking space. Home improvement activities should be distinguished from regular home maintenance or repair activities, as Potepan (1989) points out, the latter are only aimed at maintaining housing units in good condition and offsetting physical deterioration of housing capital. Home maintenance and repairs usually do not add value to a housing unit or prolong its life. Home improvement is also substantially different from new housing production, due to the so-called fixed capital constraint (see Potepan (1989)). Therefore home improvement and new housing development present two options of limited substitutability for households who choose to adjust their current housing consumptions.

At micro level, home improvement investment is a major adjustment to household consumption bundle and asset portfolio. Home improvement investment can also have significant social consequences which go beyond the household level. Home improvement is a constituent part of homeownership. And the value of homeownership depends on the quality and vitalization of neighborhood, which connects home improvement decisions and neighborhood quality. The empirical analysis of Boehm and Ihlanfeldt (1986), for example, shows that improvement input costs and neighborhood quality have significant impacts on the improvement expenditures of city homeowners. Rohe and Stewart (1996) find that there is considerable association between homeownership, property improvement, and neighborhood stability. One causal explanation for this relationship is that, home improvement as part of homeownership generates a positive neighborhood spillover. The existence of neighborhood spillover effects has important implications for public policy because the aggregated outcomes no longer necessarily reflects the simple summation of individual household behaviors or any representative household's behavior. As Rossi-Hansberg et al. (2010) argue that, housing spillover effects imply that equilibrium allocations will differ from efficient outcomes and hence potentially justify a role for government intervention. The goal of this paper is to explore how the household decisions between home improvement and moving shape urban land development and housing markets, and what is the role of neighborhood spillover.

2. Literature Review

In the literature, there is a rich body of empirical examinations in new housing supply and home improvement investment separately, but the linkage between two has not been well understood yet. Mendelsohn (1977), Seek (1983), and Eastwood and Garner (1986) are among the earliest empirical studies on household decisions of home improvement and the choice between improving and moving. Mendelsohn (1977) points out that home repairs and improvements by homeowners are important components of housing supply activities.

For the first time, Mendelsohn (1977) estimates the income elasticity of home improvements as 0.60 for the mean household. Seek (1983) finds that when facing need of housing consumption adjustment, home improvement is preferred for most of households who have the choice of moving or improving. Eastwood and Garner (1986) focus on how home improvements are performed. They developed a model based on household time use to study the choice between self and contracted repairs. The results suggest that housing policies aimed at promoting home improvements should consider the diversity of improvement categories and of households. Note that improving or moving are not always two separable choices. Littlewood and Munro (1997) find that movers frequently undertake some improving activities to adjust newly acquired dwellings. Baker and Kaul (2002) and Fisher and Williams (2011) provide some recent empirical evidences on homeowners' home improvement decisions.

One of the first discussions on neighborhood spillover effects of home improvement is Shear (1983). Shear (1983) points out that one of the main concerns in housing policy is which households benefit and which households bear costs due to investment in housing capital in a neighborhood. Helms (2003) empirically finds that the housing renovation activities exhibit spatial dependence. Neighborhood spillover effects may cause renovations performed on one building to increase the likelihood that other nearby buildings will be renovated. Glaeser and Sacerdote (2000), Ellen and Voicu (2006), and Rossi-Hansberg et al. (2010) among other authors have studied the neighborhood spillover effects associated with housing investment in general. In order to thoroughly understand household decision-making on home improvement from a supply side perspective, and how these individual decisions shape the urban spatial structure, an agent-based simulation model of home improvement is developed in this paper. The basic model is then further developed to incorporate neighborhood spillover effects.

Agent-based modeling (ABM) has been widely used in land use, urban and regional modeling. One of the main advantages of ABM simulation is that it can capture Emergent Phenomena which results from the interactions among individual agents (Bonabeau, 2002). The rationale behind the methodology is that the interactions among the parts can lead the whole to be more than the sum of parts. One of the earliest urban housing market simulation dates back to the NBER Urban Simulation Model (Kain and Apgar, 1979) in 1970s. In recent literature, Magliocca et al. (2011) present an economic ABM simulation of housing and land markets that captures the conversion of farmland to residential housing over time. Spencer (2012) proposes an agent-based model to simulate the social dynamics of creativity within an evolutionary economic geography framework. ABM simulations have three essential components: stochasticity, heterogeneity, and social interactions. Stochasticity (sources of randomness) is the basic driving forces of a simulation and dynamics. The importance of heterogeneity and social interactions has been frequently highlighted in the literature. For example, both Parker and Filatova (2008) and Filatova et al. (2010) put emphasis on incorporating heterogeneity, interactions, and out-of-equilibrium dynamics into simulation of land and housing markets.

In this paper, stochasticity is generated through financial market fluctuations and incomes shocks. Heterogeneity is brought in through household income levels and relative locations. Neighborhood spillovers of home improvement form social interactions among households. The analytical model framework is built upon individual household decisions between two options - improving current housing unit or moving out through new development within a monocentric city.

Rest of the paper is organized in the following structure. Section 3 develops the basic analytical models for urban spatial structure and home improvement decisions, the models are then extended to incorporate neighborhood spillover effects. Section 4 introduces the setup and algorithm of simulations, and with a summary of simulation results followed. Section 5 discusses the implications for public policy-making, and Section 6 concludes the paper.

3. Model

3.1 Overview

Every urban household is an organic component of the large urban system which can be broadly defined as an open network consisting of the movements of labor, capital, goods, services, and ideas. It is the interactions (market and non-market) in the network among different locations generating the location-based demand for density and concentration. From a production and supply side perspective, this network effect may be interpreted as agglomeration effect or economy of scale. To understand the spatial structure of an urban system and its dynamics, it is necessary to start with the behavior of its building components

- each individual household. Each household occupies certain amount of land within the urban area, but they are not isolated from each other. Households interact frequently through market and non-market mechanisms. In recent decades, the development of modern transportation system and communication technologies has further facilitated the social interactions in cities. The new urban development trend has fundamental implications for industry structure, environment system, land use and housing markets. The focus of this paper is on the social interactions through housing markets and its implications for public policy.

3.2 Urban Spatial Structure

A basic principle of urban spatial structure is that the transportation cost differences must be compensated for by the differences in housing prices and spatial distribution of amenities. The principle is implicit in most of the monocentric models of urban spatial structure, for example, the Herbert-Stevens model (Herbert and Stevens, 1960), the Alonso-Mills-Muth model (Alonso, 1964; Mills, 1967; Muth, 1969), and the Rosen-Roback Model (Rosen, 1979; Roback, 1982). In a monocentric city with homogeneous households, given the amount of non-housing consumption, urban spatial structure can be represented by the balance between transportation costs, housing consumption and housing price. In a long run equilibrium, housing price can be considered being as the equilibrium outcome of housing supply and demand. Note that the term housing price here reflects not only the physical construction or land development cost of a housing unit, but also the value of all of the location related characteristics or attributes attached to the housing unit. Assuming that all households are homogeneous and identical, the spatial equilibrium of the urban area should guarantee identical utility levels (or more plainly, the quality of life) for all households. The spatial variation of unit housing price (i.e., the price per square foot of floor space) becomes a key instrument to achieve identical utilities across the entire urban area (Brueckner, 1987).

In a simple monocentric city model, everyone who live in the city commute to the central business district (CBD) and a fixed unit transportation cost t occurs. Assuming that the utility of each household depends on two types of consumption: housing and non-housing, and the housing consumption is featured by one single attribute - lot size or living space S. Denoting the unit housing price and non-housing consumption as p and M, respectively; at any given location D (measured by the distance to the CBD) the budget constraint is given as:

$$Y = pS + tD + M \tag{1}$$

where the price of non-housing goods is standardized to 1. The household's consumer problem can be given in the form of utility maximization:

$$\max_{S} \quad U(M,S) \quad = \quad U(Y - pS - tD, S) \tag{2}$$

Given housing price p, the household's optimal choice of living space can be derived from the first order conditions of (2). If the household's desired utility level is further set at U^0, following Brueckner (1987), the combination of p and S which satisfies both the desired utility level and the first order conditions of (2) can be solved from the following simultaneous system:

$$\begin{cases} p^* & = \frac{\partial U/\partial S}{\partial U/\partial M} \\ U^0 & = U(Y - pS^* - tD, S^*) \end{cases} \tag{3}$$

At any given location D, a pair of values for (p,S) can be solved upon the specification of other parameter values of the system: Y, U^0, and t. The set of (p,S) values across all locations will then represent a simple spatial structure of the city basing on housing markets. Generically, we can show by total differentiating (3) that $\partial p/\partial D < 0$. If we assume an Cobb-Douglas preference structure, $U = S^{\alpha_s} M^{\alpha_m}$ with $0 < \alpha_s, \alpha_m \leq 1$, we can have a useful result:

$$p = \alpha_s \left[\frac{\alpha_m^{\alpha_m} (Y - tD)^{\alpha_s + \alpha_m}}{U^0} \right]^{\frac{1}{\alpha_s}} \tag{4}$$

where U^0 can also be considered as the desired quality of living of a household.

3.3 *A Model of Home Improvement*

At every stage of family life cycle, a household has to make decisions regarding its housing consumption, to stay and make no change, to stay and invest in existing housing unit(s), or to move. The adjustment decision depends on housing market conditions, the household income, technological and regulatory constraints. For example, based on survey data from Australia, Seek (1983) finds that home improvements are undertaken as response to changes in household demographic and economic conditions. The level of home improvement investment is mainly constrained by income level, financial and wealth status. In general, a household's housing decision lies between improving current housing unit and moving. Staying at current housing unit without any investment on home improvement can be considered as a special case of improving with zero investment. Moving, in its ultimate sense, can be considered as a type of new development - adding new housing units to existing housing stock[1]. In short it is the decision of improving or moving that constitutes the microfoundation of the supply side of housing markets.

The earliest analytical model that describes the decision of home improvement goes back to Arnott et al. (1983). In their model, the time of construction, maintenance expenditure over the life of the housing unit, and the time of demolition or rehabilitation are integrated into one landlord's profit-maximization problem. The limitation of this model is that the entire urban spatial structure is ignored, and attention is attached on one particular plot of land. Therefore there are no locational effects or any neighborhood effects related to home improvement investment. Around the same time, Shear (1983) uses a multinomial logit model to analyze the decisions of rehabilitation and moving simultaneously with household, housing unit, and neighborhood characteristics being taken into account. One of the key conclusions from his empirical study is that the ability of households to adjust their level of housing consumptions through rehabilitation investment affects their moving behavior, which is supported by Seek (1983). Potepan (1989) models households as decision makers who face two options - improving existing housing or moving, and the optimal choice is affected by changes in interest rates and income. The aggregated outcome of all individual housing decisions is then used to provide an explanation for

[1]Given that the housing market is in equilibrium without housing vacancy and migration effects, as population of the urban area grows, we can assume that the moving-out households occupies recent developed housing units while the newly established households fill in the vacant existing housing units. Even though some of the newly established households may occupy part of the new housing units, the net effect can still justify this assumption.

the observed growth in home improvement expenditures. Amin and Capozza (1993) take a developer rather than a homeowner's perspective to examine the re-investment (sequential development) on initial housing development. Their analysis suggests that the qualitative results under multi-stage development are similar to those of the single-stage development case. However, the quantitative results can be dramatically different when sequential development is allowed.

In this paper, households as homeowners make decisions between improving their current housing unit and moving (to obtain additional housing in the form of new development, see footnote 1). All households are assumed to have purchased their housing units through finance - mortgage with fixed interest rates r. Without loss of generality, households only pay the mortgage interests rp every time period[2]. S^* represents the household's current housing consumption, home improvement can be considered as an addition to current housing consumption, denoted as $\triangle S$ (i.e., the housing gap in Seek (1983)). Assuming that the household can finance home improvement with the same mortgage interest rate r, the cost of home improvement to the household is $rp\triangle S$.

The other option - moving through new development is also financed but with uncertainty in mortgage interest rates. The interest rate for this outside option, denoted as r', is assumed to follow a stochastic process. Assuming that the real estate market is competitive and the household can sell the housing unit at its current value pS^* which repays the principal, but with a transaction cost (e.g., sales commission, legal fee, time). The cost of moving for the household is $r'p'(S^* + \triangle S') - rpS^* + t(D' - D) + cpS^*$. p' is the housing price at the new location. D' is the new distance to the CBD, and $t(D' - D)$ is the corresponding change of transportation cost. $\triangle S'$ is the increase of housing consumption after moving and it is assumed to be non-negative[3]. c is the per unit transaction cost, and $0 \leq c \leq 1$. Given $\triangle S', \triangle S > 0$, the household's decision on additional housing can then be represented in the following way:

$$\begin{cases} moving & if \quad \frac{r'p'(S^*+\triangle S')-rpS^*+t(D'-D)+cpS^*}{\triangle S'} < \frac{rp\triangle S}{\triangle S} \\ improving & if \quad \frac{r'p'(S^*+\triangle S')-rpS^*+t(D'-D)+cpS^*}{\triangle S'} \geq \frac{rp\triangle S}{\triangle S} \end{cases} \tag{5}$$

[2]This basically assumes that all mortgages are infinite long. In this case, the household makes only interest payments regularly until the housing unit is sold, and the entire principal is repaid.

[3]Note that it is possible to have $\triangle S' < 0$. As Seek (1983) points out, at certain life cycle stages (e.g., older family) a household may choose to move and reduce its housing consumption.

Now, the critical question left to answer is how much additional housing should the household consume - the determination of $\triangle S$ and $\triangle S'$. Since the current housing consumption S^* is already optimal given the income level, desired living quality, and transportation cost, the demand for additional housing must be triggered through exogenous changes. Intuitively, an increase in household income will lead to demand for additional housing, so will a decrease in transportation cost through income effects. Given a positive income shock $\triangle Y$, $\triangle S$ and $\triangle S'$ can be determined through:

$$S^* + \triangle S = \underset{S}{argmax} \quad U(Y + \triangle Y - rpS - tD, S) \tag{6}$$

$$S^* + \triangle S' = \begin{cases} \underset{S}{argmax} \quad U(Y + \triangle Y - r'p'S - tD' - cpS^*, S) & if \quad \triangle Y > \triangle C \\ S^* & if \quad \triangle Y \leq \triangle C \end{cases} \tag{7}$$

where $\triangle C = t(D' - D) + cpS^*$. The condition $\triangle Y \leq \triangle C$ implies that the income increase is not enough to cover the transportation cost change and transaction costs associated with moving. Note that the housing prices p and p' in (6) and (7) are different from the one in (3). In (6) and (7) rpS ($r'p'S$) is household housing expenditure every time period, and pS ($p'S$) is the housing asset price. The former is a flow variable, and the latter is not. rp in (6) is equivalent to p in (3).

Even though the exogenous changes may not affect the decision between improving and moving directly, the indirect effects through the change of $\triangle S$ ($\triangle S'$) can lead to switching between two options. On the other hand, as it is apparent from (5), the decision can also be affected by changes in transaction cost and relative mortgage interest rates. However, the exact effects of transportation cost change and mortgage interest rate change is unclear. The simulations implemented in Section 4 can shed light on them.

3.4 Urban Interactions and Neighborhood Spillover Effects

A city is a combination of physical and human environments in a dense form, but it contains much more than the simple summation of its building elements. A city represents on average higher productivity, on average higher income and living qualities. Glaeser et al. (2001)'s study suggests that the demand for living in cities has been rising, and what is important to cities is not only the agglomeration economy in production but also the clustering effects in consumption - the effects of density. One possible explanation to the phenomenon is the non-market urban interactions. Glaeser et al. (2000) points out urban economics needs to draw more attention on non-market interactions given their central role in understanding the causes and effects in cities. And the flow of ideas that occurs through non-market interactions may provide explanations for most of the features of cities. Rossi-Hansberg et al. (2010) argue that, at any given location, land price should already reflect a variety of non-market interactions among residents and their houses. The intensity of these non-market interactions is beyond the control of any single household, but it indeed affects the behavior of every household within the location-based neighborhood, especially through the connections between homeownership and neighborhood. The importance of integrating urban interactions is analytically illustrated in Helsley and Strange (2007). The authors demonstrate that the vitality of an urban center and thus its value to households and individuals are always produced as an aggregate outcome of interacting individual decisions.

Neighborhood spillover effects, as an important form of non-market interactions, are fundamental to the vitalization of urban communities and urban economy. To study the neighborhood spillover effects of home improvement, we build upon the basic model constructed from (1) to (7). A model of urban interactions through housing markets, given household i, is specified as:

$$I(S_i, \triangle S_{-i}) = V(S_i, f(S_i, \triangle S_{-i})) \tag{8}$$

where the household utility from housing consumption depends on own home improvement (reflected in the new housing consumption level S_i), and other households' home improvement in the neighborhood. $\triangle S_{-i}$ is the average home improvement level of all other households in the neighborhood. $f(S_i, \triangle S_{-i})$ represents the neighborhood interactions. The interaction function in (8) has the similar strategic complementarity feature as the one proposed in Cooper and John (1988), where following properties are satisfied: $V_1 < 0$, $V_2 > 0$, $f_1 > 0$, and $f_2 > 0$. $I_2 = V_2 f_2 > 0$ implies the existence of positive neighborhood spillover. In this paper, we choose $f(S_i, \triangle S_{-i}) = S_i + \alpha_i \triangle S_{-i}$, where $\alpha_i \geq 0$ measures the weight that household i ties on neighborhood spillover effects of home improvement activities. α_i can be an important source of household heterogeneity.

Further, we parameterize a special structure on $V(\cdot,\cdot)$ which satisfies the partial derivative conditions:

$$I(S_i, \triangle S_{-i}) = (S_i + \alpha_i \triangle S_{-i})^2 S_i^{-1} \tag{9}$$

$I(S_i, \triangle S_{-i})$ represents all of the subutility that household i can draw from both own and others' housing consumptions. If the household utility function is assumed to be separable with an Cobb-Douglas preference structure over consumptions as before, the household utility function becomes:

$$U = I_i^{\alpha_s} M_i^{\alpha_m} = \left[(S_i + \alpha_i \triangle S_{-i})^2 S_i^{-1}\right]^{\alpha_s} M_i^{\alpha_m} \tag{10}$$

where $0 \leq \alpha_s \leq 1$ and $0 \leq \alpha_m \leq 1$ are constant preference parameters. Note that if $\alpha_i = 0$ (no neighborhood spillover), the utility function simply reduces to $U = S_i^{\alpha_s} M_i^{\alpha_m}$ as in the basic model.

If there is an exogenous change which leads to an equivalent income effect $\triangle Y$, i.e., relaxing the budget constraint in (1) by $\triangle Y$, and the transportation cost is further assumed being fixed at the original level, the household can allocate the additional income between home improvement and non-housing consumption M. Under the *improving* option, the household decision can be represented by a constrained utility maximization problem:

$$\begin{cases} \underset{S_i, M_i}{max} & \left[(S_i + \alpha_i \triangle S_{-i})^2 S_i^{-1}\right]^{\alpha_s} M_i^{\alpha_m} \\ s.t. & 0 \leq rpS_i + M_i \leq Y_i + \triangle Y_i \end{cases} \tag{11}$$

where optimal S_i represents the new housing consumption, and the difference between optimal S_i and S^* gives the amount of home improvement $\triangle S$. Note that α_i here is not a decision variable but it can be household specific. The rationale behind the role of α_i is that different households may have different relative aesthetic valuation between their own houses and the architecture of the entire neighborhood. Under the *moving* option, where no spillover occurs, the household decision problem becomes:

$$
\begin{cases}
\max\limits_{S_i,M_i} & S_i^{\alpha_s} M_i^{\alpha_m} \\
s.t. & 0 \leq r'p'S_i + M_i \leq Y_i + \triangle Y_i - \triangle C
\end{cases}
\tag{12}
$$

where the condition $\triangle Y_i > t(D_i' - D_i) - cpS^*$ is satisfied, and the difference between optimal S_i and S^* gives the increase of housing consumption $\triangle S'$ after moving. The two optimization problems in (11) and (12) constitutes the foundation of the ABM simulation which involves solving the decision-making problems for all households simultaneously every time period. The simultaneous system consists of a large number of maximization problems with nonlinear objectives. In this paper, we solve the problem iteratively for all households.

Note that the proposed home improvement model only allows for quantity change. A possible extension to the model would be allowing for quality change as well. Allowing both quantity and quality changes will generalize the concept of home improvement, to the extent that home improvement may include home maintenance and upgrade (e.g., flooring replacement, bathroom upgrade, and kitchen remodeling). From theoretical modeling aspect, allowing for quality change implies that a housing unit may depreciate over time, which points to a promising future research direction. Another possible implication for modeling is on housing price. In the current model housing price is determined through the monocentric urban spatial structure. The neighborhood spillover effects could be expanded to housing price with housing quality change possible.

4. Algorithm and Simulation

The focus of this paper is to understand the role of home improvement in the dynamics of urban development, and it takes a disaggregated perspective on urban modeling. This sets it different from frameworks where the urban spatial equilibrium is of key interest. In the simulation, there are two main sources of randomness - fluctuations in financial markets and exogenous income shocks. The fluctuations in financial markets generate uncertainty in mortgage rates which plays an important role in household decisions regarding housing consumption. The time series of mortgage rates is simulated by a Wiener process (standard Brownian motion). The exogenous income shock, generated by a non-negative distribution, is an important determinant of the size of simulated home improvement and the spatial distribution of improving activities.

4.1 Assumptions and Setup

The basic mechanism of the simulation follows the models developed in section 3. The specific setup and important assumptions are summarized as follows:

(1) The city spans over a two-dimension space. The space is divided into grids of equal size, where each grid cross represents a parcel. All land parcels are homogenous, and housing units built upon are characterized only by S. The city is monocentric and consists of two types of land use: open vacant land (available for new development), and residential area (has been developed). The open vacant land is always located at the edge of developed area, i.e., the urban development expands outward continuously.

(2) At the beginning of each time period, every household receives an income shock with certain probability. The amount of income shock follows a positive folded standard normal distribution, i.e., households only receive positive income shocks. Note that it is possible to model negative income shocks as well. However, housing is a durable good and it is economically difficult to downsize it. With a negative income shock households more likely choose to move to reduce their housing consumptions. The nucleus of this paper is on home improvement which increases housing consumption, therefore we ignore the case of negative income shocks.

(3) Upon receiving income shocks, current households make decisions between two options: 1) invest on improving their current housing units; 2) sell their current housing units and move out - building a new housing unit at a different location. The decisions are made basing on the cost of housing consumption adjustments as discussed in section 3. A simplifying assumption made here is that homeowner is also the home builder. The new location to move is determined by minimizing the increase of transportation cost.

(4) Whichever options a household chooses, it is financed through a fixed rate mortgage. Under the *improving* option, a household can finance its home improvement investment with the interest rate r at which the housing unit was purchased. Under the *moving* option, households face a new interest rate r' which is stochastic. This implies that every time a household moves it has a new interest rate on its mortgage.

(5) If the current household decides to move and sells its housing unit, the

vacant housing unit is automatically filled in by a newly established household (can be considered as a population growth process). The new household will face the new interest rate r' same as for the moving household. Note that implicitly we assume the housing market is in a long run dynamic equilibrium, and the vacancy rate is zero.

(6) Both home improvement and new development can be completed instantaneously, within the same time period of making decisions. Housing prices p and p' reflect all of the costs related to home improvement and new development, respectively.

(7) U^0, the desired quality (utility) of living, is assumed to be increasing with income level Y.

(8) In the interaction model, $\triangle S_{-i}$ at time period t is computed as the average home improvement level of all other households in the neighborhood from previous time period $t-1$.

(9) No housing demolition or housing depreciation is allowed in the simulation. Given the model structure developed, a constant housing depreciation works in a way similar as non-random negative income shocks. For the reason discussed above, we ignore the case with housing depreciation.

Another important part of simulation is parameterization. Table 3.1 summarizes all of the parameters and corresponding values for the basic model and the interaction model. Ideally, all of the parameter values should be calibrated with real data or basing on a realistic scenario. The simulations in this paper are all based on the designed monocentric city. There are two sets of parameters essential in the simulation models: utility function parameters α_m and α_s, and weight α_i. Household utility function presents constant returns to scale property given $\alpha_m + \alpha_s = 1$. $\alpha_s > \alpha_m$ implies that housing consumption is more important to household utility than non-housing consumption. α_i controls the strength of interactions associated with home improvement. Instead of calibrating, sensitivity analysis is performed on α_i, and other two important parameters t and NR.

4.2 Simulation Results

Figure 3.1 shows the time series of mortgage rates (left) generated and the initial state of city landscape (right). The time series is scaled so that the volatility stays in a realistic range. The trend in the interest rates is clear. In the landscape map, green (light) dots represent all developed land parcels (19.81%). The large red (dark) dot at $[20,20]$ is the city center (CBD). Both the mortgage rates time series and the initial landscape in Figure 3.1 will be kept same in all further simulations.

Variable	Value	Variable Definition
T	100	total simulation time period
$[I,J]$	$[40,40]$	city range (centers at $[20,20]$)
c	0.005	per unit transaction cost
t	0.01	per unit transportation cost
Y	20	household initial income
$\triangle Y$	$\theta \cdot \Phi \cdot Y_t$	income shock, Φ ˜ folded standard normal, $\theta = 0.06$
P_0	0.4	probability of income shocks
U^0	$Y_t/2$	desired quality (utility) of living
α_m	$1/3$	utility function parameter
α_s	$2/3$	utility function parameter
α_i	$0(basic), 2(interaction)$	weight on neighbors' improvement
r_0	0.08	mortgage interest rate at $t = 1$
NR	6	interacting neighborhood radius

Table 3.1: Parameterization of Simulations

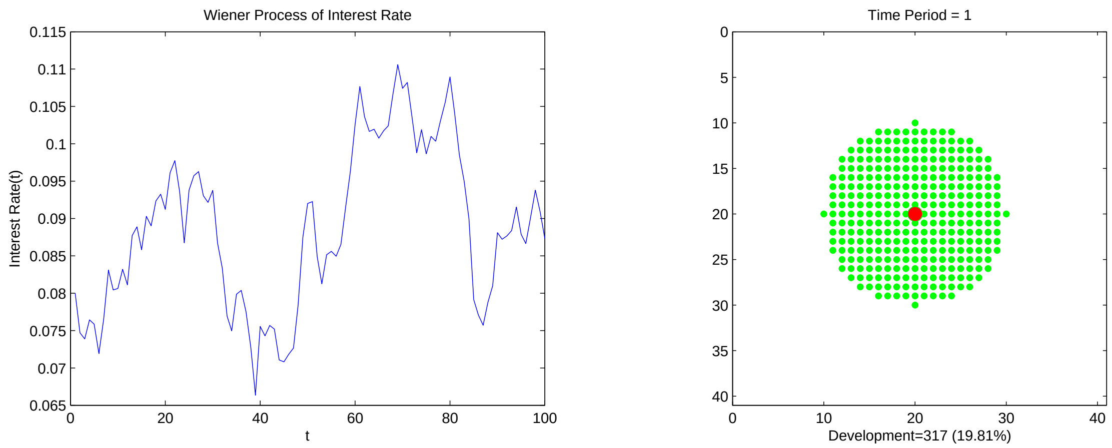


Figure 3.1: Time Series of Interest Rates (left) and Initial Landscape (right)

Figure 3.2 presents statistical results of the simulation basing on the basic model of home improvement ($\alpha_i = 0$). The top left graph shows the percentage of urban land being developed over time, which starts from the 19.81% initial development. It is evident that at the early stage land development process is slow. After certain threshold, the land development process speeds up. The threshold is likely to be determined by the distance to CBD rather than time[4]. The top right graph shows number of new development each time period, which tells the same pattern. The lower left graph shows average duration of residence of all current city households. Intuitively, the duration of residence is supposed to show opposite pattern to previous two graphs. Increase of movings (new development) tends to reduce average household duration of residence. The lower right graph shows average per household home improvement - average adjustment of housing consumption. The amount of improvement overall keeps increasing, which can be explained by the cumulative growth of household income levels.

[4]That is, after the urban development reaches certain range, the *moving* option becomes a much less expensive choice. Given that we have a linear transportation cost, the accelerated development process is likely to be driven by the price effects of increasing commuting distance to CBD.

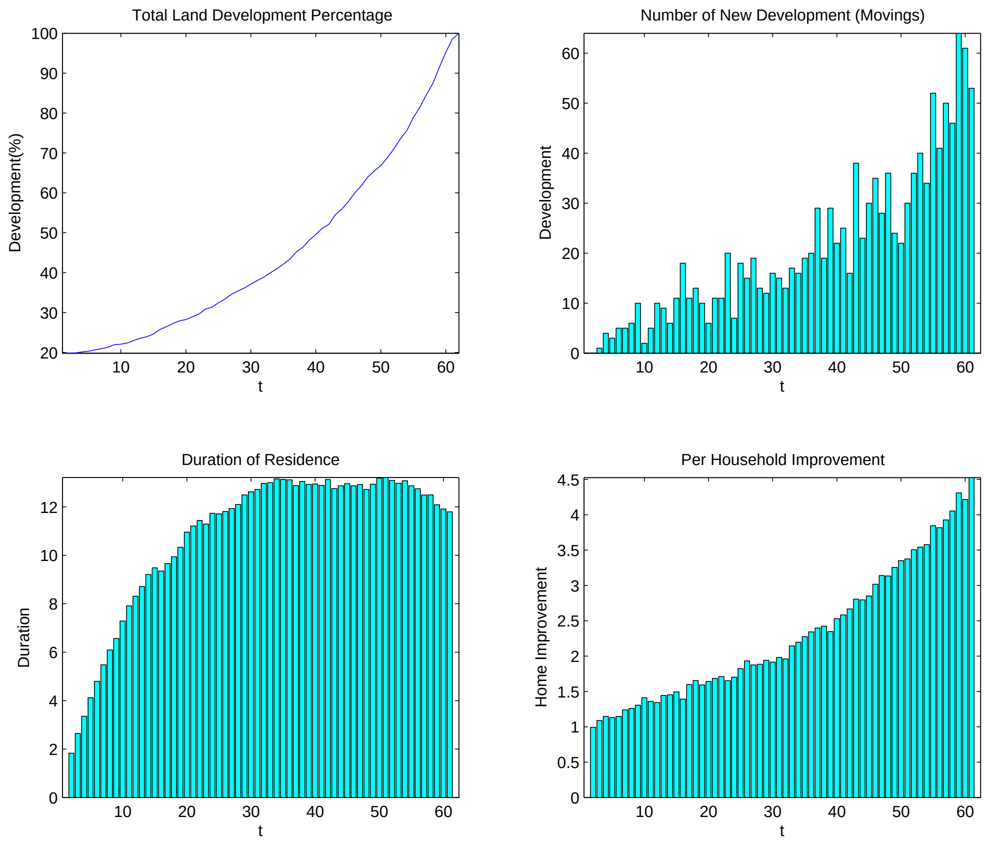


Figure 3.2: Land Development and Home Improvement (basic model, $\alpha_i = 0$ for all i)

Figure 3.3 shows the change of landscape in the basic model simulation. The entire city is fully (100%) developed at time period 62. Four sub-figures show the landscape at time period 10, 30, 50, and 62, respectively. The green (light) dots represent developed parcels, and the small red (dark) dots represent all households who performed home improvement within the last two time periods. The home improvement activities indicate no clear spatial pattern. The observed spatial pattern of home improvement activities is mainly driven by income shocks, but also by the trade-off between *improving* and *moving* options. Since income shocks are generated randomly across the space, it is difficult to identify a clear spatial pattern out of the landscape.

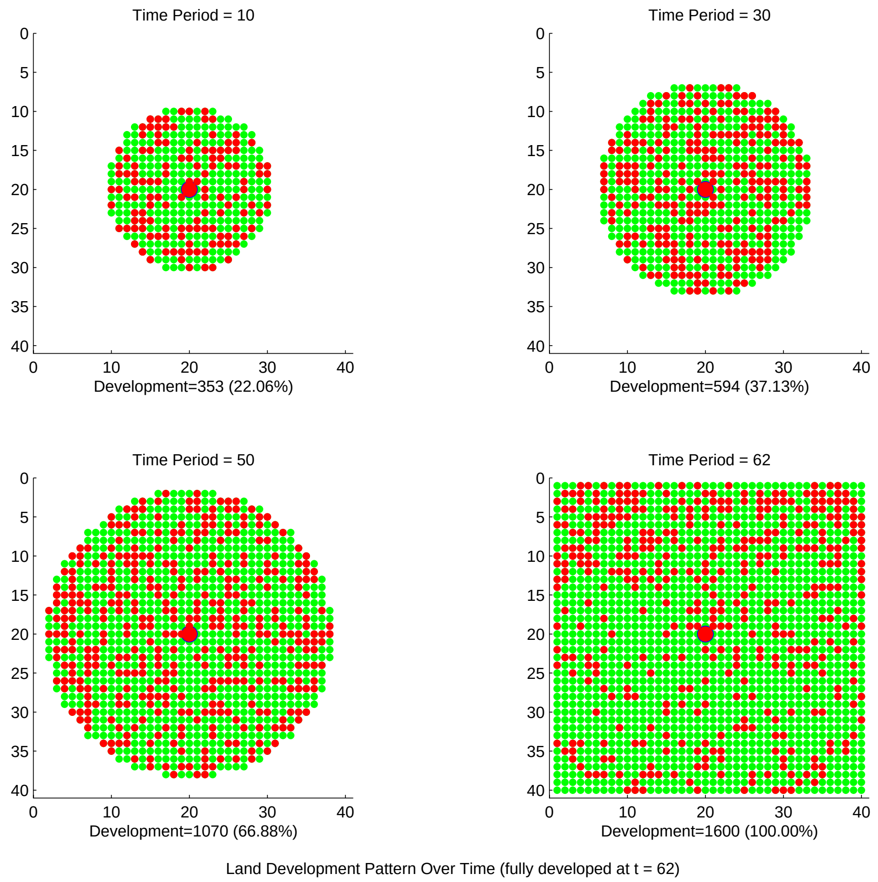


Figure 3.3: Land Development Pattern Over Time (basic model, $\alpha_i = 0$ for all i)

Results for simulation with the interaction model are drawn in Figure 3.4 and Figure 3.5. Both figures can be interpreted in the similar way as Figure 3.2 and Figure 3.3, the main difference is the introduction of neighborhood spillover effects ($\alpha_i = 2$). There are two major results new. Neighborhood spillover, as a form of urban interactions, slows down the pace of urban land development. At time period 100 (simulation ends) only 89.94% of the land is developed, while with the basic model all land is developed by time period 62. Another result which follows naturally is that on average the home improvement amount is much higher, even though income levels are still kept in the same range. So is the average household duration of residence, which implies that the spillover effects promote neighborhood stability.

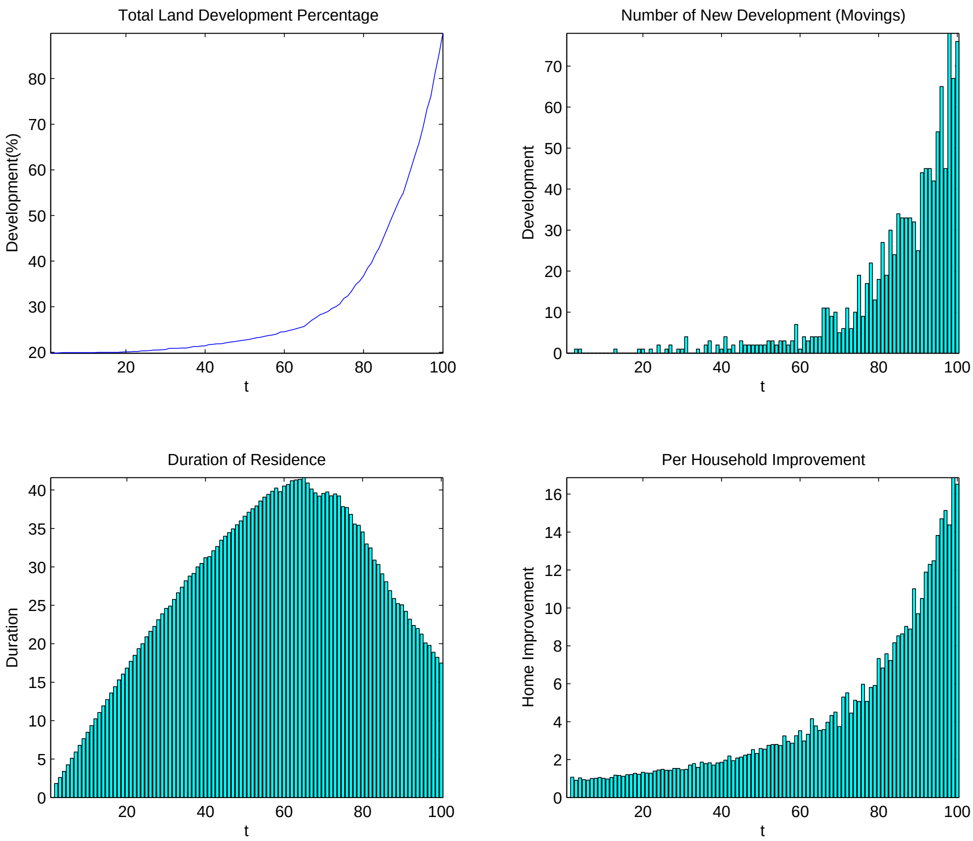


Figure 3.4: Land Development and Home Improvement (interaction model, $\alpha_i = 2$ for all i)

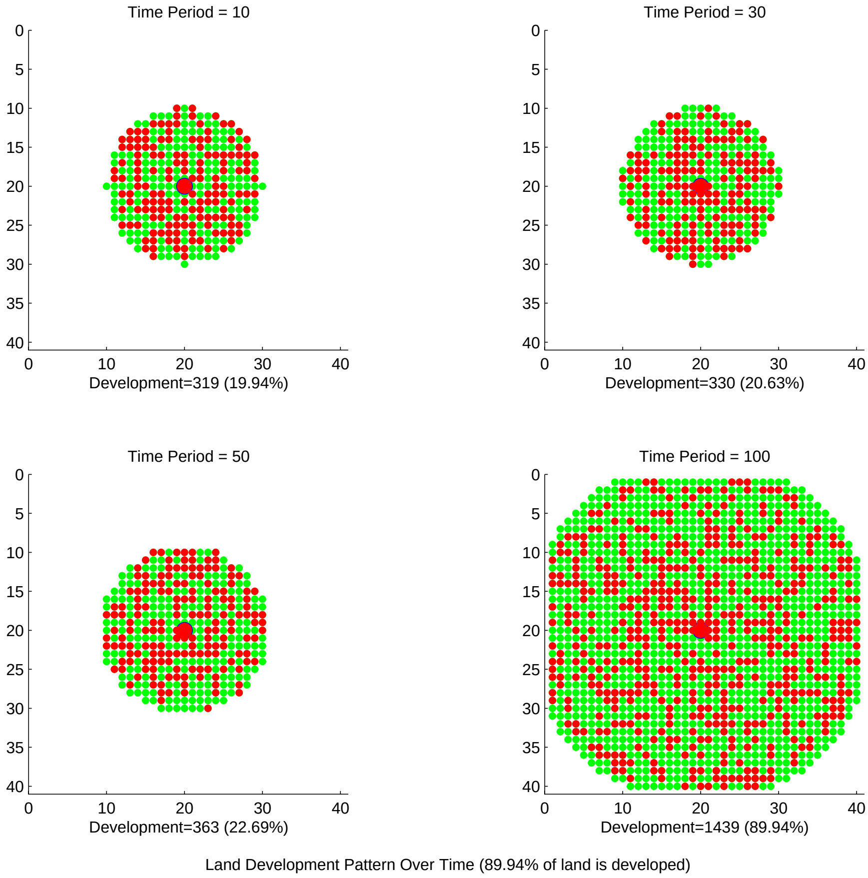


Figure 3.5: Land Development Pattern Over Time (interaction model, $\alpha_i = 2$ for all i)

The two simulation exercises have provided preliminary answers to our research question regarding the role of neighborhood spillover. The existence of neighborhood spillover effects associated with home improvement leads to a slower urban land development process, which has important implications for urban policies. A slow pace of land development is essential for the conservation of urban open space and natural amenities. Higher amenity level then improves community values and quality of life in the city. On the other hand, low level of household mobility, as a consequence of slow land development, creates incentives for investment in homeownership and local social capital. The existence of neighborhood spillover effects substantially extends household duration of residence (Figure 3.4) and helps to strengthen homeownership. Glaeser and Sacerdote (2000) argue that through homeownership households as homeowners build a significant asset, and the value of which depends on the quality of community. The neighborhood spillover effects identifies an interactive linkage between homeownership value and community quality.

4.3 Sensitivity Analysis

To explore more intuitions out of the simulation exercises, we perform sensitivity analysis on three key parameters: α_i, t, and NR. For each set of parameter values (e.g., $\alpha_i = 1$, $t = 0.01$, $NR = 6$ in Table 3.2) the simulation is ran 50 times, the one with or close to median value (of 'development', or 'time to fully develop') is chosen. The purpose of repeated simulations is to average out the influence of random income shocks. If all of the land in the city is developed, the time period at which development reaches 100% is reported. If not fully developed by time period 100, the percentage of development at time period 100 is reported. The mean values (across all time periods) of three other measures are also reported: per household improvement, number of new development, duration of residence. Per household improvement measures the average home improvement amount in the city. Number of new development measures the average pace of land development in the city. Duration of residence is used as a measure of homeownership length and community stability.

α_i is a measure of the strength of social tie, though elusive to quantify, that a household attaches to its neighborhood behavior in the framework of this paper. Table 3.2 shows how the change of α_i affects land development process and housing markets. As α_i increases from 0 to 5, the process of land development quickly slows down first, and the effect diminishes when α_i gets close to 5. Number of new development shows similar pattern. Per household improvement goes up quickly until reaching a peak around $\alpha_i = 2$, and declines steadily after that. This inverse U-shape pattern can be explained by two effects. Between $\alpha_i = 0$ and 2, the suppression effect of neighborhood spillover on new land development pushes up the home improvement level. Given income level as the city shrinks (smaller development percentage by $t = 100$, and relatively smaller D), according to (4), housing price p goes up. The effects of increasing housing price become dominant when α_i is larger than 2, which leads to a decline in average home improvement level. Duration of residence shows an opposite pattern to the pace of development, goes up quickly but with a diminishing effect when α_i gets larger.

Table 3.3 reports the effects of neighborhood size on land development and housing markets. Overall, the change of neighborhood size does not have strong effects on any of the four measures. One reason is that the neighborhood home improvement level $\triangle S_{-i}$ is computed as a simple average of all other households. Given that home improvement activities distribute relatively evenly across the space, as shown in Figure 3.3 and 3.5, the average value of home improvement level is unlikely to vary significantly with neighborhood size. However, other factors such as distance to CBD do play a role here. This may explain the slight U-shape pattern shown in the land development process and number of new development, as well as the slight inverse U-shape pattern shown in average per household improvement level and duration of residence. Note that, neighborhood is defined as a round circle with radius NR in the simulation. When neighborhood radius gets too large it goes beyond the city range, and an increase in neighborhood size does not necessarily add more neighbors.

Transportation cost always plays an important role in urban planning and public policy. Table 3.4 shows the impacts of increasing transportation cost t. Given the model framework in this paper, transportation cost change has two effects: direct income effect and price effect. Increasing commuting costs in a monocentric city discourage households to live further from CBD due to the direct impact on household disposable income for housing and non-housing consumption. This income effect tends to reduce the pace of new land development. On the other hand, increasing transportation cost brings down the housing price p at any given location. This price effect makes living further from CBD more attractive, and therefore stimulates the land development process. With the given simulation setup, the price effect dominates, which explains the monotonic increasing trend observed in new development. Both average per household improvement and duration of residence go in the opposite direction and experience significant declines as transportation cost goes up. Note that the results may qualitatively change with an alternative approach of modeling transportation cost, or within a non-monocentric urban spatial structure.

α_i	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
development (%, by $t = 100$)	-	-	-	-	89.94	66.88	56.31	48.13	43.19	41.75	38.19
time to fully (100%) develop	62	76	87	97	-	-	-	-	-	-	-
number of new development	20.52	16.69	14.43	12.59	11.22	7.53	5.84	4.53	3.74	3.51	2.94
per household improvement	2.28	2.57	3.18	3.62	4.22	3.63	3.34	3.08	3.04	2.96	2.88
duration of residence	10.76	14.41	19.14	23.43	26.79	29.88	32.08	34.73	35.52	36.36	34.33

Note: $t = 0.01$, Neighborhood Radius (NR) = 6; number of new development, per household improvement, and duration of residence are all in mean values.

Table 3.2: Sensitivity Analysis on Interactions Weight α_i

NR	2	3	4	5	6	7	8	9	10
development (%, by $t = 100$)	-	90.38	89.31	90.28	89.94	94.13	93.38	-	-
time to fully (100%) develop	98	-	-	-	-	-	-	99	100
number of new development	12.74	11.29	11.12	11.27	11.22	11.89	11.77	12.60	12.41
per household improvement	3.36	3.90	3.86	3.78	4.22	3.86	3.79	3.86	3.71
duration of residence	22.90	26.02	26.32	26.62	26.79	25.43	25.66	24.44	24.47

Note: $t = 0.01$, $\alpha_i = 2$; number of new development, per household improvement, and duration of residence are all in mean values.

Table 3.3: Sensitivity Analysis on Neighborhood Radius NR

5. Public Policy

A thorough knowledge of housing markets is crucial to public policies. Home improvement, as an important source of housing supply, attracts considerable attentions in public policy-making. For example, the HOME program of the U.S. HUD, which provides funds that may be used to assist existing homeowners with the repair, rehabilitation or reconstruction of owner-occupied units[5]. In general, housing markets closely relate to three different types of public policies, housing policy, land use policy, and transportation policy. Basing on the modeling exercises and simulation results in this paper, we can learn some implications for these policies and intuitions behind.

5.1 Housing Policy

Housing policy is a core part of public policies. Housing policy works through two different channels, the demand side and the supply side. On the sup-

[5] U.S. Department of Housing and Urban Development (HUD), March 2008, Building HOME, Page 4-1.

t	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
development (%, by $t = 100$)	89.94	97.38	-	-	-	-	-	-	-	-
time to fully (100%) develop	-	-	97	92	86	80	75	69	63	59
number of new development	11.22	12.41	13.17	13.99	14.52	16.13	16.81	18.31	20.05	21.91
per household improvement	4.22	3.93	3.68	3.31	3.17	2.85	2.86	2.69	2.59	2.63
duration of residence	26.79	24.98	23.03	20.71	18.81	16.58	15.44	13.79	12.06	11.14

Note: $\alpha_i = 2$, Neighborhood Radius (NR) = 6; number of new development, per household improvement, and duration of residence are all in mean values.

Table 3.4: Sensitivity Analysis on Transportation Cost t

ply side, one basic question is that how should government intervene with the housing supply that includes a variety of housing types (owner - occupied single family house, multi-family house, condominium, rental townhouse and apartments, and etc.). In this paper, the housing supply is simply divided into two categories, either through new development or through improving the existing housing stock. If the governments want to subsidize the housing supply so that it becomes more affordable to households with certain demographics, then a practical question is that how much subsidy should be allocated to new development, and how much to home improvement on existing housing stocks. Given the existence of potential spillover effects in land use and housing markets, quantifying the magnitude and characteristics of these externalities (e.g., how they decline with distance) is also essential in understanding the effects of urban housing policy.

Within the framework of this paper, one potential housing policy is to subsidize (in the forms of grants, loan programs, tax credits, discount programs, local incentives, and etc.) home improvement. The policy discounts current mortgage interest rate r, which makes *improving* option preferable to *moving* option. As time goes, the policy slows down the land development process, in a way similar as zoning, development boundary, and other land use regulations. Other than making home improvement projects more affordable, a potential role for housing policy is to correct or supplement land use policies. The challenge is the coordination issue between two types of policies. Housing policy is usually initialized at federal and state levels , while land use policy often stays within local jurisdictions. For example, Orfield (2005) recommends that land use and housing policies should be aligned to reduce residential racial segregation and concentrated poverty, and state legislatures must coordinate policy-making.

5.2 Land Use Policy

Land use policy implications are two-fold. As discussed before, moving out through new development is an important outside option for households to adjust housing consumption, but new development requires vacant land. The supply of vacant land is usually subject to geographic and regulatory constraints. By restricting the amount of vacant land available for new development or imposing additional costs on new development process, governments and urban land development authorities can mediate the pace of land development. On the other hand, the development control regulations provide incentives for households to invest more on home improvement. Figure 3.6 illustrates the impacts of a development limit (the number of new development each time period≤ 15) policy with the interaction model (Figure 3.6(a)) and the basic model (Figure 3.6(b)), respectively. Given that the city only has residential land use, the development limit acts like a zoning policy under which regulatory permission to develop is restrictive and scarce.

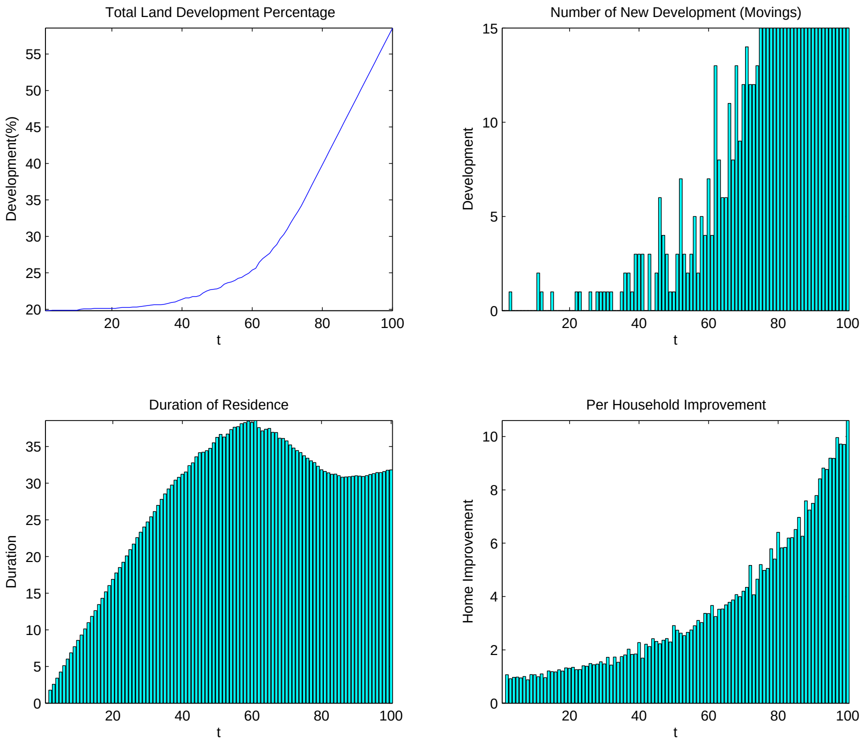
As shown in Figure 3.6, when there is a strong neighborhood spillover the development limit does not have significant effects on land development and housing markets until certain stage. In the basic model, with no neighborhood spillover, the development limit has significant effects. The land development process follows almost a linear path over time due to the restrictive limit. Comparing Figure 3.2 and Figure 3.6(b), the development limit also increases duration of residence and per household improvement as predicted.

A different way to look at the impacts of the development limit policy is through land development pressure. In this paper, land development pressure is simply defined as:

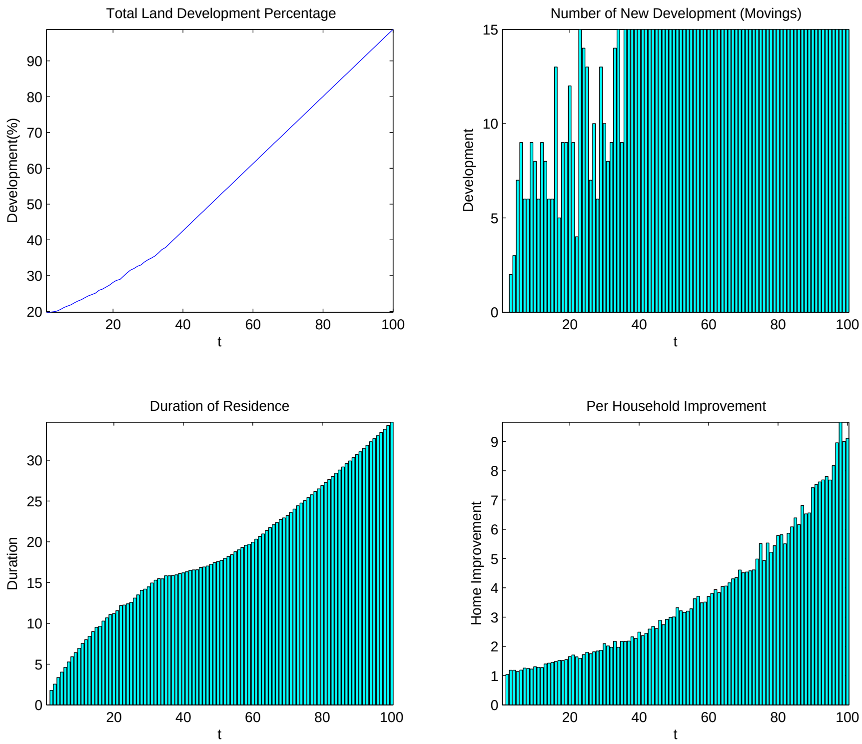
$$pressure_t = \frac{\text{number of new development } (t)}{\text{number of vacant land parcels available } (t-1)} \tag{13}$$

which is computed as the ratio between the number of new development at time period t and the number of vacant land parcels available at the end of time period $t-1$. Figure 3.7 illustrates the impacts of the development limit policy through development pressure curves. Figure 3.7(a), where no development limit is applied, is corresponding to the simulations shown in Figure 3.2 and Figure 3.4. Figure 3.7(b), where the development limit is applied, is corresponding to the simulations shown in Figure 3.6. The development pressure is significantly reduced as soon as the limit is triggered.

Another land use policy implication relates to environmental amenities, though not explicitly considered in this paper. Usually there exists land planned and left undeveloped within an urban area in the form of open space (e.g., parks, wetland). Open space is an important source of environmental amenity in urban areas. Presumably, the vacant land in open space can also be used for new development. In practice, however, there is a trade-off between amount of open space to keep and area of residential development to allow. The balance between two has to be maintained through a set of well designed land use policies.

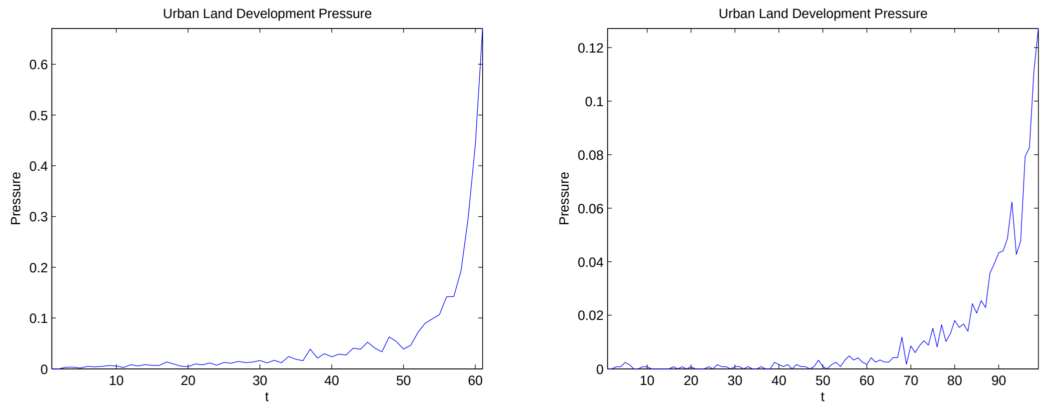


(a) Interaction Model, $\alpha_i = 2$ for all i

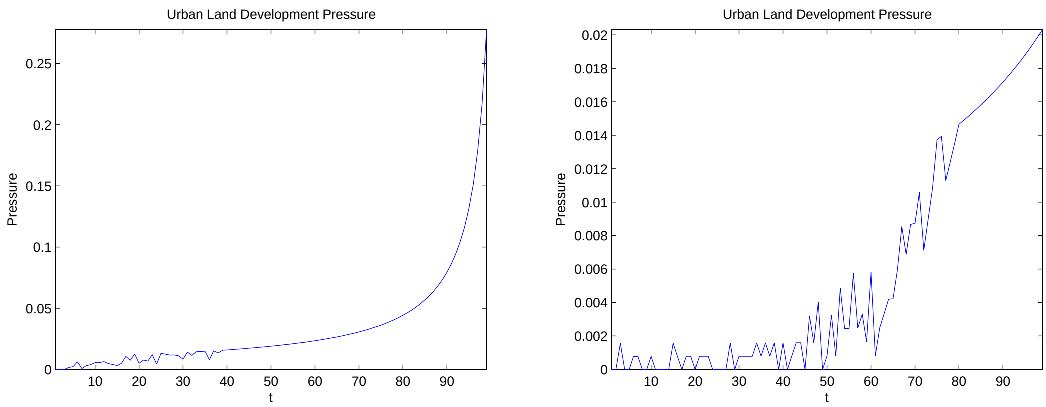


(b) Basic Model, $\alpha_i = 0$ for all i

Figure 3.6: Land Development and Home Improvement with Development Limit (≤ 15)



(a) No development limit, $\alpha_i = 0$ (left) and $\alpha_i = 2$ (right) for all i



(b) Development limit = 15, $\alpha_i = 0$ (left) and $\alpha_i = 2$ (right) for all i

Figure 3.7: Urban Land Development Pressure

5.3 Transportation Policy

Transportation cost change affects housing price and therefore costs of moving and improving. It can be shown from (4) that $\partial p/\partial t < 0$, as mentioned before which implies that any transportation policies leading higher commuting cost reduce housing price. However, the impact of transportation cost change on the relative costs of moving and improving is not straightforward from (5). The sensitivity analysis on transportation cost t in Table 3.4 provides answers to the question. One of the main conclusions is that increasing transportation cost may stimulate the urban land development process. The result implies that any policies subsidizing transportation system (therefore low commuting cost) do not necessarily lead to expansive land development (e.g., suburban sprawl in metropolitan areas), if there is a significant effect on housing prices.

One of the many ways to invest on public transportation system is the highway construction in major metropolitan areas. The improvement of transportation infrastructure reduces commuting cost, and which has an effect on speeding up the land development process. In general, housing markets value transportation system from various aspects (accessibility to local amenities, commuting cost, noise, and etc.). Klaiber and Smith (2010) find that per mile of the loop highway addition in metropolitan Phoenix can be capitalized into housing values from 73 to over 273 million dollars. High housing price can put pressure on land development, which is an effect not included in this paper. To model that part we need to integrate another type of agents - land developer - into the model, which points a promising direction for further research. Note that, in this paper we also do not take into account the value of amenities. Therefore a full evaluation of transportation policy goes beyond the monocentric framework of this paper.

Transportation cost change have very significant effects on home improvement and neighborhood stability (duration of residence). The simulations show that increasing transportation cost reduces household home improvement level and duration of residence. The results imply that transportation subsidy policies have benefit on strengthening homeownership and neighborhood stability.

6. Concluding Remarks

This paper proposes an agent-based simulation model of home improvement with neighborhood spillover to study home improvement as a constituent part of housing supply. Within a monocentric urban spatial structure, neighborhood spillover effects associated with home improvement are modeled through a complementarity framework. The existence of neighborhood spillover effects slows down the pace of urban land development, while it also significantly increases average household duration of residence and amount of home improvement. In practice, the neighborhood spillover effects can be considered as a form of social capital which connects homeownership to neighborhood quality. Basing on the simulation results and sensitivity analysis on key policy relevant parameters, the paper also explored implications for public policy-making related to housing markets, land use, and transportation. In 2004, the U.S. homeownership rate reached a record high of 69.2% in the second quarter, and steadily went down since then. By 2013, the homeownership rate decreased to the 1995 level, barely above 65%. Even though rental properties meanwhile may benefit from the drop in homeownership, there is a pressing need for policy to prevent the rate from slipping further. The dynamic simulation analysis tool developed in this paper, though simplified, can help to shed light on designing related policies.

This paper takes a cost-based perspective on housing supply and land development instead of an asset-based perspective. And land developer (if different from homeowner) does not play an active role in the modeling. Housing price depends on income level and location (measured as distance to CBD) in this paper. If housing price is otherwise determined through demand and supply on housing markets, then land developer could become an important agent in the modeling. This points to a promising direction for future research.

One other limitation of this paper is that the role of environmental amenity and public goods is ignored. In general, housing markets value all sorts of amenities (e.g., open space, recreational facilities, school quality). The level of environmental amenities can be considered as characteristics in the location package, which is reflected in the housing value as a bundle of nonuse (existence) benefits. In a broad sense, the structure of a housing unit itself is part of the surrounding environment. The structure and landscape of a housing unit can be considered as an affective and aesthetic response to the natural environment from homeowners (Ulrich, 1983). In other words, a household who values the structure of its housing unit should value the surrounding environmental amenities in a similar way, vice versa.

Public goods relate to land and housing markets more directly. The provision of public goods gives ground for municipalities to shape their residential environments and their property-tax base through policy instruments. To directly incorporate this political process into modeling, it is necessary to extend the current modeling framework and incorporate another type of agents - governments or public sector.

Reference

1. Alonso, W. 1964. Location and Land Use. Cambridge, MA: Harvard University Press.
2. Amin, K., and D. R. Capozza. 1993. "Sequential Development." Journal of Urban Economics 34: 142-158.
3. Arnott, R., R. Davidson, and D. Pines. 1983. "Housing Quality, Maintenance and Rehabilitation." Review of Economic Studies 50(3): 467-94.
4. Baker, K., and B. Kaul. 2002. "Using Multiperiod Variables in the Analysis of Home Improvement Decisions by Homeowners." Real Estate Economics 30: 551-566.
5. Boehm, T. P., and K. R. Ihlanfeldt. 1986. "The Improvement Expenditures of Urban Homeowners: An Empirical Analysis." Real Estate Economics 14: 48-60
6. Bogdon, A. S. 1992. "The Determinants of Homeowner Expenditures for Renovation, Alternation and Repair." Ph.D. Dissertation, Harvard University.
7. Bonabeau, E. 2002. "Agent-based Modeling: Methods and Techniques for Simulating Human Systems." Proceedings of the National Academy of Sciences of the United States of America 99(Suppl 3): 7280-7287.
8. Brueckner, J. K. 1987. \The Structure of Urban Equilibria: A Unified Treatment of The Muth-Mills Model." in: E. S. Mills (ed.), Handbook of Regional and Urban Economics, Edition 1, vol. 2, 821-845, Elsevier.
9. Cooper, R., and A. John. 1988. "Coordinating Coordination Failures in Keynesian Models." Quarterly Journal of Economics 103(3): 441 - 463.
10. Dipasquale, D. 1999. \Why Don't We Know More About Housing Supply?" Journal of Real Estate Finance and Economics 18(1): 9-23.
11. Eastwood, D. B., and S. G. Garnerl. 1986. "Home Repairs: A Household Production Perspective." Journal of Behavioral Economics 15 (1-2): 25-39.
12. Ellen, I. G., and I. Voicu. 2006. "Nonprofit Housing and Neighborhood Spillovers." Journal of Policy Analysis and Management 25(1): 31-52.
13. Filatova, T., D. C. Parker, and A. van der Veen. 2010. \Introducing Preference Heterogeneity into a Monocentric Urban Model: An Agent-Based Land Market Model." in Simulating Interacting Agents and Social Phenomena: The Second World Congress, Agent-Based Social Systems 7, Edited by K. Takadama, C. Cioffi-Revilla, and G. Deffuant, 101-117. Springer.
14. Fisher, J. D., and E. D. Williams. 2011. "Home Maintenance and Investment Decisions." Cityscape 13(1): 147-164.
15. Glaeser, E. L., and B. Sacerdote. 2000. "The Social Consequences of

Housing." Journal of Housing Economics 9: 1-23.

16. Glaeser, E. L., V. Henderson, and R. P. Inman. 2000. "The Future of Urban Research: Nonmarket Interactions." Brookings-Wharton Papers on Urban Affairs, 101-149.
17. Glaeser, E. L., J. Kolko, and A. Saiz. 2001. "Consumer City." Journal of Economic Geography 1: 27-50.
18. Gyourko, J., and A. Saiz. 2004. "Reinvestment in The Housing Stock: The Role of Construction Costs and The Supply Side." Journal of Urban Economics 55(2): 238-256.
19. Helms, A. C. 2003. "Understanding Gentrification: An Empirical Analysis of The Determinants of Urban Housing Renovation." Journal of Urban Economics 54(3): 474-498.
20. Helsley, R. W., and W. C. Strange. 2007. "Urban Interactions and Spatial Structure." Journal of Economic Geography 7: 119-138.
21. Herbert, J. D., and B. H. Stevens. 1960. \A Model for the Distribution of Residential Activity in Urban Areas." Journal of Regional Science 2(2): 21-36.
22. Kain, J. F., and W. C. Apgar. 1979. "Simulation of Housing Market Dynamics." Real Estate Economics 7(4): 505-538.
23. Klaiber, H. A., and V. K. Smith. 2010. "Valuing Incremental Highway Capacity in a Network." NBER Working Paper, No. 15989.
24. Littlewood, A., and Munro, M. 1997. "Moving and Improving: Strategies for Attaining Housing Equilibrium." Urban Studies 34: 1771-1787.
25. Magliocca, N., E. Safirova, V. McConnell, and M. Walls. 2011. \An Economic Agent-based Model of Coupled Housing and Land Markets (CHALMS)." Computers, Environment and Urban Systems 35 (3): 183-191.
26. Mendelsohn, R. 1977. "Empirical Evidence on Home Improvements." Journal of Urban Economics 4: 459-468.
27. Mills, E. S. 1967. \Transportation and Patterns of Urban Development: An Aggregative Model of Resource Allocation in a Metropolitan Area." The American Economic Review 57(2): 197-210.
28. Muth, R. F. 1969. Cities and Housing. Chicago: University of Chicago Press.
29. Orfield, M. 2005 . "Land Use and Housing Policies to Reduce Concentrated Poverty and Racial Segregation." Fordham Urban Law Journal 33(3): 877-936.
30. Parker, D. C., and T. Filatova. 2008. \A Conceptual Design for a Bilateral Agent-based Land Market with Heterogeneous Economic Agents." Computers, Environment and Urban Systems 32(6): 454-463.

31. Potepan, M. J. 1989. “Interest Rates, Income, and Home Improvement Decisions.” Journal of Urban Economics 25: 282-294.
32. Roback, J. 1982. \Wages, Rents, and the Quality of Life", Journal of Political Economy 90(4): 1257-1278.
33. Rohe, W. M., and L. S. Stewart. 1996. “Homeownership and Neighborhood Stability.” Housing Policy Debate 7(1): 37-81.
34. Rosen, S. 1979. \Wage-Based Indexes of Urban Quality of Life." In Current Issues in Urban Economics, edited by P. Mieszkowski and M. Straszheim. Baltimore: Johns Hopkins University Press.
35. Rossi-Hansberg, E., P. D. Sarte, and R. Owens. 2010. “Housing Externalities.” Journal of Political Economy 118(3): 485-535.
36. Seek, N. H. 1983. “Adjusting Housing Consumption: Improve or Move.” Urban Studies 20: 455-469.
37. Shear, W. B. 1983. “Urban Housing Rehabilitation and Move Decisions.” Southern Economic Journal 49(4): 1030-1052.
38. Spencer, G. M. 2012. “Creative Economies of Scale: An Agent-based Model of Creativity and Agglomeration.” Journal of Economic Geography 12(1): 247-271.
39. Ulrich, R. S. 1983. “Aesthetic and Affective Response to Natural Environment.” Human Behavior and Environment 6: 85-125.

Appendix

The simulations are programmed in MATLAB and implemented on a 64-bit Windows 7 operating system, with a 3.40 GHz Intel Core i7-2600 processor and 12.0 GB RAM. For the simulation shown in Figure 3.3 and Figure 3.4, it takes around 6 seconds to execute. The MATLAB code for the main program is attached to this Appendix.

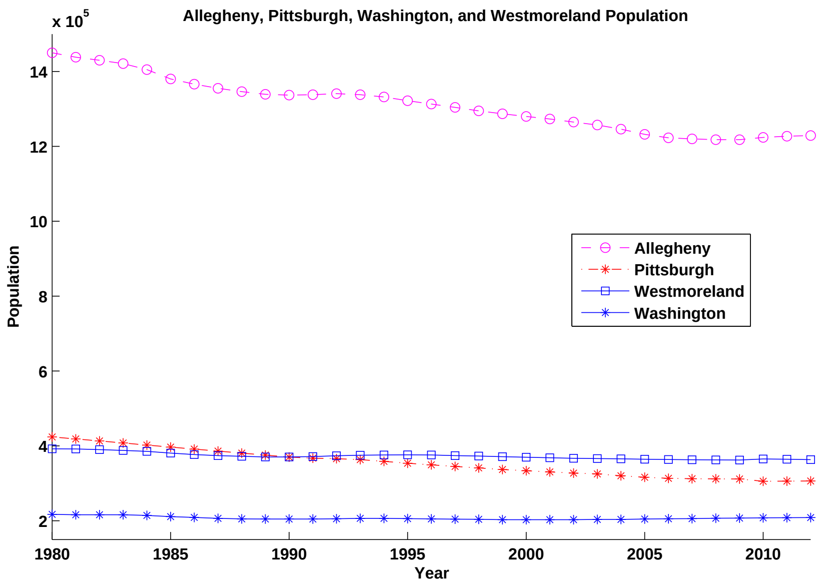
IV: Manufacturing Decline, Improved Air Quality, and Urban Land Development

1. Introduction

The socio-economic and environmental consequences of manufacturing decline in the second half of the 20th century have generated much public concern and policy initiatives in many regions across the United States. Among which, the so-called 'manufacturing belt' has undergone the largest decline, where both the manufacturing employment and population in many metropolitan areas have suffered dramatic loss[1]. According to Kahn (1999), the manufacturing employment in the manufacturing belt region declined by 32.9% from 1969 to 1996. The fraction of manufacturing employment in the region fell by almost 20% from 1950 to 2000 (Alder et al., 2012). Beeson (1990) finds that the erosion of the productivity growth advantage is the main source of the decades-long decline, together with the continued decline in the growth of labor and lower rate of capital accumulation in the region. Along with this industrial deconcentration trend, one direct consequence of the reduced manufacturing activity has been the improved environmental quality in the deindustrialized regions (Kahn, 1999). Another important economic and ecological consequence, which the literature has not paid much attention on, is the potential land use transition to manage the legacy of industrial land use.

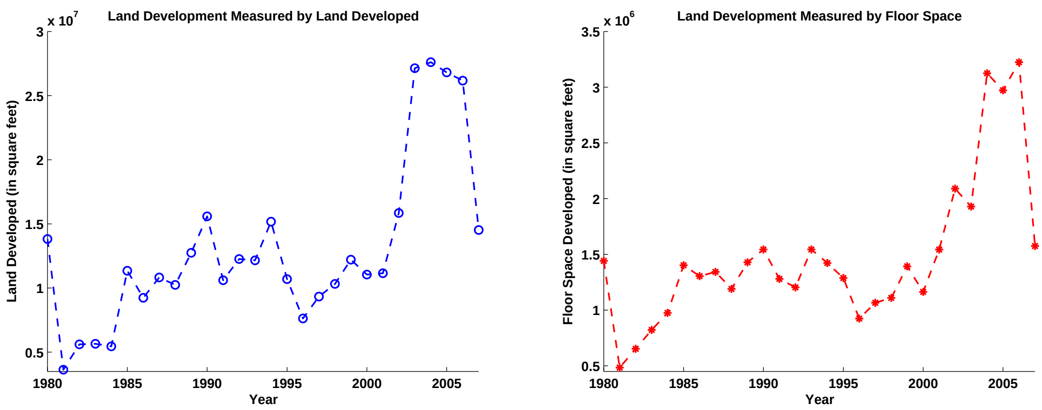
This paper studies urban land development in the context of manufacturing decline. In particular, the paper focuses on one of the major industrial cities in the manufacturing belt - Pittsburgh metropolitan area. Over the last several decades, while both the city of Pittsburgh and Allegheny county (core part of the metropolitan area) have experienced dramatic population decline ($20 \sim 30\%$ in population), new land development (mainly residential development, measured in terms of floor space built and land developed) has been increasing and only slowed down after the recent housing bubble in 2006-2007. Figure 4.1 shows population trend in the region since 1980. Figure 4.2 shows residential development trend in Allegheny county measured by land developed (left) and floor space (right) built during the same time period. The striking difference between population decline and increasing land development leads to an interesting question, what has been driving the development?

[1] In the literature, the region is often referred as the rust belt, or the steel belt as well. The core region of manufacturing belt includes Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, and West Virginia. In some studies, Wisconsin and New Jersey are also included as parts of the region. According to Hartley (2013), between 1970 and 2006, population in four major rust belt cities (Cleveland, Detroit, Buffalo, and Pittsburgh) has declined more than 40%.



Data Source: U.S. Census Bureau.

Figure 4.1: Population in Pittsburgh metropolitan area



Data Source: calculated basing on DataQuick's nationwide assessor/recorder database for Allegheny county.

Figure 4.2: Residential land development in Allegheny county

The regional economy of Pittsburgh area has been a very special case in the manufacturing belt. Since 1970s, the industrial transition in Pittsburgh has reshaped the regional economy from heavy manufacturing industries to an economic structure of light manufacturing and service industries. Following the industrial transition, the city of Pittsburgh began the urban renewal project Renaissance II in the late 1970s and lasted until 1990s. The project modernized city environment infrastructure, and established constructive public-private partnerships. All of these urban renewal and economic transition efforts led to a boom in commercial building activity. According to Oates and Schwab (1997), the average value of building permits in Pittsburgh increased by 70.43% from 1960-79 period to 1980-90 period. The only other city in the manufacturing belt which experienced an increase in the value of building permits is Columbus, OH, by 15.43% during the same period. Even though the commercial construction activity did not extend to the rest of the metropolitan area, as Oates and Schwab (1997) point out, persistent urban renewal effort and steady suburbanization have widely spread out in the entire metropolitan area.

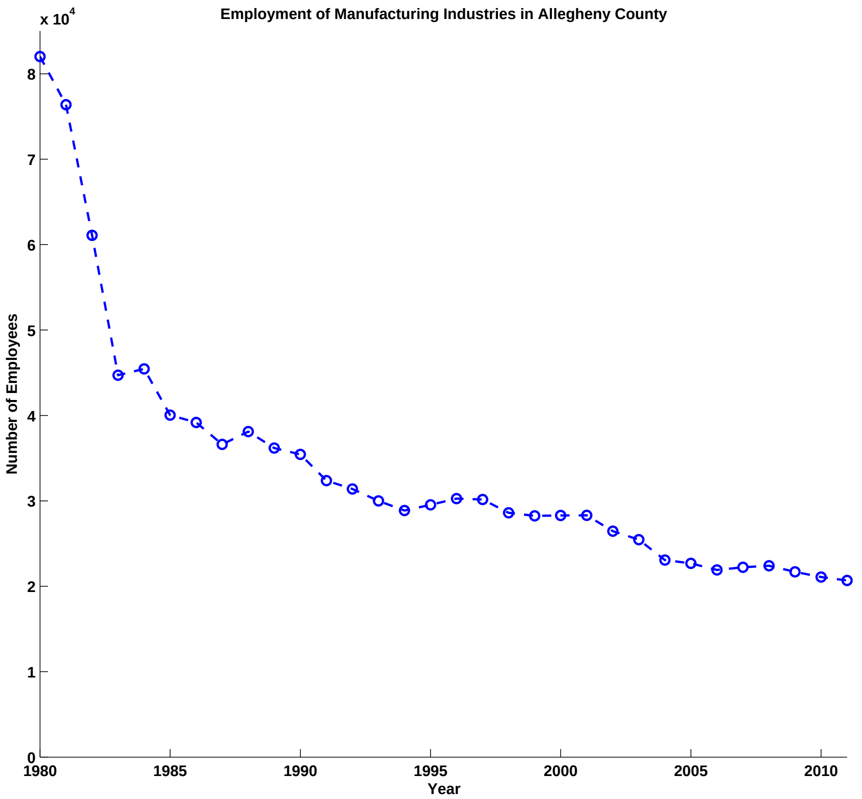
The main goal of this paper is to explore the linkage among the observed manufacturing decline, urban land development, and environmental quality. As a result of increasing foreign competition and rising domestic cost pressures, the Pittsburgh area has undergone a far-reaching deconcentration of manufacturing activity, especially in the steel industry. Environmental regulation is another potential reason for relocation and closing of manufacturing plants in the area (Deily and Gary, 1991). Henderson (1996) finds a reduction in the presence of polluting industries in counties of non-attainment status (failing to meet federal air quality standards under the Clean Air Act). The National Association of Manufacturers has also identified the escalating compliance costs for regulatory pollution abatement being one of the critical obstacles in manufacturing industries (Leonard, 2003). Figure 4.3 shows the number of employees of major polluting manufacturing industries in Allegheny county [2]. The change in number of employees clearly reflects the decline trend of manufacturing industries. Since the manufacturing industries in Pittsburgh area consist mainly of pollution creating plants, as these plants close or move out of the area one legacy left behind is abandoned industrial land (e.g., so-called brownfields[3]). Even though the unused industrial land may have environmental contamination, the location advantages and proximity to existing infrastructure make their cleanup and redevelopment potentially attractive. On the other hand, the decline of industrial land use also reduces negative spillover effects (e.g., noise, air pollution, truck

[2]Before 1998, the 4-digit SIC (Standard Industrial Classification) code is used. The number of employees shown in Figure 4.3 covers: SIC 2800 (Chemicals and Allied Products), SIC 2900 (Petroleum Refining and Related Industries), SIC 3000 (Rubber and Miscellaneous Plastics Products), SIC 3100 (Leather and Artificial Leather Products), SIC 3200 (Stone, Clay, Glass, and Concrete Products), SIC 3300 (Primary Metal Industries), SIC 3400 (Fabricated Metal Products, except Machinery and Transportation Equipment), SIC 3500 (Industrial and Commercial Machinery and Computer Equipment).

From 1998 and on, the 3-digit NAICS (North American Industry Classification System) code is used. The number of employees shown in Figure 4.3 covers: NAICS 324 (Petroleum and Coal Products Manufacturing), NAICS 325 (Chemical Manufacturing), NAICS 326 (Plastics and Rubber Products Manufacturing), NAICS 327 (Nonmetallic Mineral Product Manufacturing), NAICS 331 (Primary Metal Manufacturing), NAICS 332 (Fabricated Metal Product Manufacturing), NAICS 333 (Machinery Manufacturing). For more information about NAICS and SIC Codes, please visit http://www.naics.com/search/.

[3]According to the U.S. EPA, brownfields are defined as real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

traffic) on surrounding land uses. Thus, unattractive areas around old industrial sites may become attractive and profitable for new land development and redevelopment.



Data Source: calculated basing on County Business Patterns Database from U.S. Census Bureau.

Figure 4.3: Number of Employees of polluting manufacturing industries in Allegheny county

In this paper, I use panel data to test the hypothesis that there is a strong linkage between reduced manufacturing activities and increasing land development. I control for factors traditionally expected to affect housing supply and land development, such as locational attributes, market conditions, and policy changes. To bring richer evidence on the relationship between manufacturing activities and land use change, I expand the analysis from Pittsburgh central business district (CBD) area to the broader metropolitan area. My empirical strategy is to use the spatial-temporal variations of industrial related air pollutions as a proxy for the change of manufacturing activities in the region. The results suggest that reduced manufacturing activities are strongly associated with new land development. This result is robust to alternative empirical specifications. Further, the supply-side effect of air quality improvement on the housing market could lead to bias in estimating homeowner's marginal willingness to pay (WTP) for better air quality in a hedonic price analysis.

The paper is organized as following. Section 2 discusses some background on regional economic development and land use policies in the study region. Section 3 develops an empirical framework for modeling land development. Section 4 establishes the empirical strategy. Section 5 reports data collection and processing. Section 6 and 7 present results, discussions, and extended analysis. Section 8 concludes the paper.

2. Background

The Pittsburgh metropolitan area sits in the heartland of the manufacturing belt, with inherited resources and locational advantages. Over the second half of the 20th century, three major changes reshaped the regional economic development and land use patterns: industrial transition from mainly heavy manufacturing to light manufacturing and services industries, more stringent environmental regulations, and public support for development.

In 1957, Pittsburgh and another major industrial city in the region - Cleveland had comparable total employment in major manufacturing industries. Pittsburgh had a total manufacturing employment of 358,239, and Cleveland had a total manufacturing employment of 311,471[4]. However, the primary metals industry in Pittsburgh contributed almost half (154,215) of the total manufacturing employment, more than three times as many as the primary metals industry (46,894) in Cleveland. Pittsburgh was the lead in glass and primary/fabricated metals industries. By 1980, as shown in Figure 4.3, the total number of employees in pollution-generating manufacturing industries dropped to about 80,000. The collapse of the steel industry in the early 1980s led to a profound restructuring of the region's economy through the next two decades. According to Detrick (1999), between 1980 and 1986, manufacturing employment in the greater metropolitan area decreased by 42.6% (a loss of 115,500 jobs), and nearly half of the drop was accounted for by the steel industry[5]. By 2010, the pollution-generating manufacturing industries became only a negligible part of the regional economy, with around 20,000 jobs left in Allegheny

[4]Source: Bureau of the Census, Annual Survey of Manufactures.

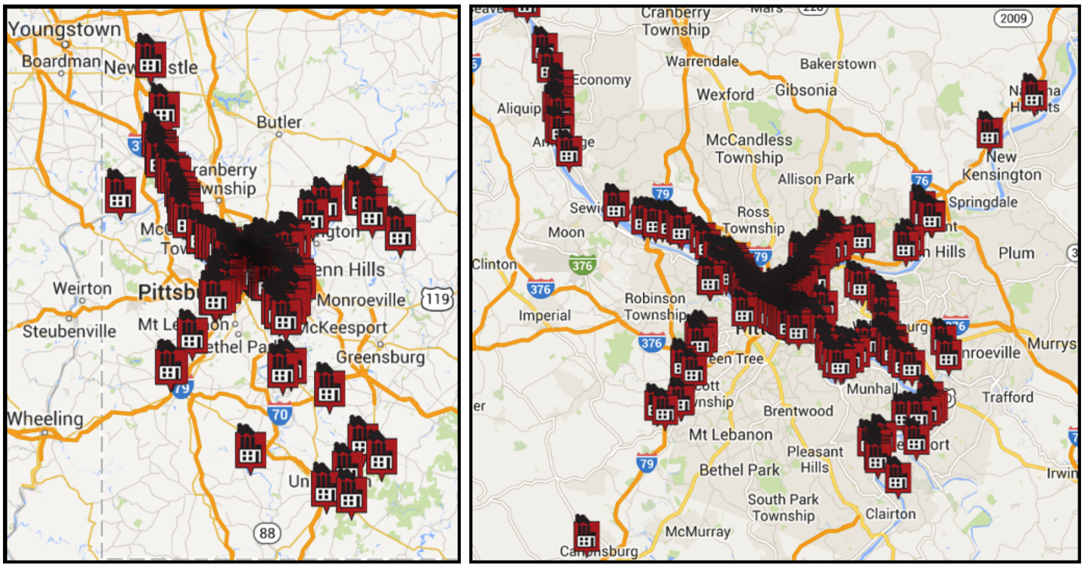
[5]The greater Pittsburgh metropolitan area covers the region with six counties: Allegheny, Beaver, Butler, Fayette, Washington, and Westmoreland.

county (most of which are in Fabricated Metal Product Manufacturing, NAICS Code = 332). The decline of manufacturing industries has substantially reshaped the landscape of the region, with reduced manufacturing employment, reduced population, but with improved environmental quality.

Unlike most of other metropolitan areas in the manufacturing belt and in contrast to the decline trend, the economy in Pittsburgh area has experienced large growth since 1950s, due mostly to the successful economic restructuring and consistent effort in environment cleaning-up. Treado and Giarratani (2008) find that, for example, Pittsburgh's intermediate steel-industry suppliers remain important to national and international steelmakers, and their cluster also remains a significant economic component of the region. Along with the collapse of the steel industry, the region had already shifted from its traditional heavy industrial structure. From 1980 to 1986, employment in services expanded by 28%, and by 12% in finance, insurance, and real estate industries (Detrick, 1999). One characteristic of the services industries is that it is more likely to cluster within the CBD. The shortage of office space in Pittsburgh CBD in 1980s and 1990s to a large extent can be explained by the formation of new services industry clusters in the city.

In the Pittsburgh region, many manufacturing plants were located in traditionally suburban area (for steel related industries, mostly along the Ohio River, Allegheny River, and Monongahela River Valley, see Figure 4.4). Plant closings have left large amount of unused industrial land. Around those unused industrial sites, land which was used to be affected by the negative spillovers of industrial processes now becomes more attractive for development. Another legacy of manufacturing industry decline is the well-developed infrastructure system, especially the transportation system, which becomes very valuable for re-development of industrial land. Public intervention (e.g., financing programs for development, subsidies, and new planning) has also helped to reduce the cost of re-developing unused industrial land. Abandoned industrial land parcels are often featured with derelict structures and fragmentation of property rights, and the transaction costs of reorganization are much lower for a public authority (Giarratani and Houston, 1989). In the process of Pittsburgh region's transition, public policy initiatives have relied heavily on the framework of public-private partnerships to stimulate the economic growth. The public-private partnerships have shown great organizational capacity and efficiency at neighborhood and community levels, which has significant impact on land re-development

(Jezierski, 1990)[6]. However, the role of the public-private partnerships has often been criticized in the literature. Detrick (1999) points out that there are inherent contradictions in the consensual basis of the partnership model. Local and community participation was limited to neighborhood real estate and economic development that is largely complementary to organized business interests (Jezierski, 1990; Ferman, 1996). Giarratani and Houston (1989) argue that, the partnership-based policy framework can be effective in addressing regional problems of both private interests and public interests. The framework, however, favors policies that attempt to stimulate economic growth and may lead to unintended and costly changes in the spatial distribution of activities within the region.



Note: After 1980, almost all plants in the CBD area were either closed or relocated.
Source: Rivers of Steel National Heritage Area, accessed at: http://www.riversofsteel.com/ on 4/4/2014.

Figure 4.4: Location of steel related plants in Pittsburgh metropolitan area (left) and Allegheny county (right) since 1850

Among many of the public policies which have affected the land development of Pittsburgh region, two of them are often highlighted: urban renewal program and two-rate property tax system. From 1940s to 1990s, there were three major urban renewal projects mainly led by the Allegheny Conference on Community Development and city & county governments. ***Renaissance I*** (1945-1970) focuses on environment improvements, air quality and flood control, renewal and rebuilding in the CBD area. ***Renaissance II*** (1977-1987) focuses more on urban re-development, especially commercial development. Major projects include

[6]For example, the Allegheny Housing Rehabilitation Corporation (AHRCO) founded in 1968 has focused on housing rehabilitation and development, the partnership consists of executive committee members from neighborhoods, public officials, and businesses.

high-rise office complexes in CBD area, convention center, cultural institutions, historic preservation, city transportation improvements, and community development. ***Strategy 21*** (1985-) designed by local and state officials was proposed to present a unified plan to secure Commonwealth of Pennsylvania economic development funds, which focuses on infrastructure development, advanced technology research, riverfront development, and cultural institutions (City of Pittsburgh and Allegheny County, 1985). Even though most of these projects were implemented within or near the CBD area, the spillover effects of these projects have extended to the broader metropolitan area through the regional economy. At the state level, in 1995, the Commonwealth of Pennsylvania enacted the Lands Recycling Program - a three Acts effort aimed at cleaning up abandoned industrial sites (i.e., brownfields) statewide. For example, the Act 3 aids with the financing of brownfields redevelopment projects. The brownfields redevelopment in Pittsburgh region has been very successful, which leads to not only long term environmental benefits but also economic benefits such as job creation and increased tax base.

The city of Pittsburgh has been a classic example of implementing a two-rate property tax system - the property tax on structures has been eliminated or reduced, with tax burden shifted toward land. The city began the two-rate/graded property tax in 1913, under which land was taxed at twice the rate of structures until 1979. From 1979, the city restructured the two-rate tax system and land in the city was taxed at a rate more than five times of the rate on structures. After accounting for the county and the overlying school district property taxes, the actual rate differential after 1979-1980 tax reform resulted in land in the city still being taxed at a rate more than twice of the rate on structures (Kwak and Mark, 2011). The city rescinded the system in 2001, as a result of downward inflexibility in tax rates and a subsequent increase in tax burden (Dye and England 2009). The land value tax has been proposed as a fiscally neutral tool to curb urban sprawl (Brueckner, 1986; Roakes, 1996; Anderson, 1999). Taxing land can potentially increase the capital/land ratio and therefore the residential densities (Bourassa, 1987; Banzhaf and Lavery, 2010; Cho et al., 2013). Banzhaf and Lavery (2010) find that the two-rate tax raises the capital/land ratio by 3-6% per decade in terms of total number of rooms in Pennsylvania, which suggests that the two-rate tax is a potentially useful tool in reducing urban sprawl. In the case of Pittsburgh, however, land value taxation plays more a role of revenue alternatives instead of a development instrument (Oates and Schwab, 1997).

3. An Empirical Framework for Modeling Land Development

The land use planning in urban development often involves alternative objectives, and trade-off among different objectives. The land use planning of a city defines its character, its potential for development, the role it can play within a regional economy and how it interacts with the natural environment (Seattle Planning Department, 1993). In this paper, the theoretical model features a representative urban planner who makes all land use planning decisions in the context of a regional economy involving three different types of land uses: industrial, conservation (e.g., open space, greenfield), and residential and related use.

3.1. Land Planning Problem

Let the land planner's decision be a profit maximization problem with an objective of three separable parts, each of which represents profit from one of three different land uses. Let π be total profit, with π_I, π_R, and π_E be profits from industrial, residential, and conservation land use, respectively.

$$\pi = \pi_I(L_I) + \pi_R(L_R, L_E, L_I) + \pi_E(L_E) \tag{1}$$

where L_I, L_R, and L_E represent the amount of land allocated to heavy manufacturing industries, residential, and conservation use, respectively. Land use in non-declining industries is assumed to be fixed and thus ignored from profit function for simplicity. Any unused land generates zero profit. In the context of industrial decline, where industrial land use is not as profitable as other land uses, I make following assumption upon industrial land use:

Assumption 1: *$\pi_I(L_I) \leq \pi^0$, $\partial \pi_I / \partial L_I < 0$, $\partial \pi_R / \partial L_I < 0$ for all $L_I \geq 0$; where π^0 is a constant.*

π^0 represents the highest profit level that the declining industry can reach in a given time period. Such a profit level may depend on economic climate, external market conditions, and regulatory environment. The ***Assumption 1*** has two implications: (1) There is an incentive for land planner to reduce industrial land use; (2) The best outcome of industrial land use is to reduce L_I to a level L_I^0 such that $\pi_I(L_I^0) = \pi^0$. The optimal level of L_I may change over time. To establish conditions for which the best outcome $\pi_I(L_I) = \pi^0$ is realized, I use another assumption.

Assumption 2: *At every time period t with $L_I < L_I^0$, the myopic land planner reduces industrial land use by $\triangle L_{I,t} = L_{I,t-1} - L_{I,t}$, so that $\pi_I(L_{I,t}) > \pi_I(L_{I,t-1})$, and $\pi_I(L_{I,t}) - \pi_I(L_{I,t-1})$ is maximized*[7].

The ***assumption 2*** implies that the land planner adjusts industrial land use every time period so that the profit condition from the declining industries gets improved, even though it may not lead to a positive profit. Given that the manufacturing industries in our study region have faced increasing foreign competition and escalating domestic cost pressures, the assumption is not too far from reality. The assumption also implies that the adjustment of industrial land use is a gradual process.

In theory, the optimal level of industrial land use, L_I^0, can be determined through market equilibrium. Given that $\partial\pi_I/\partial L_I < 0$, in the long run, the optimal level of industrial land use $L_I^0 = 0$. In reality, the industrial land use adjustment can be a slow and costly process. Therefore, the land use in decline industries may not reach its optimal level in a relatively long time.

Assumption 3: $\partial\pi_R/\partial L_R \geq 0$, $\partial\pi_R/\partial L_E \geq 0$, $\partial\pi_E/\partial L_E \geq 0$ *for all* $L_R,\ L_E \geq 0$,

where $\partial\pi_R/\partial L_E \geq 0$ implies that the residential land/housing markets value land in conservation as an amenity. With the three assumptions stated above, the land planner's decision-making can be written as:

$$\begin{cases} \underset{L_{R,t},L_{E,t}}{\text{Max}} & \pi = \pi_R(L_{R,t}, L_{E,t}, L_{I,t}) + \pi_E(L_{E,t}) \\ \text{s. t.} & L_{R,t} + L_{E,t} = \triangle L_{I,t} + D_t \end{cases} \tag{2}$$

where D_t denotes the amount of land available for residential development or conservation at time period t[8]. Note that, here we also implicitly assume that

[7]Maximizing profit increase is equivalent to maximizing land use change $\triangle L_{I,t}$, because of $\partial\pi_I/\partial L_I < 0$ from ***Assumption 1***. In reality, reduction of industrial land use is likely involving some physical, institutional, and political constraints (e.g., to keep local jobs). Therefore, the land planner can only reduce the land use by certain amount in a given time period, instead of to the ideal level L_I^0.

[8]Land use in non-declining industries is assumed to be fixed, and therefore it is not accounted

there is no cost associated with land use transition from industrial to residential and conservation[9]. To solve the profit maximization problem in (2), I specify the profit function of residential land use as:

$$\pi_R(L_{R,t}, L_{E,t}, L_{I,t}) = P_H(L_{R,t}, L_{E,t}, L_{I,t})L_{R,t} - C(L_{R,t}) \tag{3}$$

where P_H is the unit value of developed residential land, and $C(L_{R,t})$ is the present value of costs (such cost includes expenses on permits, construction, ongoing maintenance, taxes, and etc.) of development which depends on the amount of residential land use. Further, a simplifying assumption is imposed on conservation land use.

Assumption 4: *The land in conservation has a constant amenity value, i. e.,* $\partial \pi_E / \partial L_{E,t} = \alpha$, *and* $\alpha > 0$.

Combining (2), (3), and ***Assumption 4***, the land planner's decision-making can be simplified into:

$$\underset{L_{R,t}}{\text{Max}}\ \pi = P_H(\triangle L_{I,t} + D_t - L_{R,t}, L_{R,t}, L_{I,t})L_{R,t} - C(L_{R,t}) + \pi_E(\triangle L_{I,t} + D_t - L_{R,t}) \tag{4}$$

with the first order necessary condition being as[10]:

$$P_H^*(\triangle L_{I,t}, D_t, L_{R,t}^*) + L_{R,t}^*(\frac{\partial P_H}{\partial L_{R,t}} - \frac{\partial P_H}{\partial L_{I,t}} - \frac{\partial P_H}{\partial L_{E,t}}) - \frac{\partial C}{\partial L_{R,t}} - \alpha = 0 \tag{5}$$

Solving (5) for $L_{R,t}^*$ gives the optimal level of residential land use:

$$L_{R,t}^* = L_{R,t}(\alpha, \triangle L_{I,t}, D_t, e_R, \frac{\partial P_H}{\partial L_{I,t}}, \frac{\partial P_H}{\partial L_{E,t}}, \frac{\partial C}{\partial L_{R,t}}) \tag{6}$$

where e_R denotes the price elasticity of residential land supply, and is as-

for in the optimization problem.

[9]This could be a strong assumption. For example, the environmental cleaning-up cost of brownfields after industrial use can be really high. In this paper, I maintain the zero transition cost assumption as necessary only due to data limitation.

[10]According to ***Assumption 2***, $\triangle L_{I,t} = L_{I,t-1} - L_{I,t}$ is determined exogenously. Hence, given $L_{I,t-1}$, $P_H^*(\triangle L_{I,t}, D_t, L_{R,t}^*) = P_H^*(\triangle L_{I,t}, D_t, L_{R,t}^*, L_{I,t}^*)$.

sumed to be constant in this study[11]. $\partial P_H / \partial L_{I,t}$ is the marginal spillover effect of industrial land use on housing value. $\partial P_H / \partial L_{E,t}$ is the marginal value of land in conservation to homeowners at equilibrium. $\partial C / \partial L_{R,t}$ is the marginal cost of land development. Basing on (6), the empirical framework for modeling land development is established in this paper.

3.2. *An Empirical Framework*

The empirical model of this study concentrates on the residential land development in Allegheny county. Land development creates essentially a series of discrete events, because in practice vacant land is converted parcel by parcel (in some cases, land conversion decision is made at subdivision level). Another feature of the empirical model is the amount of land available for development, D_t, on the right hand side. Therefore, I choose a Poisson model to estimate the amount of residential land development basing on (6).

The basic assumption of the Poisson model is that, the amount of residential land development, $L_{R,t}$, is generated by a Poisson distribution with mean $\lambda_{R,t}$, which depends on a set of socio-economic variables as suggested in (6), and other variables controlling for land characteristics. Let $X_t = [\ \triangle L_{I,t} \quad MP_t \quad MC_t\ ]$ with $MP_t = \partial P_H / \partial L_{E,t}$ and $MC_t = \partial C / \partial L_{R,t}$, and Z being a matrix of time-invariant controlling variables (e.g., distance to CBD, municipality fixed effects), then

$$\lambda_{R,t} = exp(\beta_0 + X_t \beta_1 + Z\beta_2) \tag{7}$$

Because the amount of land developed directly depends on the amount of land available for development, D_t becomes a natural candidate for the exposure of the Poisson model. (7) can be accordingly revised into:

$$\frac{\lambda_{R,t}}{D_t} = exp(\beta_0 + X_t \beta_1 + Z\beta_2) \tag{8}$$

Note that, at each time period $\triangle L_{I,t}$ is counted into D_{t+1} instead of D_t. Taking logarithmic transformation on (8), in a spatial-temporal setting, the empirical model can be written as:

[11]According to Green et al. (2005), the price elasticity of housing supply in Pittsburgh MSA is 1.43.

$$ln(L_{R,it}) = \beta_0 + X_{it}\beta_1 + Z_i\beta_2 + ln(D_{it}) + \varepsilon_{it} \tag{9}$$

where the coefficient of the 'exposure' term $ln(D_{it})$ is restricted to 1 in empirical estimation, and ε_{it} is a random error term following normal distribution. An alternative way to understand the empirical model in (9) is that, a linear model is used to model the rate of land development, $L_{R,it}/D_{it}$, which depends on X_{it} and Z_i. Because the restriction on the coefficient of the 'exposure' term, maximum likelihood estimation is used to estimate the model in (9).

3.3. Air Quality Change as A Demand Side Signal

Better air quality can be valued as an environmental amenity, which matters to the housing market (e.g., Chay and Greenstone, 2005). Cleaner air is capitalized into housing value and leads to price differential. Would this environmental amenity and price differential transform into demand for more housing? The answer to this question is unclear. On one side, better environmental quality attracts new residents. On the other side, higher housing price depresses housing demand. Therefore, the net demand side effect of air quality change depends on the relative magnitude of effects from both sides. In the literature, demand for housing is an ambiguous concept. The confusion arises between the narrowly defined housing service (from the housing structure only) and the broadly defined housing service which includes neighborhood and environmental attributes as well (Zabel 2004). This also complicates the problem. In this paper, the signal effect of air quality change on demand side is ignored due to data limitation.

4. Empirical Strategy

The key variable to the research question of this paper is $\triangle L_{I,it}$, the change of industrial land use. Due to data limitation, I do not have direct information on this variable at micro level. Thus, an empirical strategy has to be designed to approximate the industrial land use change along with manufacturing decline. This paper uses two approaches, indirect approximation and direct approximation.

4.1. Indirect Approach

An indirect measure on industrial land use change would be the reduction of manufacturing activities. Given that this paper focuses on the change of industrial land use from pollution-generating industries, air quality levels can be used as an indicator of the scale of manufacturing activities, and therefore a proxy for industrial land use change. The advantage of using air quality levels is that they can measure both the industrial land use and potential negative spillovers associated. For example, to large extent all area within say 5 miles of a steel mills is under direct or indirect impacts of the steel production. Variation in air pollutants level within the 5 miles radius tends to be highly correlated with the scale of steel production in the steel mills. Another advantage of using air quality proxy is that air quality varies spatially in consistent ways.

Let Q_{it} measures the level of some air pollutant (e.g., SO_2) at site i in time period t, then an estimable empirical model is[12]:

$$ln(L_{R,it}) = \beta_0 + \begin{bmatrix} Q_{it} & MP_{it} & MC_{it} \end{bmatrix} \beta_1 + Z_i\beta_2 + ln(D_{it}) + \varepsilon_{it} \tag{10}$$

where β_1 is an 3×1 vector of coefficients, and β_{11} is expected to be negative. The lower the air pollution level (higher the air quality), the larger the industrial land use change, and potentially more residential land development. One potential issue with using Q_{it} as an approximation is that the observed air pollution level may also affect residential land development from demand side (i.e., better air quality leads to higher housing demand). As a solution for the issue, I adjust the air pollutant level by pollution sources so that Q_{it} only reflects emissions from industrial sources. The detail of the adjustment is discussed in data section.

4.2. Direct Approach

Alternatively, an approximation for $\triangle L_{I,it}$ can be derived in a more structural way. First, following assumption about the pollution-generating industry is made:

Assumption 5: *The industry operates at a steady state with constant return*

[12]As defined in section 3.2, $MP_t = \partial P_H / \partial L_{E,t}$, $MC_t = \partial C / \partial L_{R,t}$.

to scale, thus the industry output level (Y) is directly proportional to the industry employment level (E), i.e., $Y \propto E$.

The ***Assumption 5*** implies that employment level, E, can be used as an approximation for total emission of pollutants, since actual emission is directly proportional to output level given the production technology. It then gives:

$$E \propto L_I Q \tag{11}$$

where $L_I Q$ is the total emission of pollutants, given that Q measures average pollution density[13]. Note that the approximation in (11) only works if Q measures average density of pollutants across the land space. In a spatial-temporal setting, we then have:

$$\triangle L_{I,it} \propto \frac{E_{it-\triangle t}}{Q_{it-\triangle t}} - \frac{E_{it}}{Q_{it}} \tag{12}$$

where $\triangle t$ is the time period over which $\triangle L_{I,it}$ is recorded. Denoting the right hand side of (12) as Φ_{it}, another estimable empirical model is given as:

$$ln(L_{R,it}) = \beta_0 + \begin{bmatrix} \Phi_{it} & MP_{it} & MC_{it} \end{bmatrix} \beta_1 + Z_i \beta_2 + ln(D_{it}) + \varepsilon_{it} \tag{13}$$

Now the coefficient β_{11} is expected to be positive. By estimating β_{11} we can identify the relationship between industrial land use change and residential land development up to some constant.

5. Data

Data used to estimate (10) and (13) for Allegheny county includes four parts: micro level land development history, site level air quality data, manufacturing employment and housing market data, and land characteristics. The data is then aggregated at both school district and municipality level to create panel data sets for estimation. The study period is between 1980 and 2007. Right before 1980, there were two major policy changes which may lead to structural

[13]An implicit assumption being made here is that all pollutions are localized.

change: the beginning of the urban renewal program ***Renaissance II*** in Pittsburgh in the late 1970s, and change of environmental regulations (major Clean Air Act Amendments of 1977).

The land development data is obtained from DataQuick, which consists of parcel level property characteristics and development history of all land parcels in Allegheny county. From the data, a subset of all parcels developed between 1980 and 2007 is selected as a sample for this study. The GIS shape file of all land parcels is obtained from Pennsylvania Spatial Data Access (PASDA), which is used as the spatial base for all spatial calculation. Two alternative measures for dependent variable, $L_{R,it}$, are constructed: land developed, and floor space built. All land use types (as defined by the county assessor's office) are recoded into 10 codes to simplify the analysis, as shown in Table 4.1[14]. This paper focuses on residential development (land use code 1, 2, 3) only, which covers the majority of properties within the county. The data is also used to calculate the 'exposure' term, D_{it} - the amount of land available for development, at aggregated level (school district and municipality). The variable is the area sum of all currently vacant residential, commercial, and industrial properties, and land parcels developed after time period t. The reason to include currently vacant commercial and industrial properties is that it is possible for these land to get re-developed into residential use in the future. Therefore, they should be counted as part of the 'exposure'.

Land Use Code	Code Description	Proportion (of all parcels)
1	single family residential	68.99%
2	condo residential	12.95%
3	other residential	4.69%
4	agricultural	0.09%
5	industrial	0.01%
6	commercial	0.12%
7	miscellaneous	0.62%
8	vacant residential	1.52%
9	vacant commercial & industrial	4.47%
10	vacant others	6.55%

Note: The proportion is calculated based on the number of parcels.

Table 4.1: Land use codes and data composition

[14]DataQuick has its own unified property use codes defined, which are similar to the codes used by county assessors across the country.

The site level air quality data comes from U.S. EPA AirData which provides air quality data collected at outdoor monitors across the United States. In this paper I use data for two pollutants: sulfur dioxide and particulate matter (PM10)[15]. Sulfur dioxide is measured as daily max 1 hour concentration level (unit: parts-per-billion, ppb). PM10 is measured as daily mean concentration level (unit: $\mu g/m^3$ SC). Both pollutants are highly related to energy intensive iron and steel industry and other heavy industries (Deily and Gray, 1991; Kahn, 1999). Figure 4.5 shows air quality monitoring sites of four different pollutants in Allegheny county during the study period. Another reason for using AirData is that it provides daily data by monitoring site which enables us to calculate average pollutant concentration level by season. In this study, seasonality is expected to affect results because in some seasons non-industrial sources may contribute substantially more to the total emissions (e.g., residential heating during the winter).

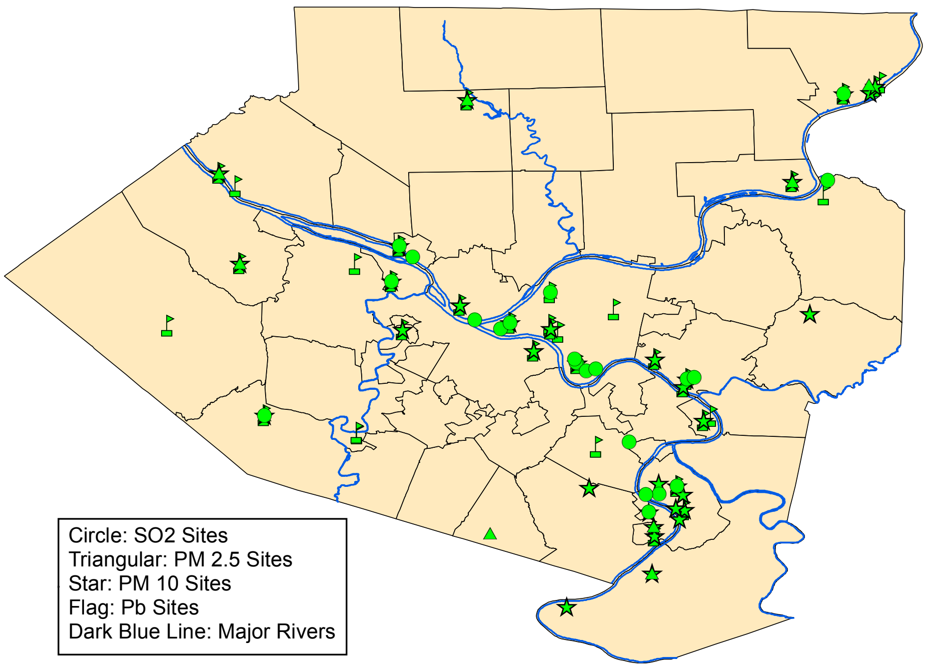
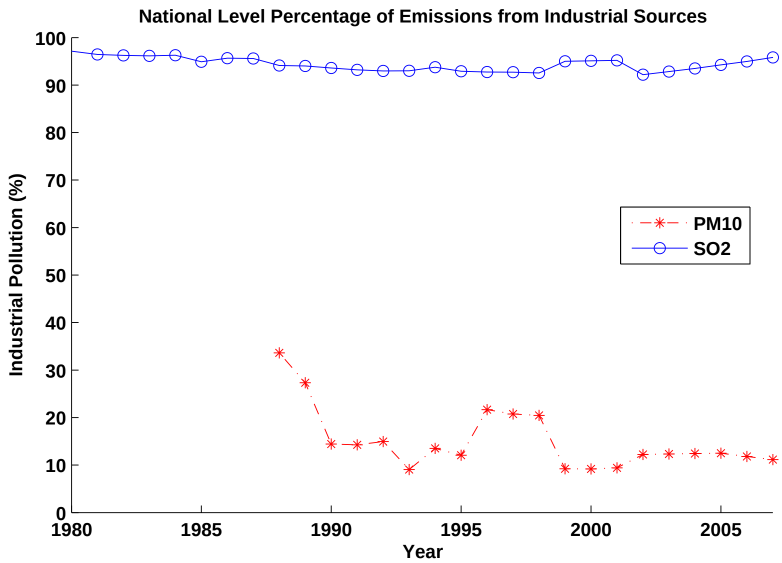


Figure 4.5: Air quality monitoring sites in Allegheny county (overlapping with school districts)

[15]Nitrogen oxides (e.g., NO_2) is another major pollutant which is regularly present in heavy manufacturing industries, especially steel plants. Nitrogen oxides is excluded from this study because the data is only available for 3 monitor sites in Allegheny county.

One adjustment made to the observations from AirData is to control for non-industrial sources. Transportation has been another major contribution to the air pollution level. In this study I do not have local level information on the composition of air pollution sources, therefore national percentages are used[16]. For each pollutant, emissions from waste, transportation (on-road and off-road), and miscellaneous sources are excluded basing on national average percentages, which leaves an air pollution level measure reflecting mainly the industrial sources. The adjustment is different for each year. Figure 4.6 shows the national average percentage of emissions from industrial sources, which is used for adjustment in this paper.



Note: Data for PM10 starts from 1988, a different statistical measure was used for particulate matters in National Air Quality and Emissions Trends Reports before 1988.

Figure 4.6: SO_2 and PM10 emissions from industrial sources

Manufacturing industrial employment data used to estimate (13) is extracted from U.S. Census County Business Pattern (CBP). For data going back to 1980, the ZIP code level industry employment data is not available[17]. Therefore, to calculate E_{it}, county level total employment for all pollution generating industries are used (for SIC and NAICS codes of industries included, see footnote 2). Ideally, E_{it} should be assigned to school district (or municipality), in this paper county level E_{it} is used for all school districts due to data limitation.

[16] Source: National Air Quality and Emissions Trends Report (U.S. EPA Office of Air Quality), for corresponding years.

[17] According to U.S. Census website (http://www.census.gov/econ/cbp/), ZIP Code Business Patterns (ZBP) data is available only for 1998 and after.

Among other factors traditionally expected to affect residential land development, expectation on future housing market is important. Following Cunningham (2006), housing price volatility, denoted as $\hat{\sigma}_{it}^2$, is used to measure expectation on future housing market, which is calculated as the moving variance of housing price indices (HPI) in Pittsburgh metropolitan statistical area (MSA). The data used is the quarterly HPI published by the Federal Housing Finance Agency (FHFA). $\hat{\sigma}_{it}^2$ is defined as:

$$\hat{\sigma}_{it}^2 = \sum_{k=0}^{T-1} \frac{(P_{i,T-k} - \bar{P}_{it})^2}{T} \tag{14}$$

and,

$$\bar{P}_{it} = \frac{1}{T} \sum_{s=0}^{T-1} P_{i,T-s} \tag{15}$$

where $P_{i,T-k}$ is the HPI for location i in quarter $T-k$ of previous year(s), and T is the number of quarters averaging over. For one-year-ahead measure of price uncertainty, $T = 4$. For two-year-ahead measure, $T = 8$.

The last part of the data include two measures on land characteristics: land slope, and distance to Pittsburgh CBD (city center at coordinates: 40.441667, -80). The distance is calculated as the average of distance from all parcels within a school district (or municipality) to the CBD. Distance to CBD here is used as a proxy for marginal value of land in conservation. For example, open space near central city usually receives a much higher valuation through housing market than open space of same quality in the suburban area. Therefore, distance to CBD provides a time-invariant measure for MP_{it}.

The land slope data for Allegheny county is obtained from Allegheny County Geographic Information Systems Group, which is published in December 2007. The slope data is coded according to slope range as following: 1 = 0 - 4.99%, 2 = 5 - 9.99%, 3 = 10 - 14.99%, 4 = 15 - 24.99%, 5 = 25 - 39.99%, 6 = 40+ %. Slope is used as a proxy for a constant marginal development cost. Residential housing construction cost consists mainly of two costs: physical cost and market related cost. Housing construction industry is a very competitive industry, and there is not enough monopoly power that would allow any price manipulations within a region (Gyourko, 2009). Therefore, the variation of construction costs within

Variable Description	Mean	Standard Deviation
Daily max 1 hour SO_2 concentration (ppb)	41.33	23.93
Daily mean PM10 concentration ($\mu g/m^3$) (1988-2007)	3.42	2.42
Pollution-generating industry employment (county level, in 1000)	35.89	14.97
Land slope (1 - 6)	2.54	0.49
4-quarter moving variance (volatility) of HPI	1.95	1.31
8-quarter moving variance (volatility) of HPI	6.70	4.65
Distance to CBD (miles)	9.59	3.45
Log(developed land measured by floor space (square feet))	9.82	1.41
Log(developed land measured by lot size (square feet))	11.72	1.66
Log(developable land measured by floor space (square feet))	14.26	0.89
Log(developable land measured by lot size (square feet))	16.41	0.93
Development density ($\frac{\text{floor space}}{\text{number of stories}\times\text{lot size}}$)	0.12	0.09

Note: School district is the unit of analysis, with time period going from 1980 to 2007 unless otherwise noted. There are 962 observations overall. Several small school districts are excluded from estimation due to no new development in certain years.

Table 4.2: Summary statistics of all variables at school district level

Allegheny county should be primarily driven by variations of physical construction cost, which leaves land slope a proper proxy for marginal development cost. The summary statistics for all variables are reported in Table 4.2.

6. Results

Main estimation results of empirical model (10) and (13) are reported in Table 4.3, 4.4, and 4.5. All models are estimated by fixed effects panel data models ($\beta_0 = 0$ in (10) and (13)). School district panel consists of 43 school districts. Municipality panel consists of 85 municipalities[18]. To eliminate potential noise in air pollutant measures from air pollution due to heating in the winter season (the first quarter and forth quarter), the average of daily measures in the second quarter is used in all models. Results using measures from other quarters are similar, with only differences in magnitude[19].

[18]There are 130 municipalities in Allegheny County according to the Allegheny County Municipal boundaries shape file (obtained from PASDA, published in 2009 by Allegheny County Division of Computer Services Geographic Information Systems Group) used in this study. Some very small municipalities are excluded due to no development.

[19]Results of models using air pollutant measures from other quarters are available upon request from the author.

6.1. *Indirect Approach*

Table 4.3 presents estimates for models with land area developed (logarithm transformed) as dependent variable. Table 4.4 presents estimates for models with floor space built (logarithm transformed) as dependent variable. The results are very similar, which suggests that both lot size and floor space are good representation for residential land development. The significant negative estimates on SO_2 level and PM10 level suggest to accept the hypothesis that increase of unused industrial land (as a result of manufacturing industry decline) is an important source of new residential development nearby. Distance to CBD tends to have a positive sign, but only significant in models with SO_2 level, implies that relatively more residential development locates in suburban area. This result agrees with Oates and Schwab (1997) on that the development boom in Pittsburgh in 1980s and 1990s was primarily a boom in commercial building activity. Since distance to CBD is also a proxy (the larger the distance, the lower the MP) to marginal value of land in conservation, the positive estimate implies that lower valuation on conservation land encourages residential development. This empirical result is consistent with what economic theory of land use would predict.

The insignificant estimates on land slope in all models suggest that physical construction cost is unlikely an important determinant of residential development, even though Allegheny county has many hilly residential areas. This is entirely consistent with Gyourko (2009) finding that structure production costs are not key factors in explaining housing supply. The positive estimates of housing price volatility, especially the relatively long term (8-quarter) volatility, suggest that land developers tend to invest on high volatility. Given that the housing market of Pittsburgh metropolitan area has been on a steady increasing trend since 1970s, which may lead developers to be more confident on the possibility that high volatility provides potential investment opportunities due to price fluctuations relative to intrinsic housing values. To control for potential public policy impacts on new residential development, two dummy variables are included in estimation. Land recycling program is set to 1 for all years after 1995, otherwise 0, to capture the fact that the Commonwealth of Pennsylvania enacted the Lands Recycling Program in 1995. The high significance of the estimates on land recycling program suggests that the residential development rate was much higher after 1995.

Variables	Model of Land Area Developed, $ln(L_{it})$			
	SO_2 (1)	SO_2 (2)	PM10 (1)	PM10 (2)
SO_2 level (max)	-0.0008*	-0.0027***		
	(0.0005)	(0.0008)		
PM10 level (mean)			-0.0107**	-0.0128***
			(0.0045)	(0.0046)
Distance to CBD	0.0345***	0.0421***	0.0166	0.0306
	(0.0137)	(0.0154)	(0.0172)	(0.0194)
Land slope	0.0240	0.0200	0.0172	0.0340
	(0.0226)	(0.0219)	(0.0281)	(0.0264)
4-quarter price volatility	-0.0098	-0.0137*	0.0152	0.0248*
	(0.0081)	(0.0080)	(0.0142)	(0.0136)
8-quarter price volatility	0.0118***	0.0143***	0.0086***	0.0093***
	(0.0024)	(0.0023)	(0.0031)	(0.0030)
Land recycling program	0.2171***	0.2714***	0.1591***	0.2283***
	(0.0245)	(0.0241)	(0.0264)	(0.0256)
Land value tax		0.0023		-0.2486*
		(0.0814)		(0.1320)
Fixed effects	school dist	municipality	school dist	municipality
'Exposure'	Log(developable lot size)			
Log-Likelihood	-2029.92	-2265.8799	-1394.25	-1630.47

Note: Standard errors in parentheses. ***, **, * indicate two-tail test significant at 1%, 5%, 10%, respectively. All air pollutant measures are calculated from daily monitoring data of the second quarter in each year. Model SO_2 (1) and PM10 (1) in the first and third column are school district fixed effects models. Model SO_2 (2) and PM10 (2) in the second and forth column are municipality fixed effects models.

Table 4.3: Land area model using indirect approach

Another important public policy related to land development is land value taxation, which has attracted much attention in the literature (see Banzhaf and Lavery (2010) for a recent review). In all municipality fixed effects models, a dummy variable is set to 1, otherwise 0, if a municipality has land value tax implemented in a given year. There are four municipalities in Allegheny county having land value tax during the study period, Clairton, Duquesne, McKeesport, and Pittsburgh[20]. The results indicate that the land value tax, potentially due to small sample of observations, has virtually no impacts on new development. The significant negative (at 10% level) estimate in the land area developed model with PM10 level and municipality fixed effects, and other insignificant negative estimates, reveals potentially same results as in Oates and Schwab (1997). The largest municipality where the land value tax was in place - Pittsburgh - had

[20]Land value tax is collected in various jurisdictions across the United States, and most commonly in the state of Pennsylvania. For a complete treatment of the land value tax in Pennsylvania, see Hughes (2006).

Variables	Model of Floor Space Built, $ln(L_{it})$			
	SO_2 (1)	SO_2 (2)	PM10 (1)	PM10 (2)
SO_2 level (max)	-0.0012**	-0.0024***		
	(0.0006)	(0.0009)		
PM10 level (mean)			-0.0128***	-0.0151***
			(0.0050)	(0.0050)
Distance to CBD	0.0175	0.0285*	-0.0002	0.0122
	(0.0149)	(0.0171)	(0.0189)	(0.0216)
Land slope	-0.0253	-0.0158	-0.0345	-0.0120
	(0.0247)	(0.0242)	(0.0307)	(0.0294)
4-quarter price volatility	-0.0148*	-0.0134	0.0181	0.0251*
	(0.0088)	(0.0089)	(0.0155)	(0.0150)
8-quarter price volatility	0.0132***	0.0150***	0.0090***	0.0101***
	(0.0026)	(0.0026)	(0.0034)	(0.0033)
Land recycling program	0.2239***	0.2840***	0.1565***	0.2299***
	(0.0268)	(0.0268)	(0.0288)	(0.0283)
Land value tax		-0.0130		-0.2081
		(0.0882)		(0.1439)
Fixed effects	school dist	municipality	school dist	municipality
'Exposure'	Log(developable floor space)			
Log-Likelihood	-1940.57	-2105.45	-1328.91	-1509.86

Note: Standard errors in parentheses. ***, **, * indicate two-tail test significant at 1%, 5%, 10%, respectively. All air pollutant measures are calculated from daily monitoring data of the second quarter in each year. Model SO_2 (1) and PM10 (1) in the first and third column are school district fixed effects models. Model SO_2 (2) and PM10 (2) in the second and forth column are municipality fixed effects models.

Table 4.4: Floor space model using indirect approach

land development dominated by non-residential development during the study period.

6.2. Direct Approach

Table 4.5 presents the estimation results with industrial land use change approximated directly using the direct approach suggested in (12). While estimates on other variables being consistent with models using air pollutant level as proxy for industrial land use change, the estimates with direct approach further confirm that, at local level, there exists a strong positive relationship between unused industrial land and new residential development. Even though the same relationship is not commonly observed in other metropolitan areas across the manufacturing belt, the unique historical background and policy environment of Allegheny county has facilitated such a linkage through successful land use transition. Overall, we can conclude at least from the experience of Allegheny county that the legacy of manufacturing decline could have been an important source of regional economic development rebound.

One remark to the empirical analysis is that, the marginal spillover effect of industrial land use on housing value, $\partial P_H/\partial L_{I,t}$, is not included in the estimation. Due to data limitation, we can not quantify the negative spillover effects on housing value. Therefore, this paper ignores the spatial-temporal variation of $\partial P_H/\partial L_{I,t}$ and treats it as a constant. Such a negative spillover effect, however, does exist as has been found in the literature. Davis (2011) finds that, for example, residential properties within 2 miles of power plants experience 3% - 7% decreases in values and rents. How the magnitudes of such negative externalities affect the supply side of housing market remains a question to answer in future research.

6.3. Robustness Analysis

In this paper, micro level air pollution data is used to approximate manufacturing decline and associated industrial land use change. One caveat that may lead to measurement error and bias in the results is the spatial distribution of monitoring sites on air pollutant levels. As shown in Figure 4.5, the several large school districts in the northern part of the county have virtually no monitoring sites within or nearby, with only one site on the upstream of Pine creek (North Allegheny school district). To account for this spatial error, a set of further estimations is run by excluding the four school districts (about 30% of the sample in terms of number of parcels) in the northern part of Allegheny county. The results are reported in Table 4.6.

After correcting for the spatial distribution of monitoring sites, the estimates are still consistent with the results with full sample. The significance of estimates on SO_2 level in both land developed and floor space models decreases a little bit, but maintains the expected sign and similar magnitude. One short explanation for this is the reduction of sample size. Another possible explanation is that, SO_2 level is measured as daily 1 - hour max concentration value. The measure may be a good indication for air quality but not a good indication of

Model	Lot Size		Floor Space	
Variables	PM10 (1)	PM10 (2)	PM10 (1)	PM10 (2)
$\triangle L_I$	0.0077**	0.0109***	0.0080**	0.0106***
	(0.0034)	(0.0035)	(0.0037)	(0.0038)
Distance to CBD	0.0088	0.0173	0.0008	-0.0045
	(0.0203)	(0.0251)	(0.0224)	(0.0278)
Land slope	0.0261	0.0243	-0.0322	-0.0104
	(0.0357)	(0.0370)	(0.0391)	(0.0407)
4-quarter price volatility	0.0099	0.0135	0.0139	0.0160
	(0.0147)	(0.0146)	(0.0161)	(0.0161)
8-quarter price volatility	0.0112***	0.0142***	0.0115***	0.0151***
	(0.0031)	(0.0031)	(0.0034)	(0.0034)
Land recycling program	0.1115***	0.1475***	0.0976**	0.1448***
	(0.0378)	(0.0397)	(0.0413)	(0.0437)
Land value tax		-0.1985		-0.1847
		(0.1445)		(0.1574)
Fixed effects	school dist	municipality	school dist	municipality
'Exposure'	Log(developable lot size)		Log(developable floor space)	
Log-Likelihood	-955.27	-1002.48	-910.06	-939.36

Note: Standard errors in parentheses. ***, **, * indicate two-tail test significant at 1%, 5%, 10%, respectively. All air pollutant measures are calculated from daily monitoring data of the second quarter in each year. Model PM10 (1) in the first and third column are school district fixed effects models. Model PM10 (2) in the second and forth column are municipality fixed effects models. When calculating $\triangle L_I$, 5-year differences of employment and PM10 level are used, i.e., $\triangle t = 5$ in (12).

Table 4.5: Model using direct approach with PM10

the actual SO_2 pollutant level, which provides a potential technical reason for the instability of the results.

Another caveat is that, the residential land development in the CBD area may behave differently than in suburban area. To eliminate the impacts from potential interaction between residential development and non-residential development, the same set of estimations is run by excluding the city of Pittsburgh. The results are reported in Table 4.7, which is consistent with the results of full sample presented in Table 4.3, 4.4, and 4.5. This suggests that the strong relationship between manufacturing decline and land development is identified mainly through the variation of manufacturing and development activities in suburban area, riverfront area in particular.

Model	Lot Size			Floor Space		
Variables	SO_2	PM10 (1)	PM10 (2)	SO_2	PM10 (1)	PM10 (2)
SO_2 level (max)	-0.0007			-0.0010*		
	(0.0005)			(0.0006)		
PM10 level (mean)		-0.0094**			-0.0116**	
		(0.0048)			(0.0053)	
$\triangle L_I$			0.0062*			0.0072*
			(0.0037)			(0.0041)
Distance to CBD	0.0265*	0.0194	0.0154	0.0114	0.0042	0.0103
	(0.0145)	(0.0181)	(0.0215)	(0.0158)	(0.0198)	(0.0236)
Land slope	0.0328	0.0257	0.0379	-0.0188	-0.0276	-0.0224
	(0.0233)	(0.0290)	(0.0373)	(0.0254)	(0.0317)	(0.0408)
4-quarter price volatility	-0.0076	0.0148	0.0106	-0.0134	0.0172	0.0144
	(0.0088)	(0.0153)	(0.0159)	(0.0095)	(0.0167)	(0.0174)
8-quarter price volatility	0.0109***	0.0080**	0.0102***	0.0125***	0.0086**	0.0107***
	(0.0026)	(0.0034)	(0.0034)	(0.0028)	(0.0037)	(0.0037)
Land recycling program	0.1930***	0.1383***	0.0963**	0.2062***	0.1415***	0.0858**
	(0.0263)	(0.0285)	(0.0414)	(0.0287)	(0.0311)	(0.0451)
Fixed effects	school dist	school dist	school dist	school dist	school dist	school dist
'Exposure'	Log(developable lot size)			Log(developable floor space)		
Log-Likelihood	-1764.16	-1212.56	-822.40	-1692.21	-1159.52	-785.69

Note: Standard errors in parentheses. ***, **, * indicate two-tail test significant at 1%, 5%, 10%, respectively. All air pollutant measures are calculated from daily monitoring data of the second quarter in each year. All models are school district fixed effects models. When calculating $\triangle L_I$, 5-year differences of employment and PM10 level are used, i.e., $\triangle t = 5$ in (12).

Table 4.6: Model excluding four northern school districts

7. Implications for Hedonic Pricing Analysis: WTP for better air quality

The empirical models in this paper use air pollution level as an important instrument in identification strategy. While the main goal of this paper concerns the supply side of housing market, air quality has gained much attention in the literature on the demand side of housing market (e.g., Smith and Huang, 1995; Chattopadhyay, 1999; Chay and Greenstone, 2005). The strong linkage that has been established between air quality improvement and land development therefore housing supply implies that traditional hedonic valuations of air quality may be subject to bias due to omitting supply side effects. The potential bias can be illustrated by following simplified housing market supply-demand model:

Model	Lot Size			Floor Space		
Variables	SO_2	PM10 (1)	PM10 (2)	SO_2	PM10 (1)	PM10 (2)
SO_2 level (max)	-0.0013*			-0.0015*		
	(0.0008)			(0.0009)		
PM10 level (mean)		-0.0102**			-0.0128***	
		(0.0046)			(0.0051)	
$\triangle L_I$			0.0077**			0.0081**
			(0.0035)			(0.0038)
Distance to CBD	0.0335**	0.0265	0.0153	0.0229	0.0122	0.0085
	(0.0161)	(0.0175)	(0.0209)	(0.0178)	(0.0793)	(0.0230)
Land slope	0.0158	0.0238	0.0324	-0.0274	-0.0290	-0.0261
	(0.0240)	(0.0283)	(0.0364)	(0.0265)	(0.0310)	(0.0398)
4-quarter price volatility	-0.0107	0.0154	0.0094	-0.0143	0.0182	0.01331
	(0.0090)	(0.0145)	(0.0150)	(0.0100)	(0.0158)	(0.0164)
8-quarter price volatility	0.0112***	0.0085***	0.0107***	0.0127***	0.0089***	0.0111***
	(0.0027)	(0.0032)	(0.0032)	(0.0030)	(0.0035)	(0.0035)
Land recycling program	0.1956***	0.1536***	0.1119***	0.1917***	0.1514***	0.0970**
	(0.0275)	(0.0270)	(0.0384)	(0.0303)	(0.0295)	(0.0419)
Fixed effects	school dist	school dist	school dist	school dist	school dist	school dist
'Exposure'	Log(developable lot size)			Log(developable floor space)		
Log-Likelihood	-1611.28	-1343.17	-916.30	-1529.58	-1279.91	-873.47

Note: Standard errors in parentheses. ***, **, * indicate two-tail test significant at 1%, 5%, 10%, respectively. All air pollutant measures are calculated from daily monitoring data of the second quarter in each year. All models are school district fixed effects models. When calculating $\triangle L_I$, 5-year differences of employment and PM10 level are used, i.e., $\triangle t = 5$ in (12).

Table 4.7: Model excluding city of Pittsburgh

$$\begin{cases} H_s &= \alpha_s P_H + \beta_s Q + \gamma_s X_s \\ H_d &= \alpha_d P_H + \beta_d Q + \gamma_d X_d \end{cases} \tag{16}$$

where H_s, H_d, and P_H denote logarithm transformed housing supply, housing demand, and housing price, respectively. Therefore, α_s and α_d are price elasticity of supply and price elasticity of demand, respectively. Q is a measure for air quality, such as SO_2 level and PM10 level[21]. X_s and X_d are other supply and demand shifters, respectively. Under the equilibrium condition $H_s = H_d$, a reduced form housing price model can be derived as:

$$P_H = \frac{\beta_d - \beta_s}{\alpha_s - \alpha_d} Q + \frac{\gamma_d}{\alpha_s - \alpha_d} X_d - \frac{\gamma_s}{\alpha_s - \alpha_d} X_s \tag{17}$$

[21]In this paper's framework, air quality is measured by air pollutant level directly. Therefore, β_d and β_s are expected to be negative.

According to (17), the total marginal WTP for air quality improvement of housing market is $\frac{\beta_d-\beta_s}{\alpha_s-\alpha_d}$, which consists of two parts: household (demand side) WTP $\frac{\beta_d}{\alpha_s-\alpha_d}$, and developer (supply side) WTP (in the form of a lower price) $\frac{-\beta_s}{\alpha_s-\alpha_d}$. If the air quality is assumed only being a demand side factor ($\beta_s = 0$), the first term on the right hand side of (17) reduces to $\frac{\beta_d Q}{\alpha_s-\alpha_d}$. The potential bias of omitting supply side effects thus is $\frac{\beta_s}{\alpha_s-\alpha_d}$, which implies that the demand side marginal WTP for air quality improvement may be underestimated[22]. To get more precise understanding of the magnitude of the bias, I use data from Pittsburgh housing market to estimate the elasticity of housing demand with respect to air quality and the marginal WTP for better air quality. The example starts with estimating a reduced form hedonic pricing model of housing market with school district being as unit of analysis:

$$P_{H,i} = \delta_0 + \delta_1 PM10_i + \delta_2 DCBD_i + \delta_3 PITTS_i + \varepsilon_i \tag{18}$$

where $P_{H,i}$ is the logarithm transformed average per square foot housing price, averaged at school district level from individual housing prices. The model is estimated using 2007 home sales data from Allegheny county, with an average housing price at \$94.87/sqft and a standard deviation of \$24.56 (in 2007 dollar). $PM10_i$ is the PM10 level in the second quarter of 2007 aggregated at school district level, with a mean of 22.79 $\mu g/m^3$ and a standard deviation of 4.33 $\mu g/m^3$. $DCBD_i$ is the distance to Pittsburgh CBD. $PITTS_i$ is the dummy variable for Pittsburgh school district. The small sample regression returns an $\hat{\delta}_1 = -0.0348$ with a standard error of 0.0180 and adjusted $R^2 = 0.32$. For this particular example, it means $\frac{\beta_d-\beta_s}{\alpha_s-\alpha_d} = -0.0348$. From the previous results, we know that in a floor space model with school district fixed effects, the estimate on industrial-adjusted PM10 level is -0.0128. By re-estimating the model with observed PM10 level without any adjustment, it gives an estimate of -0.0046 with a standard error of 0.0025. Therefore, an approximation for β_s is -0.0046. Now the unknown parameters are α_s and α_d, which I get from the literature.

According to Green et al. (2005), the price elasticity of housing supply in Pittsburgh MSA is 1.43, which gives an $\alpha_s = 1.43$. For the price elasticity of housing demand specific to Pittsburgh area, Hanushek and Quigley (1980) provides one of the recent estimates - an 95% confidence interval of $[-0.33, -0.95]$. For the lower bound $\alpha_d = -0.33$, we have $\beta_d = -0.0658$. For the upper bound $\alpha_d = -0.95$, we have $\beta_d = -0.0874$. Using the average PM10 level 22.79 $\mu g/m^3$,

[22] Given that housing is a normal good, $\alpha_s > 0$ and $\alpha_d < 0$, which gives $\alpha_s - \alpha_d > 0$.

the elasticity of housing demand with respect to PM10 level is then in the range of $[-1.50, -1.99]$. If omitting the supply side effects (i.e., set $\beta_s = 0$), the elasticity of housing demand with respect to PM10 level range becomes $[-1.40, -1.89]$.

Basing on the estimation results of (18), the total marginal WTP for reduction of PM10 level is \$3.30/sqft at the average housing price \$94.87/sqft. For the lower bound $\alpha_d = -0.33$, the marginal WTP bias (due to supply side effects) is \$0.25/sqft. For the upper bound $\alpha_d = -0.95$, the corresponding bias is \$0.18/sqft. According to the data used in this paper, average household floor space in Allegheny county is 2325 square feet, which gives a range for potential bias of $[\$419, \$581]$. In other words, for an average household in Allegheny county, the marginal WTP for air quality improvement (by 1 $\mu g/m^3$) in terms of PM10 level through housing market could have been underestimated by somewhere between \$419 and \$581 (or about 5-8%).

8. Concluding Remarks

Using local air quality change as a proxy for manufacturing decline, this paper tests the relationship between manufacturing decline and increased residential land development in Allegheny county. The results suggest that the transition from unused industrial land to residential land development has been successful in the study region, which can be explained by both the growing regional economy and stimulating public policy environment. Further analysis on the identified relationship between local air pollution level and residential development shows that the supply-side effect of air quality improvement on housing market could lead to bias in estimating homeowner's marginal WTP for better air quality using hedonic pricing models though that bias is relatively small. For an average household in Allegheny county with 2325 square feet living space, the marginal WTP for air quality improvement (by 1 $\mu g/m^3$) in terms of PM10 level through housing market could have been underestimated by somewhere between \$400 and \$600 (in 2007 dollar, or about 5-8%), accounting for possible measurement errors.

Integrating regional economic development and land use has gained much attention recently in both academic argument and policy practice. Partridge and Rickman (2014) stress that it is important to have research on regional economic development and land use economics integrated in an interactive way. In this paper, two areas are linked through an environmental perspective. In practice, such a need has also been pushed forward to inform policy marking process. For example, multi-county regional development organizations in Pennsylvania have initialized many programs to integrate land use, transportation, regional economic development in Pennsylvania (NADO Research Foundation, 2010).

A caveat of the analysis in this paper is the potential measurement error involved in approximating the decline of manufacturing activities and the change of industrial land use. Due to data limitation, I do not observe the change of land zoning codes, as well as the plant-level output/emissions continuously over the study period. This limits the precision of analysis results. However, as one of the first empirical research that tries to link together regional economic development and land use change, the evidence presented in this paper can provide useful guidance for further research and public policy-making.

Reference

1. Anderson, John E., 1999. Two-rate property tax effects on land development. Journal of Real Estate Finance and Economics 18, 181-190.
2. Alder, Simeon., Lagakos, David., Ohanian, Lee., 2012. The decline of the U.S. Rust Belt: A macroeconomic analysis. Society for Economic Dynamics 2012 Meeting, Papers 793.
3. Banzhaf, H. Spencer., Lavery, Nathan., 2010. Can the land tax help curb urban sprawl? Evidence from growth patterns in Pennsylvania. Journal of Urban Economics 67, 169-179.
4. Beeson, Patricia E., 1990. Sources of the decline of manufacturing in large metropolitan areas. Journal of Urban Economics 28, 71-86.
5. Bourassa, Steven C., 1987. Land value taxation and new housing development in Pittsburgh. Growth and Change 18, 44-56.
6. Brueckner, Jan K., 1986. A modern analysis of the effects of site value taxation. National Tax Journal 39, 49-58.
7. Chattopadhyay, Sudip., 1999. Estimating the demand for air quality: New evidence based on the Chicago housing market. Land Economics 75, 22-38.
8. Chay, Kenneth Y., Greenstone, Michael., 2005. Does air quality matter? Evidence from the housing market. Journal of Political Economy 113, 376-424.
9. Cho, S. H., Kim, S. G., Lambert, D. M., Roberts, R. K., 2013. Impact of a two-rate property tax on residential densities. American Journal of Agricultural Economics 95, 685-704.
10. City of Pittsburgh, Allegheny County, 1985. Economic development strategy to begin the 21st century: A proposal to the commonwealth of Pennsylvania. Pittsburgh, PA.
11. Cunningham, C. R., 2006. House price uncertainty, timing of development, and vacant land prices: Evidence for real options in Seattle. Journal of Urban Economics 59, 1-31.
12. Davis, L. W., 2011. The effect of power plants on local housing values and rents. The Review of Economics and Statistics 93(4), 1391-1402.
13. Deily, Mary E., Gray, Wayne B., 1991. Enforcement of pollution regulations in a declining industry. Journal of Environmental Economics and Management 21, 260-274.
14. Detrick, Sabina., 1999. The post industrial revitalization of Pittsburgh: Myths and evidence. Community Development Journal 34, 4-12.
15. Dye, Richard F., England, Richard W. (Eds.), 2009. Land Value Taxation,

Theory, Evidence and Practice. Cambridge, MA: Lincoln Institute of Land Policy.

16. Ferman, Barbara., 1996. Challenging the growth machine: Neighborhood politics in Chicago and Pittsburgh. Lawrence, KS: University Press of Kansas.
17. Giarratani, Frank., Houston, David B., 1989. Structural change and economic policy in a declining metropolitan region: Implications of the Pittsburgh experience. Urban Studies 26, 549-558.
18. Gray, Wayne B., 1997. Manufacturing plant location: Does state pollution regulation matter? National Bureau of Economic Research Working Paper No. w5880.
19. Green, Richard K., Malpezzi, Stephen., Mayo, Stephen K., 2005. Metropolitan-specific estimates of the price elasticity of supply of housing, and their sources. American Economic Review 95, 334-339.
20. Gyourko, Joseph., 2009. Housing supply. Annual Review of Economics 1, 295-318.
21. Hanushek, Eric A., Quigley, John M., 1980. What is the price elasticity of housing demand? The Review of Economics and Statistics 62, 449-454.
22. Hartley, D., 2013. Urban decline in rust-belt cities. Economic Commentary: Federal Reserve Bank of Cleveland, 2013-06.
23. Henderson, J. Vernon., 1996. Effects of air quality regulation. American Economic Review 86, 789-813.
24. Hughes, Mark Alan., 2006. Why so little Georgism in America? Using the Pennsylvania cases to understand the slow, uneven, progress of land value taxation. Unpublished paper. Cambridge, MA: Lincoln Institute of Land Policy.
25. Jezierski, Louise., 1990. Neighborhoods and public-private partnerships in Pittsburgh. Urban Affairs Review 26, 217-249.
26. Kahn, Matthew E., 1999. The silver lining of rust belt manufacturing decline. Journal of Urban Economics 46, 360-376.
27. Kwak, Sally., Mak, James., 2011. Political economy of property tax reform: Hawaii's experiment with split-rate property taxation. American Journal of Economics and Sociology 70, 4-29.
28. Leonard, Jeremy A., 2003. How structural costs imposed on U.S. manufacturers harm workers and threaten competitiveness. Manufacturers Alliance/MAPI Report, The Manufacturing Institute of the National Association of Manufacturers.
29. NADO Research Foundation, 2010. Integrating land use, transportation and economic development in Pennsylvania. Washington, DC: National

Association of Development Organizations.

30. Oates, Wallace E., Schwab, Robert M., 1997. The impact of urban land taxation: The Pittsburgh experience. National Tax Journal 50, 1-21.
31. Partridge, Mark D., Rickman, Dan S., 2014. Integrating regional economic development analysis and land use economics. In Duke, Joshua M., Wu, JunJie (eds.) The Oxford Handbook of Land Economics. New York: The Oxford University Press.
32. Seattle Planning Department, 1993. A citizen's guide to the draft comprehensive plan. Toward a sustainable Seattle: Seattle's plan for managing growth. Seattle, WA: Seattle Planning Department.
33. Smith, V. Kerry., Huang, Ju-Chin., 1995. Can markets value air quality? A meta-analysis of hedonic property value models. Journal of Political Economy 103, 209 - 227.
34. Treado, Carey D., Giarratani, Frank., 2008. Intermediate steel-industry suppliers in the Pittsburgh region: A cluster-based analysis of regional economic resilience. Economic Development Quarterly 22, 63-75.
35. Zabel, Jeffrey E., 2004. The demand for housing services. Journal of Housing Economics 13, 16-35.

V: Summary

"...... *we shall assume that the city sits on a featureless plain. This plain may contain lakes, or reserved land such as cemeteries, which are holes on the surface of the plain. In this sense our featureless plain is not featureless. What is does not have are such features as hills, low land, beautiful views, social ratchet, or pleasant breezes. These are undoubtedly important, but no way has been found to incorporate them into the type of theory that will be presented. However, the reader may perhaps prefer to think of the featureless plain not as a simple gray surface, but rather an average of cities, where an elevation in one city may be matched by a depression in another, or the social disesteem of an area in this city is compensated by the historic associations of a matching area in that city. These incidents of such importance in the particular case are distractions when one considers the general case in order to understand the process and structure of urban areas.*" - William Alonso, 1964.

This dissertation research takes three different approaches to study the urban land development process, mainly from a supply side perspective. The three approaches are organized into different essay chapters. Each chapter has its independent framework and methodology. Chapter 2 uses numerical optimization methods to explore how residential households allocate across space with introduction of distance related amenity/disamenity, as well as under non-monocentric urban spatial structure. Chapter 3 proposes an agent-based simulation of housing market and land development to understand the role of home improvement as part of housing supply. An important feature of the proposed agent-based simulation model is that it allows for neighborhood spillover effects among home improvement activities. Chapter 4 assembles a micro panel data to empirically investigate the relationship between manufacturing decline and increased residential land development in Allegheny county, PA. One policy implication of the results is that, there might be a significant underestimate of household willingness to pay (WTP) for better air quality, due to the supply side effect of manufacturing decline induced air quality change.

Specifically, in Chapter 2, I reinterpret the Herbert-Stevens model and propose a general procedure to solve the two-step residential land allocation problem via numerical optimization. In the first step, I convert Wheaton (1974)'s unconstrained optimization problem into a constrained NLP problem which is then solved by the Frank - Wolfe algorithm. Through numerical examples, I show that the Frank - Wolfe algorithm can solve the first step NLP problem within a small number of iterations, and the algorithm is applicable to large scale problem as well. In the second step, I solve the LP problem of the Herbert-Stevens model, and obtain the optimal residential land allocation for the urban area. The solution presents the best scenario that the urban planner can achieve, which gives an Pareto equilibrium in a static sense. A dynamic version of the model can also be developed, which will be an interesting direction for future research. The monocentric Herbert-Stevens model is further developed into the duocentric city framework. In the duocentric Herbert-Stevens model, the inter-city distance is endogenized to the urban spatial structure. Methodologically, the model framework and algorithm proposed in this essay present an effective technique for identifying the limits of feasible urban performance from a planning perspective.

The duocentric model makes two essential changes to the monocentric model, the congestion cost between two cities and the endogenized inter-city distance. The inter-city distance directly affects transportation cost and congestion cost. It also affects household utility through the average distance to city centers which is used as an approximate measure for distance related amenity/disamenity. The numerical illustration of the duocentric model shows that low income households choose to live in the fringe between two cities further from both urban centers. A major implication of the results to urban planners and policy makers is that the economic planning of a multi-city urban area requires potentially different transportation, environment, and land use policies. Especially, the income effect of transportation policies on low income households should be considered. A development plan that solves the deterioration issues in inner urban area may lead to new deterioration in suburban area. A policy that is proper in a monocentric city may have opposite results in a non-monocentric city.

In Chapter 3, an agent-based simulation model of home improvement with neighborhood spillover is designed to study home improvement as a constituent part of housing supply. Within a monocentric urban spatial structure, neighborhood spillover effects associated with home improvement are modeled through a complementarity framework. The existence of neighborhood spillover effects slows down the pace of urban land development, while it also significantly increases average household duration of residence and amount of home improvement. In practice, the neighborhood spillover effects can be considered as a form of social capital which connects homeownership to neighborhood quality. Basing on the simulation results and sensitivity analysis on key policy relevant parameters, the essay also explores implications for public policy-making related to housing markets, land use, and transportation. In 2004, the U.S. homeownership rate reached a record high of 69.2% in the second quarter, and steadily went down since then. By 2013, the homeownership rate decreased to the 1995 level, barely above 65%. Even though rental properties meanwhile may benefit from the drop in homeownership, there is a pressing need for policy to prevent the rate from slipping further. The dynamic simulation analysis tool developed in this paper, though simplified, can help to shed light on designing related policies.

The main goal of Chapter 4 is to link the observed manufacturing decline, urban land development, and environmental quality together. This essay uses local air quality change as a proxy for manufacturing decline, and tests the relationship between manufacturing decline and increased residential land development in Allegheny county, PA. The results suggest that the transition from unused industrial land to residential land development has been successful in the study region, which can be explained by both the growing regional economy and stimulating public policy environment. Further analysis on the identified relationship between local air pollution level and residential development shows that the supply-side effect of air quality improvement on housing market could lead to bias in estimating homeowner's marginal WTP for better air quality using hedonic pricing models. For an average household in Allegheny county with 2325 square feet living space, the marginal WTP for air quality improvement (by 1 $\mu g/m^3$) in terms of PM10 level through housing market could have been underestimated by somewhere between \$400 and \$600 (in 2007 dollar, or about 5-8%), accounting for possible measurement errors.

Traditionally, concerns regarding manufacturing decline have been mainly attached to loss of jobs in the U.S.. This essay looks at the issue from a different perspective, and presents new quantitative evidences for both policy making and further research. Revitalizing regional economy, especially in the manufacturing belt, is a complicated project and has lots of uncertainty involved. In the era of industrial transition and manufacturing rebound, however, land use and environmental consequences from any changes and new policies should be anticipated.

Overall, I have reached the objective for this dissertation research which is to understand how cities use land resources from a supply side perspective. The three studies in this research, by no means, present a comprehensive picture for understanding housing supply and urban land development. However, they do contribute substantial insights on factors affecting urban land use hence the spatial structure, especially from an environmental and a social interaction angle.

HAYOING WANG

(Agricultural, Environmental and Regional Economics, Operations Research)
Department of Agricultural Economics, Sociology and Education
The Pennsylvania State University
University Park, PA 16802-5600 USA
Email: halking@psu.edu, halking.econ@gmail.com (permanent)

Education

2014 THE PENNSYLVANIA STATE UNIVERSITY
Ph.D. in ***Agricultural, Environmental and Regional Economics*** *and* ***Operations Research***
Dissertation: Essays on Land Development, Housing Markets, and Environment.

2010 THE UNIVERSITY OF ARIZONA
Master of Science in ***Agricultural and Resource Economics***

2008 XIAMEN UNIVERSITY
Master of Arts in ***Political Economics***

2005 JILIN UNIVERSITY
Bachelor of Science in ***Material Science and Engineering***

Research Interests: Urban and Regional Economics, Environmental and Resource Economics, Applied Econometrics, Computational Economics.

Fellowships, Honors and Awards

2014 Nomination to Penn State Chapter of Gamma Sigma Delta - The Honor Society of Agriculture.

2013-2014 Thomas C. and Jackie M. Floore Memorial Scholarship in Agricultural Economics, Pennsylvania State University.

2010 Funding for Excellence in Graduate Recruitment (FEGR), Pennsylvania State University.

2009-2010 E. Ray Cowden Scholarship, University of Arizona.

2007 Honor for Outstanding Performance in Field Research, Xiamen University.

2005-2008 National Graduate Student Scholarship, Xiamen University.

2001-2004 Jilin University Student Scholarship (undergraduate), Jilin University.

Affiliations: Agricultural & Applied Economics Association (AAEA), Western Agricultural Economics Association (WAEA), Spatial Econometrics Association (SEA)

References (as of 2014)

Spiro Stefanou (advisor)
Professor, Department of Agricultural Economics, Sociology and Education, Pennsylvania State University. Email: ttc@psu.edu.

Richard Ready (advisor)
Professor and Program Director, Department of Agricultural Economics, Sociology and Education, Pennsylvania State University. Email: rready@psu.edu.

James Shortle
Professor, Department of Agricultural Economics, Sociology and Education, Pennsylvania State University. Email: jshortle@psu.edu.

Allen Klaiber
Assistant Professor, Department of Agricultural, Environmental and Development Economics, Ohio State University. Email: klaiber.16@osu.edu.