ABSTRACT

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This dissertation contributes to the literature on urban spatial structure by addressing two research questions. First, it empirically examines the urban economic theory by testing the relationship between the distance elasticities of land prices and housing prices. The theory indicates that land prices are more elastic with respect to distance from the city center than housing prices; in other words, land prices decline faster than housing prices. Using data from Beijing, which include matched housing and land prices, my findings support the theory.

Second, this dissertation investigates the impacts of housing services production in general and the impacts of the capital-land substitution in particular on urban spatial structure. Using a constant elasticity of substitution (CES) production function for housing services, I theoretically derive the impacts of the elasticity of capital-land substitution on urban spatial structure, which is measured in terms of the distance gradients of land prices and capital densities, the housing output per unit of

land, and the ratio of the distance elasticity of land prices to the distance elasticity of housing prices. The derived results suggest that an increase in the elasticity of capital-land substitution leads to increases in the land price, the capital density, and the housing output per unit of land at any location within the city, flattening of the land price and capital density curves, an increase in the ratio of the distance elasticity of land prices to the distance elasticity of housing prices, an expansion of the city boundary, and a growth in the population. These theoretical results are verified by numerical simulations and empirical estimations using the Beijing data. The simulations also reveal the magnitudes of these impacts: a 1% change in the elasticity of capital-land substitution leads to 15-20% changes in the total land value and housing output.

The findings of this dissertation have practical implications in housing market behaviors, land value assessment for property taxation, and urban land use policy and planning.

MARKET FORCES AND UBAN SPATIAL STRUCTURE:
EVIDENCE FROM BEIJING, CHINA.

By

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Dedication

To Father and Mother

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Chapter 1: Introduction

1.1 Why Urban Spatial Structure Matters

Urban spatial structure is of both academic and practical importance and has attracted wide interest from scholars, planners, and officials for the following reasons. First, urban spatial stricture is associated with urban agglomerative effects that serve as a primary engine for cities to exist and grow. Spatial proximity facilitates intra-firm economies of scale and scope, labor pooling, and technology spillover (Anas et al. 1998, Bertaud 2003, Ding 2009). Second, urban spatial structure and form can be used to measure and indicate the efficiency of urban resources, along with the land prices and housing prices.[1] Efficient urban development requires land use intensity to vary with prices as a result of an optimal combination of land and capital in housing services production. Third, urban spatial structure is an important determinant for urban transportation demand, for it links to population density. Population density in turn plays a key role in determining trip length and frequency, mode choice, and the overall travel (Crane 2000, Boarnet & Crane 2001, Ewing & Cervero 2001). Finally, urban spatial structure is directly or indirectly connected to negative externalities. For instance, spatial separation of different land uses can be helpful to minimize the nuance effects resulting from spatial clustering of incompatible land uses.

Studies of urban spatial structure are proved to be difficult and complicated. On the one hand, urban spatial structure reflects cumulated decision making by all

[1] Land and housing prices refer to unit prices in RMB (Chinese *yuan*) per square meter throughout this dissertation.

kinds of actors such as developers, investors, land owners, residents, planners, and government officials in urban land development. On the other hand, there are a variety of factors that influence the location, timing, uses and intensity of land development, including the market forces, infrastructure provisions, planning regulations, tax policies, social and cultural conventions, and natural endowments (Bertaud & Malpezzi 2003).

Practically, it is of great value to understand urban spatial structure, for it helps planners and policymakers dealing with problems of urban development, shaping or reshaping urban structure and form to facilitate economic development and improve the overall social welfare for businesses and residents. For example, knowledge of urban spatial structure can guide planners to direct people and activities in certain spatial nodes to foster agglomerative effects (such as Manhattan in New York City), increase public transportation ridership (Transit Oriented Development), and reduce negative environmental impacts.

1.2 Research Questions

This dissertation addresses two research questions. The first research question is an empirical question that focuses on testing the urban economic theory, which indicates that land prices are more elastic with respect to distance from the city center than housing prices; in other words, land prices decline faster than housing prices. This prediction is derived by treating land as an input factor in housing services production and regarding the demand for land as a derived demand. Despite many empirical studies on land and housing prices, few cases in the literature have examined land and housing prices of the same sites. Economic reform and rapid market development in China provide a good chance to conduct an empirical study of this kind. Taking advantage of the data collected from Beijing that include both land and housing prices from the same land development projects, this dissertation carries out an empirical inquiry on the relationship between land and housing prices by estimating and testing the ratio of the distance elasticity of land prices to the distance elasticity of housing prices.[2] In addition, compared with abundant empirical evidence for the pattern of land and housing prices over the urban space in developed countries, fewer studies in the developing countries have been conducted; this dissertation contributes to the literature in this regard.

The second research question focuses on examining the impacts of housing services production on urban spatial structure, in particular, the impacts of capital-land substitution. This dissertation investigates this question by (1) theoretical analysis that reveals the directions of the impacts (signs of partial derivatives); (2) numerical simulations that verify the analytical directions and examine the magnitudes of the impacts on social welfare; and (3) empirical estimations that provide evidence for the derived impacts. The theoretical model, which assumes a constant elasticity of substitution (CES) production function for housing services production, yields the following results: an increase in the elasticity of capital-land substitution leads to increases in the land price, the capital density, the absolute values of distance gradients of land prices and capital densities, the housing output per unit of land (or the FAR—floor area ratio) at any location with the city, an

[2] The ratio of the distance elasticity of land prices to the distance elasticity of housing prices is denoted by λ and it is also called the ratio of the two distance elasticities for short throughout this dissertation.

expansion of the city's geographical boundary and a growth in the population size.[3] These theoretical results are supported by numerical simulations and empirical estimations.

The second question contributes to the literature since the impacts of capital-land substitution on urban spatial structure has not been sufficiently addressed. Although the importance of elasticity of capital-land substitution to urban spatial structure has been well recognized (Muth 1964, McDonald 1981), how and to what extent the elasticity of capital-land substitution affects urban spatial structure has not been adequately investigated both theoretically and empirically. McDonald (1981) pointed out that the elasticity of capital-land substitution in land development plays an critical role in understanding urban spatial structure and concluded that it is "a determinant of the land rent gradient, the population density gradient, the factor share of land and housing capital and the elasticity of supply of housing both in the aggregate and on a particular site" (p. 190). The literature, however, lacks explicit examination on the directions and magnitudes of the impacts. This question is overlooked probably because of the slow change in housing production technology in the developed countries where the impacts of capital-land substitution are less relevant.

Nevertheless, this question is perhaps more relevant in China, given the profound institutional reforms of urban land and housing systems and impressive urban expansion, particularly in cities like Beijing. Dramatic changes in a relatively short period make capital-land substitution a critical factor in determining urban

[3] Capital density refers to non-land capital intensity in RMB per square meter, and housing output per unit of land is measured by floor space in square meter and thus it is equivalent to the FAR throughout this dissertation.

spatial structure in China. Even more important, Chinese cities provide an opportunity to empirically examine the linkage between capital-land substitution and urban spatial structure. Based on the data from Beijing, the simulation exercises indicate that capital-land substitution has considerable impacts on urban spatial structure. The findings of this dissertation will be of great value to urban planners and government officials in addressing the problem of housing prices, assisting property value assessment for tax purposes, and evaluating urban land use policies and planning regulations.

1.3 Organization of the Dissertation

This dissertation is organized in seven chapters.

After this introduction, chapter 2 reviews urban land and housing markets development in China, urban spatial structure evolution, and urban planning's influences on urban land use. Market forces are emerging and begin to act as important forces to shape and modify urban spatial structure in China's cities, while urban planning remains influential on urban land development.

Chapter 3 provides a literature review on urban spatial structure. Urban economic theory reveals the declining phenomena of land and housing prices, and the theory of housing services production is important to understand the formation of urban landscape. Both theoretical and empirical studies are reviewed.

Chapters 4 to 6 present respectively theoretical analysis, simulation analysis, and empirical analysis to address the two research questions. By using a CES production function, chapter 4 derives analytically the impacts of capital-land substitution in housing services production on urban spatial structure. Chapter 5 conducts numerical simulations to verify the derived directions of the impacts and examine the magnitudes of the impacts, based on the Beijing data. Chapter 6 again uses the data from Beijing, estimates and tests the negative distance gradients of housing prices, land prices, capital densities, and the housing output per unit of land (or the FARs), estimates the ratio of the two distance elasticities and tests whether it is larger than unity, and estimates the elasticity of capital-land substation as well as its impacts.

Finally, chapter 7 concludes with the findings, discusses policy and planning implications, and proposes future studies.

Chapter 2: Market, Urban Spatial Structure, and Planning in China

First of all, this chapter provides a brief overview of urban land market and housing market development, and then it reviews changes of urban spatial structure during the post-reform period, in which market forces have emerged and begin to influence urban spatial development in China. It also reviews the urban planning's influences on urban land development.

2.1 Land Reform and Land Market

The land reform launched in the late 1980s separates the land use rights from the land ownership and introduces a land leasing market to allocate state-owned urban land.[4] Prior to the reform, there was no land market, and urban land was managed and assigned to land users through an administrative process. Land was distributed to land users free of charge on the basis of need for an indefinite time period. Transactions of land between land users were prohibited. If the assigned land was not used, it was to be returned to the government and be re-assigned to other land users. Since there were no economic implications for vacant land holding, this in fact seldom happened, resulting in inefficient land uses.

One of the primary objectives of the land reform is to introduce market mechanisms to improve land use efficiency and land management. The most

[4] In China, urban land is owned by the state and managed by city government, while rural land is collectively owned by farmer collectives but is in general restricted from non-agricultural uses.

prominent change in the reform is the introduction and establishment of the Land Use Right System (LURs). In the LURs, land use rights are separated from land ownership so that private users can access state-owned urban land. City government can lease out the land use rights of state-owned urban land to private users in a long-term period depending on land uses, and a land use right fee is involved in the transaction, paid from land users to the city government.[5] This policy innovation provides an approach to paid land use without challenging the public ownership of the land, which is the cornerstone for Communist China. As expected, land leasing markets are growing quickly and begin to play a role in shaping urban spatial structure.

The rapid land market development is reflected by dramatic increases in both the number of land leasing transactions and the value of land leased. In 1987, only 5 land leasing transactions (totaling 15.7 hectare) took place in China, and this number grew to 545 in 1991 (Ding 2003). Since the middle 1990s, the number of annual land leasing transactions jumped to 10,000 and peaked at 242,763 in 2002 (figure 2-1). The area of annually leased land also increased impressively, from about 50,000 hectares in 1994 to over 200,000 hectares in 2005 (figure 2-1). The total value of annually leased land increased even more dramatically by about 15 times during 1994-2005, and it reached as high as 588.4 billion RMB in 2004 (figure 2-2).[6] In particular, the beginning years of the new century witnessed accelerated land leasing transactions. For the years 2000-2003, the area of leased land increased 4 times and

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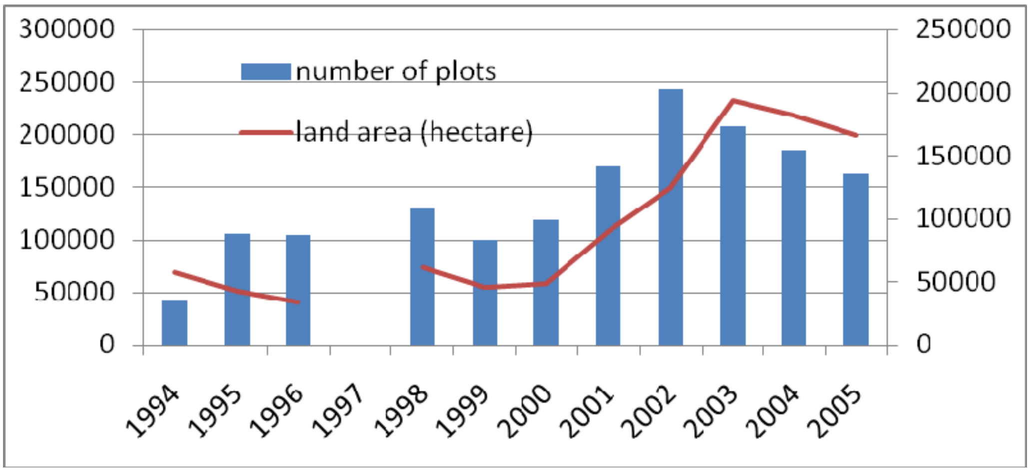
[5] The maximum time period is 70 years for residential uses, 40 years for commercial, tourist and recreational uses, and 50 years for other uses such as industrial and public uses.

[6] Price is not adjusted.

the average price of land increased 2.3 times, consistent with the fast growing economy and booming commodity housing market in China in this period. Since 1998, material housing distribution was prohibited according to an important document issued by the State Council.[7] Nevertheless, a slight decline in the number and area of land leases can be observed since 2002, a fact that probably is due to stringent policies on land uses.[8] Despite this, the total value of land leased annually appeared not much influenced, implying an increase in the unit price of land leased.



Source: China Land Resource Statistical Yearbook 2006, China Land Yearbook 1994, 1995, 1998. Data of 1997 were not available.

Figure 2-1 Land Leasing Market in China: Numbers of Plots and Hectares of Land Area, 1994-2005

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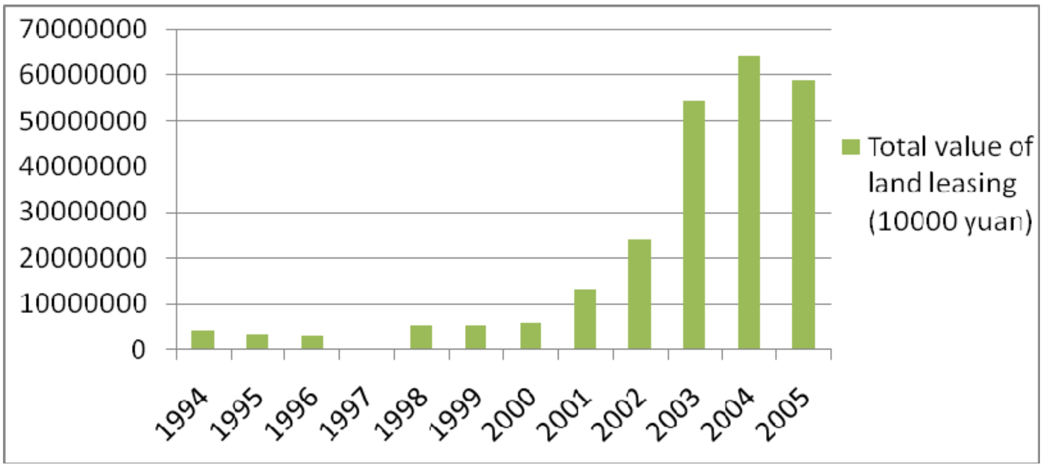
[7] The document of 1998 is entitled the *Notice on Further Deepening the Urban Housing System Reform and Speeding up Housing Construction.* Further discussion will be found in the following section on the housing market development.

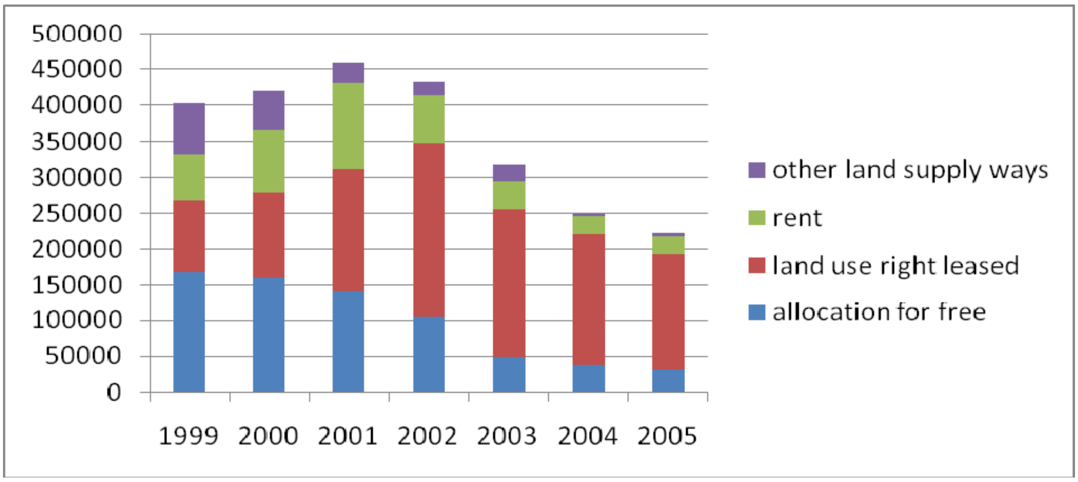
[8] In April 2002, the Ministry of Land and Resources announced the *Provisions of Tender, Auction, and Listing State-Owned Land Use Right*, requiring that leasing land use rights for profitable uses such as residential and commercial uses should be conducted through open bid procedures (including tender, auction, or listing). In March 2004, the Ministry of Land and Resources and the Ministry of Supervision issued *the Notice on Further Enforcement and Supervision on the Profitable Land Use Right Leasing through Tender, Auction, and Listing* to strictly cut off land leasing transactions through negotiation by August 31, 2004.



Source: China Land Resource Statistical Yearbook 2006, China Land Yearbook 1994, 1995, 1998. The data of year 1997 are not available.

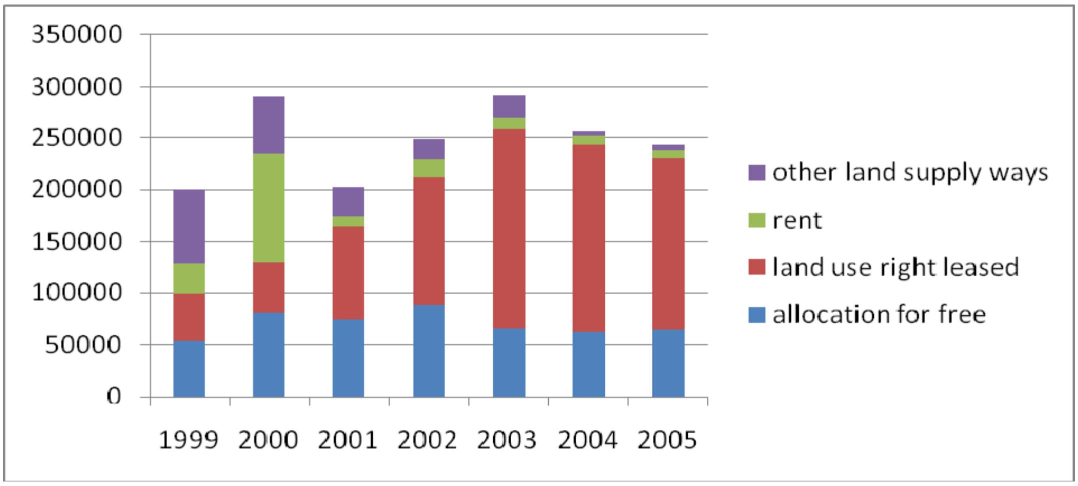
Figure 2-2 Land Leasing Market in China: Transaction Values, 1994-2005

The relative share of land leased in the total land provision also increased substantially. In 1999, leased land made up 25% and 34% in the numbers and the area of urban land provision, respectively; in 2001, leased land exceeded free allocation; and in 2005, leased land comprised up to 70% of total land provision (figures 2-3 and 2-4).



Source: China Land Resource Statistical Yearbook 2006

Figure 2-3 Land Leasing Market in China: Numbers of Land Plots by Different Approaches, 1999-2005



Source: China Land Resource Statistical Yearbook 2006

Figure 2-4 Land Leasing Market in China: Hectares of Land Areas by Different Approaches in China, 1999-2005

2.2 Housing Reform and Housing Market

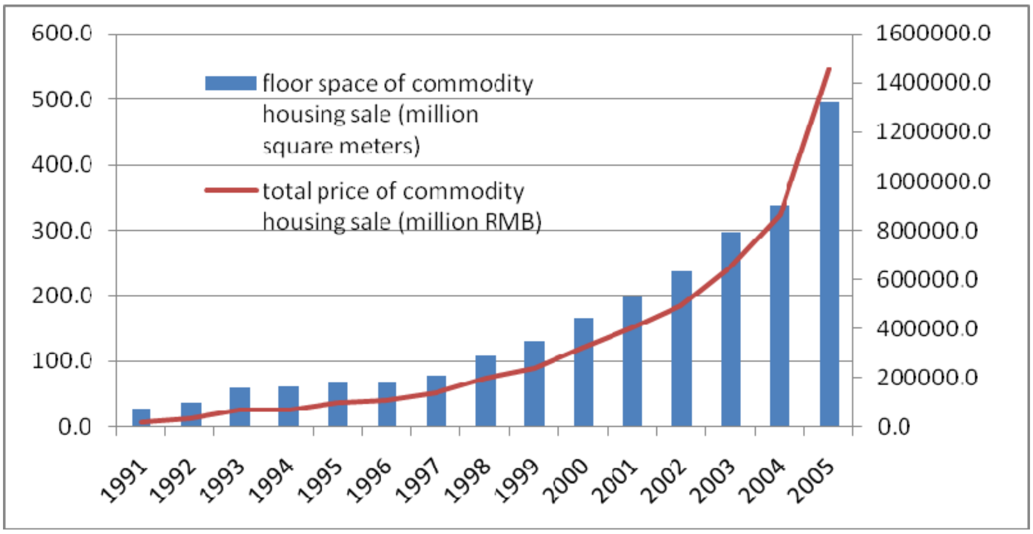
Accompanied with the land reform, China's urban housing reform was launched in the late 1980s, aiming at transforming the welfare-oriented public housing system into a market-oriented housing system (Wang & Murie 1999, Huang & Clark 2002, Li & Yi 2007). The housing reform is facilitated by the land reform, which enables private developers to obtain urban land for housing services production and enhances commercialization of housing provision.

Before the reform, housing was a public welfare attached with urban employment. After the new China was built in 1949, all private houses were systematically transferred to local government and a public housing system was built in urban areas (Wang & Murie 1999). Housing was considered a welfare benefit and allocated free from the work units (*danwei*) to their employees. Residents did not need to pay rent or only paid an extremely low rent since housing was regarded as part of the wage cost (Wang & Murie 2009, Huang & Clark 2002).

Housing reform was carried out in a gradual way and marked by two milestone steps that promoted housing privatization. In 1988, the State Council issued permits to sell public housing stocks and encouraged private-public co-financing of housing provision for employees. Under the co-financing scheme, employees usually paid up to one-third of total construction costs, which was a substantial amount of payment compared with what was paid under the material distribution of housing.

In 1998, the material distribution of housing was formally abandoned and replaced by monetary housing distribution. As expected, this triggered remarkable development in real estate sectors. Moreover, it brought enormous market opportunities that facilitated rapid changes in housing construction technology.

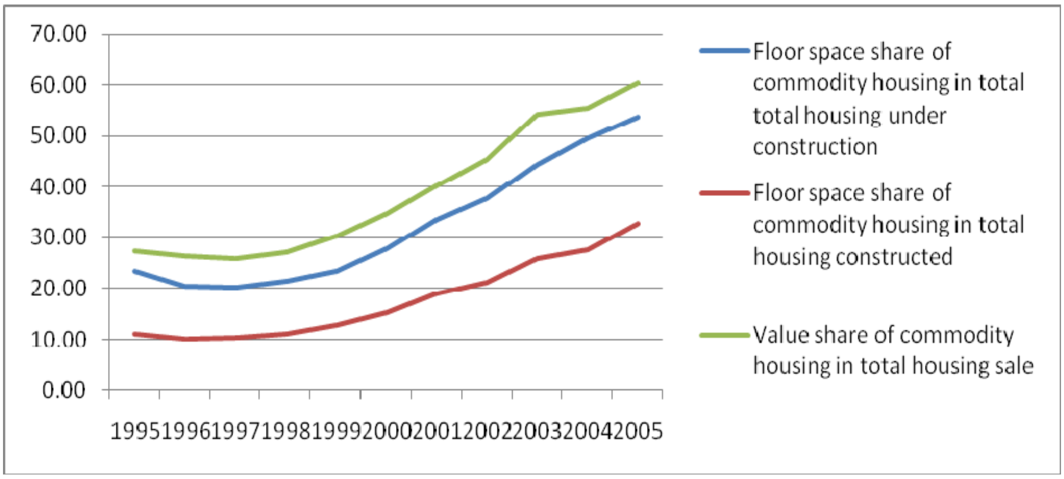
For example, the private housing market began to emerge in the early 1990s and has been growing rapidly since 1998. From 1991 to 2005, the area of annual commodity housing sales increased 18 times from 27.5 million to 495.9 million square meters at an annual growth rate of 23%, and the total value of annual commodity housing sale increased about 70 times from 20.8 billion RMB to 1456.4 billion at a remarkable annual growth rate of 35% (figure 2-5). The growth was particularly striking after 1998, when the country prohibited the channel of material housing distribution. Housing prices also rose dramatically, from 756 RMB per square meter floor space in 1991 to 2,937 RMB per square meter in 2005 (NBS 2007); this price increase to some degree indicates the development of commodity housing market.



Source: China Statistic Yearbook 2006

Figure 2-5 Commodity Housing Market in China: Floor Space and Value of Sales, 1999-2005

Commodity housing became the major component in urban housing supply, reflecting the increasing importance of the market in housing provision. As shown in figure 2-6, the shares of commodity housing in the total housing supply increased steadily since 1998 in terms of the floor area under construction, the floor area constructed, and the total housing sale value; the numbers grew from 23% to 54%, from 11% to 33%, and from 27% to 60%, respectively (NBS 2007). Noticing that the shares of commodity housing in the sale value were always higher than those in the floor area (under construction and constructed), it suggested that the prices of commodity housing were higher than other types of housing supply (such as the government subsidized reform housing and affordable housing).



Source: China Statistical Yearbook 2006

Figure 2-6 Commodity housing market in China: Share in Housing Supply, 1995-2005

Home ownership also increased greatly. Currently, about 74% of the city and town residents in China own a housing property (only the structural construct; land is still owned by the state) (Jia 2008). This is indeed a remarkable achievement, compared with the home ownership rate of the United States, which was 68.9% in 2005.[9]

With the housing market development, the urban landscape has been reshaped along with the adoption of advanced technology of construction. Both the appearance and quality of residential buildings have been improved. Perhaps the most prominent change is reflected by the growing building height. Low-rise buildings have been gradually replaced by mid-rise, mid-to-high-rise, and high-rise buildings, and since the late 1990s, high-rise buildings have become dominant in many Chinese cities.[10]

[9] U.S. Census, http://www.census.gov/hhes/www/housing/hvs/annual05/ann05t12.html

[10] According to the *Design Code for Residential Buildings* issued in 1999 by the Ministry of Construction, residential buildings that have 1-3 floors are low-rise, 4-6 floors are mid-rise, 7-9 floors are mid-to-high rise, and above 10 floors are high-rise Regarding the high-rise buildings, they are usually further divided into four kinds: 9-16 floors (less than 50 meters), 17-25 floors (less than 75 meters), 26-40 floors (less than 100 meters), and super-high-rise buildings with more than 40 floors

Improvements in technology of construction are reflected in the ways that residential buildings are built. In the 1950s, residential buildings were basically low-rise (often fewer than three floors) brick-wood (or brick-concrete) structural buildings, copied from the Soviet Union.[11] These buildings can still be found today, particularly in the neighborhoods of state-owned enterprises. Figure 2-7(a) and figure 2-8 (a) presents such examples.

In the 1960s and 1970s, no obvious change in housing construction happened (figure 2-7 (b)), but a number of the makeshift houses (*jianyi fang*) were built to cater increasing population. The makeshift houses were often characterized by shallow foundations, thin walls, and common bathrooms and kitchens (figure 2-8(b)), reflecting the influences of turbulent economic and political situations as well as natural disasters in those years.[12] At the end of the 1970s, however, higher residential buildings (7-8 floors) were developed in large cities like Beijing and Shanghai, as attempts to satisfy the increasing housing demand.[13]

(above 100 meters). http://baike.baidu.com/view/2683768.htm?fr=ala0_1

[11] http://news.dichan.sina.com.cn/2009/10/10/71722_1.html

[12] http://www.51yanxiu.com/jianzhu/ziliao/qita/jianzhu_295740.html

[13] http://news.dichan.sina.com.cn/2009/10/10/71722_1.html


(a) 50-60s (b) 70s


(c) 80s (d) 90s


(e) 21st century (f) 21st century

Photos were taken on March 17, 2010. The building ages were learned from local residents, about 12 kilometers to Tiananmen Square.

Figure 2-7 Residential Building Evolution in *Zhongguancun* Area, Beijing

(a) Late 50s

(b) 70s (Makeshift house)

(c) 80s

(d) late 90s

(e) 21st century (white building: 08-09, right: 80s)

(f) left: 93, right: 03, back: under construction

Photos were taken on March 20, 2010. The building ages were learned from local residents, about 6 kilometers to the city center.

Figure 2-8 Residential Building Evolution in *Qinchuan* Neighborhood, Xi'an

The 1980s and 1990s witnessed steady growth in building quality and height. The Ministry of Construction carried out a series of urban residential building design competitions and nationwide pilot residential projects to facilitate housing industrialization.[14] Apparently, the overall building height increased, particularly in the late 1990s (figures 2-7 (c) & (d), figures 2-8 (c) & (d)).

Since 1998, commodity housing development has entered a very fast growing period. With the adoption of new advanced building technologies (such as applications of steel frame, frame-shearwall structure, slab-column shearwall structure, etc), high-rise residential buildings rose dramatically in China. Twenty- to thirty- or even forty-floor residential buildings are commonly observed (figures 2-7 (e) & (f), figure 2-8 (e)), and redevelopment also occurred frequently to replace the old low-rise buildings and meet the growing housing demand (figure 2-8 (f)).

2.3 Spatial Structure

Rapid market development along with fast urbanization has brought two fundamental changes in China's urban landscape. One is the locational changes of land uses and the other is associated with changes in land use intensity.

2.3.1 Pre-Reform

Prior to the economic reform, the urban space of China's cities was recognized as monotonous, featured by highly mixed land uses and invariant building height and density.

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[14] The Ministry of Construction was restructured and renamed as the Ministry of Housing and Urban-Rural Development in 2008.

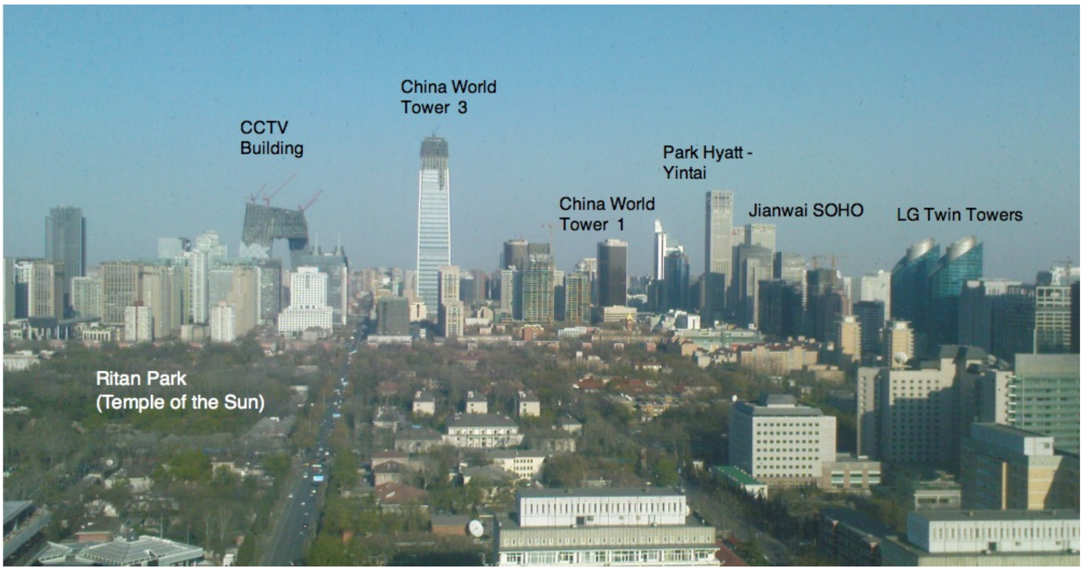
The highly mixed land use pattern was mainly a result of the *danwei*-based spatial organization of China's urban space. A *danwei* was the basic unit of working and living, usually a walled and mixed residential and industrial compound (Gaubatz 1995 & 1999). It provided not only a working place but also provided a series of public services and welfare such as housing, food distribution, education, health care, recreation, etc. (for detailed examples see Ding 2004). Therefore, each *danwei* formed a small self-sufficient community, with very diverse land uses inside a relatively small area. There were two major reasons for this. One was the fact that production was regarded to be the priority compared with consumption and *danwei* served as the basic unit of production; the other was that residents did not need to travel beyond the walls, thus, *danwei* minimized travel costs (Wu 1997, Gaubatz 1995 & 1999). As urban space grew, it spread through the increase of the cells of *danwei*. Therefore, the entire urban space featured highly mixed land uses.

The invariant land development intensity, manifested by the flat building height across urban space, was due to the lack of market mechanism. Since land was of no value and assigned to each *danwei* for free on a basis of need, there was no incentive for *danwei* to economize land or substitute land with capital to improve land use efficiency. Land development intensity was irrelevant to the location. Tall buildings were developed mostly for political reasons rather than economic reasons. Therefore, the typical urban landscape in the pre-reform period was characterized by the walled *danwei* and similar low-rise brick buildings (Gaubatz 1995 & 1999).

2.3.2 Post-Reform

Land prices rose rapidly in the post-reform period, particularly in cities like Beijing, Shanghai, Shenzhen and many other cities in the coastal regions. Rising land prices forced industrial buildings and warehouses that were occupying the central locations to relocate to urban outskirts. For instance, manufacturing firms were forced out in Beijing in the middle 1990s, and the previously occupied land was redeveloped for residential, commercial, or mixed uses (Wu 1997, Gaubatz 1995 & 1999).

Erection of skyscrapers in central locations has not only changed land use intensity but also reshaped urban landscape and created new city images. For example, development of the *Chaoyang* central business center (CBD) in Beijing has substantially increased the density in that area in the first decade of the 21st century. Recently, the former highest building in Beijing, *Jingguang Center*, which is 209 meters tall, has been overtaken by the China World Tower 3 (*Guomao Sanqi*), which is 330 meters tall with 88 floors, accompanied by the China Central Television building (234 meters tall) under construction and the *Yintai* Center (249.9 meters tall) as shown in figure 2-9.



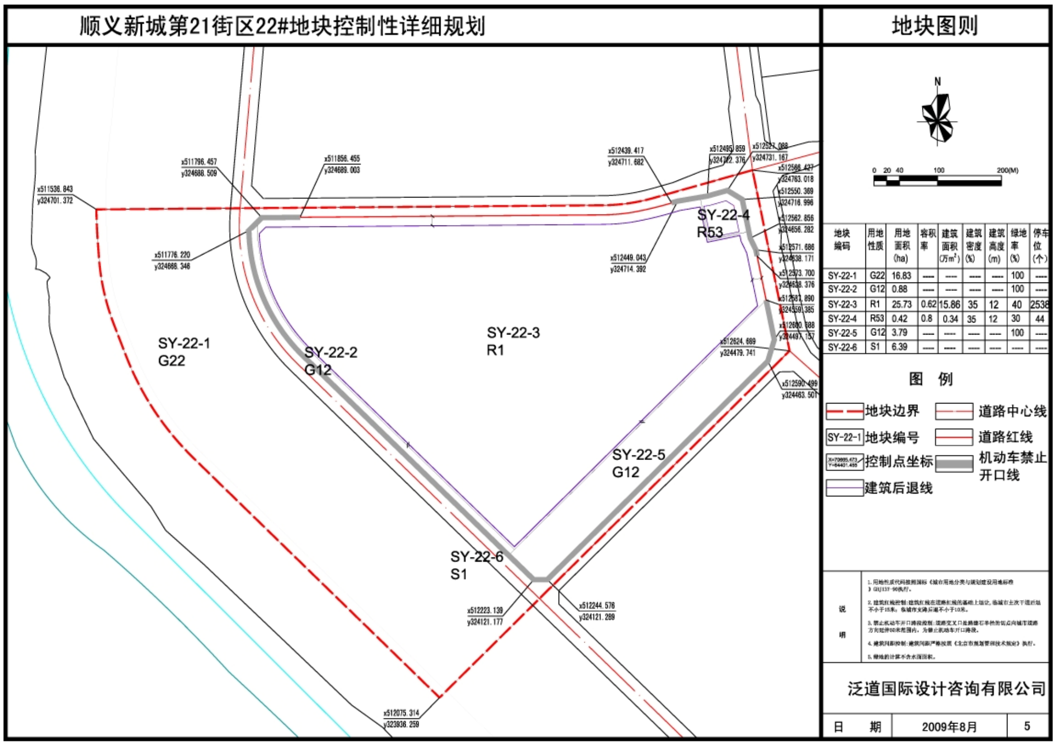
Overview of the CBD in *Chaoyang* District from *Ritan* Park.
Source: http://www.danwei.org/architecture/beijing_new_skyline.php

Figure 2-9 Beijing's Skyline

2.4 Urban Planning

Planning regulations affect urban spatial structure since land development is often subject to certain requirements and limitations. Like many other cities in Western countries, urban planning affects urban spatial structure by regulating the types (residential, commercial, industrial, education, sport, public facilities, municipal utilities, road, green space, etc.) and intensity (density and FAR) of land development at given sites. It also specifies setbacks from the roads and developable land in a given lot. By combining the permitted FAR and percentage of developable land, the maximum building height and floor space can be derived.

Figure 2-10 presents an example of a detail plan of one block in the *Shunyi* New City in Beijing. Within the boundary of the block, the attached table on the right side presents the allowable land uses, land area, FAR, floor space, building density, building height, green space ratio, and the numbers of parking lots for each land plot. Land development should strictly follow these requirements in order to obtain required construction permits from the Department of Construction (or Planning).



Source: *Shunyi* Planning Office. http://www.guihua.bjshy.gov.cn/content.aspx?id=410

Figure 2-10 Detail Plan for Block 21, Plot 22, *Shunyi* District, Beijing

It should be noted that it is not unusual for developers to break these mandated requirements such as the building height caps and FAR controls to increase their profits. There are many reports that document developers' violation of zoning requirements. However, due to lack of systematic records the total impact of the violations is hardly ever gauged.

Planning regulations on land use could be beneficial if they serve to correct market failures; however, they may hinder the formation of an efficient urban spatial structure. Under the market forces, developers optimize the combination of input factors as well as the output level based according to market rules. With strict regulations on land development intensity, such as building height and FAR controls, urban plans may act as constraints on housing services production, particularly on the substitution of capital and land. For example, suppose a 20-floor residential building is the best choice for the developer on a land lot given the technology of construction, land and capital prices, and other factors, but constructing a 20-floor building violates planning regulations and the developer has to reduce it by five floors. In this case, not only is the final housing output affected, but also the capital-land substitution is constrained and so the efficiency of resource utilization is harmed given that land and capital are not used in the most efficient way. Looking at the larger picture, citywide land use restrictions might divert urban land development from the economically efficient one and cause welfare loss.

Chapter 3: Literature Review

This chapter reviews the theoretical understanding and empirical evidence of urban spatial structure. It starts with a review of the urban economic theory that reveals the declining phenomena of land and housing prices, and then it reviews the theory of housing services production, which is also important in understanding how urban landscape is shaped. Both theoretical framework and empirical evidence are discussed.

3.1 Urban Spatial Structure and Form

Theoretical understanding of urban spatial structure was formally developed by Alonso (1964), Muth (1969) and Mills (1972). Based on the utility maximization for residents subject to the income constraint, housing price and housing consumption at a given location can be solved at the equilibrium when no one can improve their utility by simple relocation. Treating land as an input factor along with non-land capital in housing services production and taking the spatially variant housing prices given, land development intensity and land price are determined through profit maximization in competitive market. Therefore, urban spatial structure is characterized by declining housing and land prices and land development intensity with respect to distance from the city center (or the CBD).

Following Brueckner (1987), the formal model starts with the utility theory in which residents maximize their utility by making tradeoffs between housing prices and transportation (commuting) costs, both depending on location. The model is structured as follows. The city has a single CBD and residents commute to work. All residents earn identical income y and have the same strictly quasi-concave utility function $v(c,q)$, which depends on housing services consumption q and a numerical non-housing consumption c. Residents located at x kilometers from the CBD have to pay the transportation costs tx. By choosing q, residents maximize their utility subject to income constraint:

$$\max_{q} v(y - pq - tx, q) \tag{1}$$

Locational equilibrium requires the first order condition of (1) and also requires that the maximized utility at all locations are identical, denoted by u. Using these two conditions housing price p and housing services consumption q can be solved as:

$$p = p(x, y, t, u) \tag{2}$$

$$q = q(x, y, t, u) \tag{3}$$

It can be shown that p must decrease with x to balance the increasing transportation costs and q should increase with x as long as housing services are normal goods:

$$\frac{\partial p}{\partial x} < 0 \tag{4}$$

$$\frac{\partial q}{\partial x} > 0 \tag{5}$$

Housing services production requires land input L and non-land capital input K, and the production function is assumed to be concave and constant return, denoted by $H(K, L)$, in which the capital marginal productivity diminishes. Given the technology of constant return, the production function for each unit of land can be written $h(S) \equiv H(S,1)$, where S equals K/L and represents capital density, and $h_S > 0$ and $h_{SS} < 0$.[15] Assuming capital price n is spatially invariant, housing producers maximize their profit per unit of land by choosing *S*:

$$\max_S \pi = ph - nS - r \tag{6}$$

In the competitive market, profit maximization requires the first order condition of (6) and also requires the maximized profit equals zero:

$$ph_S = n \tag{7}$$

$$ph - nS - r = 0 \tag{8}$$

Simultaneously solving (7) and (8) yields equilibrium solutions for land price *r* and capital density *S*:

$$S = S(p, n) \tag{9}$$

$$r = r(p, n) \tag{10}$$

where *p* is already decided in the demand side problem by (2). By noticing that *S* and *r* depend on *x* via *p*, it is derived from (7) and (8) that *S* and *r* both decline with *x*:

$$\frac{\partial S}{\partial x} = -\frac{h_S}{ph_{SS}} \frac{\partial p}{\partial x} < 0 \tag{11}$$

$$\frac{\partial r}{\partial x} = h \frac{\partial p}{\partial x} < 0 \tag{12}$$

And the output of housing services per unit of land *h* also declines with distance *x* because of the declining *S*:

$$\frac{\partial h}{\partial x} = h_S \frac{\partial S}{\partial x} < 0 \tag{13}$$

[15] These conditions imply that elasticity of capital-land substitution is larger than zero.

Measuring housing services in terms of floor space, (13) suggests that the FAR decreases with *x*.

Defining λ as the ratio of distance elasticity of land prices to the distance elasticity of housing prices and using (8) and (12), it yields:

$$\lambda = \frac{\frac{\partial r}{\partial x} \Big/ \frac{r}{x}}{\frac{\partial p}{\partial x} \Big/ \frac{p}{x}} = \frac{h\frac{\partial p}{\partial x} \Big/ \frac{r}{x}}{\frac{\partial p}{\partial x} \Big/ \frac{p}{x}} = \frac{ph}{r} = \frac{nS + r}{r} = 1 + \frac{nS}{r} > 1 \tag{14}$$

This provides the theoretical relationship that will be tested in the first research question of this dissertation. Inequality (14) indicates that land prices are more elastic with respect to distance from the CBD than housing prices, or put differently, land prices decline faster than housing prices.

Indeed, an alternative interpretation of λ is as the housing price elasticity of land price:

$$\lambda = \frac{\frac{\partial r}{\partial x} \Big/ \frac{r}{x}}{\frac{\partial p}{\partial x} \Big/ \frac{p}{x}} = \frac{\frac{\partial r}{\partial p}\frac{\partial p}{\partial x} \Big/ \frac{r}{x}}{\frac{\partial p}{\partial x} \Big/ \frac{p}{x}} = \frac{\partial r}{\partial p} \Big/ \frac{r}{p} \tag{15}$$

This suggests that the land price is elastic to housing price since a 1% change in housing price leads to a more than 1% change in land price.

These theoretical advances in understanding urban spatial structure and form, particularly the predictions of declining land and housing prices toward the city fringe, have been supported by numerous empirical studies throughout developed and developing countries.[16] Coulson (1991) employed data from State College, a university town in Pennsylvania, which was regarded as an ideal laboratory place to

[16] There are abundant evidences in the literature regarding the pattern of declining population density (such as Mills 1972 and Macauley 1985), which is also derived from the urban economic theory.

test the monocentric model for the city well satisfied the assumptions of the model. His estimated results reported significant and negative distance gradients of house rent, and more importantly, the price fell with distance from the CBD at a rate approximately equal to the increase in transportation costs, while holding all other attributes constant. McMillen (2002 & 2003) estimated the distance gradient of housing prices in Chicago using three different approaches (hedonic, repeat sale, and Fourier expansion) and the findings indicated significantly negative gradients and a strong return of centralization to the Chicago housing market. Mok et al. (1995) estimated Hong Kong's sale prices of apartments using a hedonic approach and also found significant effect of distance. Alberson (1997) examined the value of land and houses in Sydney, Australia, and found that both prices declined exponentially with distance from the CBD during 1931-1968 and the curves were flattened, until 1970, when the curves became steeper again. Atack and Margo (1998) examined vacant land prices in New York City between 1835 and 1900 and found that land price per square footage declined significantly with distance from the CBD.

There is also strong evidence for declining housing and land prices in developing countries. Dowall (1992) investigated the land market in Bangkok, Thailand, and found negative slopes of land prices with respect to distance from the CBD. Lewis (2007) examined the land market in Jakarta, Indonesia, using market price and the findings also suggested negative linkages between distance and land value, and the land price curve was flattened over time. In transitional countries such as Russian and Poland, the emerging market forces had reversed the urban spatial structure that was previously shaped by political reasons, and the negative-sloped distance gradients began forming (Bertaud & Renaud 1997, Dale-Johnson et al. 2005). Studies in China suggested similar findings, particularly given the rapid market development since the late 1970s. Ding (2004)'s empirical estimations suggested Beijing's urban form had been greatly modified by market forces: land prices declining from the city center at different speeds depending on land use types.

It should be recognized that the literature reports a few studies showing either positive or insignificantly negative distance gradients of housing and land prices, though empirical studies that support the declining housing and land prices are overwhelming (Heikkial et al. 1989, Yiu & Tam 2004). Several reasons could account for this trend. First, the data used to estimate distance gradients did not all conform to the monocentric assumption. The trend of suburbanization and development of sub-centers, particularly after World War II, made the spatial pattern of cities more complicated. It is possible that each sub-center has its own distinctive submarket and its own distance gradients of housing and land prices, fitting well with the monocentric model, but negative distance gradients may not be found for the metropolitan area as a whole (Coulson 1991, Dubin & Sung 1987). Second, it is speculated that neighborhood effects could cause positive distance gradients in empirical studies (Richardson 1977). If the omitted neighborhood variables are positively correlated with distance, empirical tests will produce a positive distance gradient due to specification error. This may happen since neighborhood quality can hardly be fully captured due to data limitations. Finally, as one moves toward the CBD, if the overall effect of the increasing urban negative externalities (such as pollution, traffic congestions and noise) cannot be completely offset by the savings in transportation costs, positive distance gradients of land and housing prices are likely to be obtained (Richardson 1977). In this case, the urban economic model should be extended to include the amenity argument, as Brueckner et al. (1999) showed in their research, household location patterns would be affected by whether there were strong presence of positive amenities in the city core and how strongly people preferred these amenities.

To sum up, despite a great number of studies testing the negative distance gradients of housing and land prices, no study has examined the relationship between the distance gradients of housing prices and land prices, probably due to lack of data. By utilizing both housing and land prices from the same sites, this dissertation will contribute to the literature by empirically estimating and testing the relationship between the two declining prices.

3.2 Housing Services Production

Besides the urban economic theory, the other important aspect with regards to the formation and evolution of urban spatial structure is housing services production (Muth 1964, Mills 1972, Koenker 1972, Sirman & Redman 1979, McDonald 1981). According to the theory of housing services production, land is an imperative input to produce housing services and land development intensity is largely determined by the relative prices of land and capital, based on the assumption that land and capital can substitute for each other to a certain degree to produce a certain level of housing services. Therefore, housing services production plays an important role in shaping the city's capital density profile and the general urban landscape.

The theory of housing services production has two important implications. One is that the demand for land is viewed as a derived demand since people demand land for the purpose of producing housing services, and the other is related to the notion of capital-land substitution, which is a key element in forming urban spatial structure. As McDonald (1981) stated, the elasticity of capital-land substitution (σ) is "a determinant of the land rent gradient, the population density gradient, the factor share of land and housing capital and the elasticity of supply of housing both in the aggregate and on a particular site" (p. 190).

The theory of housing services production is supported by numerous empirical studies that estimated σ. Muth (1964) provided the first empirical estimation using Federal Housing Administration (FHA) data of forty-seven cities in the United States and his estimates were around 0.5. After Muth's seminal work, a substantial amount of studies followed, summarized in table 3-1. There is clearly no consensus on the value of σ. Most of the estimates ranged from 0.3 to 0.8 and were significantly smaller than unity. Only the estimates for Chicago (McDonald 1979, Clapp 1979) and for the Oregon part of Portland Metropolitan area (Thorsnes 1997) are exceptional, reporting close to or larger than unity σ. The majority of the studies employed the CES production function, while several studies employed the variable elasticity of substitution (VES) production function.[17] Comparatively, fewer studies were conducted in developing countries and often reported lower estimates of σ. The only empirical study on capital-land substitution in China, to the author's knowledge, was

[17] While the CES assumes a uniform σ in housing production but does not restrict a priori to any specific value, the VES relaxes this assumption and allows σ changing with the combination of input factors. Nevertheless, there is no theory suggesting that VES is superior to CES; it is rather an empirical question of which one is better.

conducted by Ding (2004). By using data from Beijing, Ding (2004)'s estimates of σ fell between 0.3-0.4 during 1993-1995 and jumped to over 0.45 in 1996 and steadily rose since then. Ding (2004) also showed that σ varied across land use types.

Table 3-1 Empirical Estimation of Elasticity of Capital-land Substitution for Housing Production*

Studies	Estimates**	Cities/Regions	Data Collected	Sig. less than one
Muth (1964 & 1971)	0.5-0.75 (CES)	47 metropolitan areas, United States	1966	Yes
Koenker (1972)	0.71 (CES)	Ann Arbor, United States	1964-1966	Yes
Rydell (1976)	0.50 (CES)	Brown County, United States	1974	Yes
Fountain (1977)	0.57	Los Angeles, United States	1972-1974	Yes
Clapp (1979)	0.98 (CES)	Chicago, United States	1970-1972	No
Rosen (1978)	0.43 (CES)	Single-family houses from 31 metropolitan areas, United States	1969	Yes
Arnott and Lewis (1979)	0.36 (CES)	23 Metropolitan areas, Canada	1975-1976	Yes
McDonald (1979)	1.13, 0.86 (CES, IV)	Chicago, United States	1969-1971, 1970-1972	No
Polinsky and Ellwood (1979)	0.45 (CES)	Single-family houses from 31 metropolitan area, United States	1969	Yes
Sirmans et al (1979)	0.93-0.66 (VES)	Santa Clara County, United States	1960	Yes
Sirmans and Redman (1979)	0.52,0.55,0.46 (CES)	52 metropolitan areas, United States	1967, 1971, 1975	Yes
	0.55, 0.52, 0.45 (VES)			
Asabere et al (1982)	0.53 (CES)	Accra, Ghana		Yes
Kau and Sirmans (1983)	0.227, 0.889, 0.455, 0.539 (VES)	Dallas, Dayton, Louisville, and Stockton, United States	1966-1978	Yes
Jackson et al (1984)	0.499	Knoxville, United States	1970	Yes
Dowall and Treffeisen (1991)	0.69 (CES)	Bogotá, Colombia	1984-1989	Yes
Ding (2004)	0.32-0.74 (CES)	Beijing, China	1993-2000	Yes
Thorsnes (1997)	0.88 (CES), 0.81 (VES), 0.96 (CES, IV), 1.08 (VES, IV)	Oregon part of Portland Metro, United States	1985-1989	No
Erol and Güzel (2006)	0.078 (CES), 0.118 (VES)	Ankara, Turkey	2000	Yes

* The table is an updated version based on McDonald (1981)'s review
** VES estimates are reported mean value

In theory, σ is affected by two different factors. One is technological change of construction and the other is planning regulations (such as zoning ordinance) that may impose restrictions on capital investment on a given land lot. The impacts of planning regulations depend on how rigorously they are implemented and to what extent the market forces can alter planning regulations. Empirically, there are also many studies providing evidence for the changes in σ (Simans & Redman 1979, Kau & Sirmans 1983, Jackson et al. 1984, Ding 2004, Erol & Güzel 2006).

The importance of capital-land substitution in influencing urban spatial structure is well recognized (Muth 1964 & 1971, McDonald 1981, Kau & Lee 1976); in contrast, its explicit impacts on urban spatial structure have not been adequately examined. Kau and Lee (1976) derived the impacts of σ on the prices of housing services, the supply of housing services, and the demand for housing services. However, their conclusions are undetermined and depend on extra assumptions. For example, they concluded that land rent is negatively related to σ relying on the assumptions that the base year capital land ratio is unity and capital is expanding faster than land.[18]

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[18] Kau and Lee (1976) derived $R(u)=\frac{\alpha}{1-\alpha}[\frac{K(u)}{L(u)}]^{1+\rho}r$ from the market equilibrium conditions, and further derived the partial of $R(u)$ with respect to ρ : $\frac{\partial R(u)}{\partial \rho}=r\frac{\alpha}{1-\alpha}[\frac{K(u)}{L(u)}]^{1+\rho}\log(\frac{K(u)}{L(u)})$, where $R(u)$ is the land rent at distance u , ρ is the substitution parameter and $\sigma=\frac{1}{1+\rho}$, K and L are capital and land input, r is the capital price. By assuming $\frac{K}{L}=1$ for the base year, the sign of $\frac{\partial R(u)}{\partial \rho}$ is decided by whether land is growing faster than capital. Besides the extra assumption of the initial capital-land ratio and the fast expanding speed of capital, another problem of their derivation is that it does not account for the impact of changes in

This dissertation will extend the understanding of impacts of housing services production on urban spatial structure by explicitly modeling housing services production function and analyzing impacts of σ. The investigation on the impacts of housing services production in general and the impacts of capital-land substitution in particular on urban spatial structure constitutes the major contribution of this dissertation to the literature. I will examine the impacts by theoretical analysis, numerical simulation, and empirical estimation.

ρ on the ratio of $\frac{K(u)}{L(u)}$. In fact, if ρ changes, producer's decision on inputs combination would also adjust and further should affect the equilibrium land price $R(u)$.

Chapter 4: Housing Services Production and Urban Spatial Structure

This chapter examines the linkage between housing services production and urban spatial structure. More specifically, it analyzes the impacts of capital-land substitution. Based on a CES production function for housing services, I derive the directions of the changes of urban spatial structure measured by the distance gradients of land prices and capital densities, the housing output per unit of land, and the degree that land prices decline faster with respect to distance from the CBD than housing prices, brought by a change in capital-land substitution.

4.1 The CES Production Function for Housing Services

It is assumed that housing services are provided by a CES production function in which land and capital constitute the two inputs.[19] It is specified as:

$$H(K,L) = \gamma[\delta K^{-\rho} + (1-\delta)L^{-\rho}]^{-\frac{1}{\rho}} \tag{16}$$

where H is the output of housing services; K is the non-land capital input; L is the land input, γ is the scale parameter called the neutral technological parameter and is positive; δ is the non-neutral distribution parameter, reflecting the intensiveness of capital use in production and should be positive and smaller than unity. ρ is the

[19] The CES production function was introduced by Solow (1956) and formally developed by Arrow et al. (1961).

substitution parameter, ranging from -1 to infinity. The elasticity of capital-land substitution σ is given by:

$$\sigma = \frac{1}{1+\rho} \tag{17}$$

The CES production function describes a production technology that has a constant return to scale and constant elasticity of substitution between land and capital.[20] In addition, it is demonstrated that the CES production function also has a property of positive effect of capital-land substitution on housing output and this can be written: [21]

$$H_\sigma > 0 \text{ (or } H_\rho < 0 \text{)} \tag{18}$$

Let $h = H / L$, and $S = K / L$, (16) yields the CES function for housing output per unit of land:

$$h(S) = \gamma[\delta S^{-\rho} + (1-\delta)]^{-\frac{1}{\rho}} \tag{19}$$

Accordingly, the following relationship holds:[22]

[20] The CES function includes the Cobb-Douglas function, Leontief production function (perfect complements), and linear production function (perfect substitutes) as special cases. When $\sigma \to 0$ (or $\rho \to \infty$), $H(K,L) = \gamma \min\{K, L\}$, it becomes the Leontief production function, which assumes no substitution between the two input factors and the isoquants are right-angle shaped; when $\sigma \to 1$ (or $\rho \to 0$), $H(K,L) = \gamma K^\delta L^{1-\delta}$, it becomes the Cobb-Douglass production function; and when $\sigma \to \infty$ $(\rho \to -1)$, $H(K,L) = \gamma[\delta K + (1-\delta)L]$, it implies that the extent of substitution is infinite and the isoquants become straight lines.

[21] Brown (1967, 57) had shown that all relevant limits are positive and tentatively concluded that a rise in σ raises the output rate by deriving all , but his proof does not assure that $H_\rho < 0$ for all values of variables and other parameters. This potential problem will be addressed by simulation analysis in next chapter.

[22] In this dissertation, I use h_σ to denote the partial derivative of *h* with respect to σ derived directly from the CES function for housing production (for a given set of input factors of production), and I use

$$h_\sigma > 0 \text{ (or } h_\rho < 0 \text{)} \tag{20}$$

In theory, the value of σ can range from zero to infinity in the CES production function, but for housing services production, σ should be positive and no larger than unity. This is because of the following reasons. First, given the observed capital-land substitution in housing construction, σ should not be zero but larger than zero; in other words, the Leontief function does not fit. Second, σ should not be larger than unity, as shown in (19), when $\sigma > 1$ (or $-1 < \rho < 0$), as $S \to \infty$, $h \to \infty$, and as $S \to 0$, $h \to \gamma(1-\delta)^{-\frac{1}{\rho}}$. This implies that on a given land lot of fixed size, the output of housing services will become indefinitely large as capital input keeps increasing, and when the capital input approaches zero, the output will still reach a positive lower limit. This is certainly not the case for housing services production. In reality, due to technological constraints, it is impossible to produce indefinitely large housing output on a given piece of land. Also, it is unrealistic to produce housing structure only by land input without any capital input.

On the contrary, when $\sigma < 1$, using the CES production function to describe housing services production makes sense, as shown in (19), when $\sigma < 1$ (or $\rho > 0$), as $S \to \infty$, $h \to \gamma(1-\delta)^{-\frac{1}{\rho}}$, and as $S \to 0$, $h \to 0$ (Arrow et al. 1961). This implies that when a large amount of capital is invested on a fixed piece of land, the output of housing services will reach an upper limit, and when no capital is invested, no

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$\frac{\partial h}{\partial \sigma}$ to denote the partial derivative of h with respect to σ derived from the equilibrium solution of h (after input factors adjust to σ); in fact $\frac{\partial h}{\partial \sigma} = h_S \frac{\partial S}{\partial \sigma} + h_\sigma$.

housing structure will be produced. This is intuitively true given the fact that one can neither build indefinitely tall buildings nor build houses without capital but only with land.

Brown (1967) provided an insightful interpretation of these behaviors of the CES production function from a technological point of view. According to Brown, $\sigma > 1$ indicates a technology that treats the input factors as resembling each other. When holding one input constant and increasing the other one indefinitely, the technology allows the expanding factor to easily substitute for the constant factor, and so that both factors seem to be increasing indefinitely and the output increases also indefinitely. On the other side, $\sigma < 1$ indicates a technology that views the factors as dissimilar to each other and difficult to substitute one for another, and so the output reaches an upper limit even though one input expands indefinitely. In housing services production, capital and land are dissimilar since houses are build on land with capital, and the output of housing services is to a certain degree constrained by land.

The argument of $0 < \sigma < 1$ in housing services production is also supported by empirical evidence (see chapter 3). Therefore, this dissertation examines the impacts of σ only when $0 < \sigma < 1$ is in the simulation analysis and tests the estimates of σ in the empirical analysis.

4.2 Impacts of Elasticity of Capital-Land Substitution

This section examines analytically the impacts of σ on urban spatial structure under the competitive market in the open city case.[23]

First of all, I obtain the explicit solutions for S, r, h, and λ at the market equilibrium. Substituting the housing production function per unit of land by (19) for (6) and solving the profit maximization problem by using the two conditions (7) and (8) yield land price r and capital density S as:

$$S = [\frac{(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta}{1-\delta}]^{\frac{\sigma}{1-\sigma}} \tag{21}$$

$$r = p\gamma[(\delta[\frac{(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta}{1-\delta}]^{-1} + (1-\delta)]^{-\frac{\sigma}{1-\sigma}} - n[\frac{(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta}{1-\delta}]^{\frac{\sigma}{1-\sigma}} \tag{22}$$

where p is the housing price already decided in the housing demand side question, and n is the spatially invariant capital price.

Replacing S in (19) by (21), the housing output per unit of land h at equilibrium is known:

$$h = \gamma\left[\frac{1-\delta}{1-\delta(\frac{n}{p\gamma\delta})^{1-\sigma}}\right]^{-\frac{\sigma}{1-\sigma}} \tag{23}$$

Replacing S and r in (14) by (21) and (22), λ can be solved:

[23] The author would like to argue that the open city case (which assumes free migration) approximates better the reality compared with the closed city case (which assumes no migration at all), since modern cities are hardly closed given the advances in transportation and communication. In particular, China is currently experiencing fast urbanization and witnessing mass migration among cities and from rural to urban areas. It is estimated that there are 150-200 million internal migrants in China (Ding and Zhao, forthcoming). Therefore, this dissertation focuses on the impacts of σ in the open city case.

$$\lambda = 1 + \frac{1}{\frac{p\gamma}{n}(\frac{p\gamma\delta}{n})^{\frac{1}{\sigma}} - 1} \tag{24}$$

More generally, using the relationship between σ and ρ by (17), (21)-(24) can be rewritten as:

$$S = S(p, n, \gamma, \delta, \sigma) \tag{25}$$

$$r = r(p, n, \gamma, \delta, \sigma) \tag{26}$$

$$h = h(S(p, n, \gamma, \delta, \sigma), \gamma, \delta, \sigma) \tag{27}$$

$$\lambda = \lambda(S(p, n, \gamma, \delta, \sigma), r(p, n, \gamma, \delta, \sigma), n) \tag{28}$$

In the open city case, which assumes exogenous utility level *u*, the housing price *p* and housing consumption *q* are not affected by changes in σ (or ρ). But equations (25)-(28) reveal that a change in σ will affect capital density, land price, the housing output per unit of land, and the ratio of the two distance elasticities.[24]

Following the approach of total differentiation used by Brueckner (1987), I derive the directions of impacts of σ on *r*, *S*, and *h* in a way that does not require using the complicated solutions by (21), (22), and (23).

Replacing *h* in (8) with (19) and totally differentiating (8) with respect to σ yields:

$$p[h_S \frac{\partial S}{\partial \sigma} + h_\sigma] - n\frac{\partial S}{\partial \sigma} - \frac{\partial r}{\partial \sigma} = 0 \tag{29}$$

[24] It should be noted that there are differences between ρ and σ. As a production parameter, ρ describes a production technology together with other parameters and the specified function form, and thus ρ will only change if technology changes. σ is defined as the proportional change of input factors to the proportional change of relative prices of input factors, reflecting the substitutability between input factors. Therefore, besides technology improvement, policies and regulations on land use could also affect the value of σ. Despite these differences, analytical analysis in this dissertation examines the impacts of σ by employing the relationship of $\sigma = \frac{1}{1+\rho}$ by (17).

As observed in (29), σ affects h both as a parameter of the production function (h_σ) and by affecting S ($h_S \frac{\partial S}{\partial \sigma}$). Since $ph_S - n = 0$ by (7), (29) yields:

$$\frac{\partial r}{\partial \sigma} = ph_\sigma > 0 \tag{30}$$

Inequality (30) holds because $h_\sigma > 0$ by (20) and it implies that an increase in σ leads to increase in r at each location.

Due to capital-land substitution in housing services production, developers tend to use more capital to substitute for land when land becomes more expensive. So, an increase in land price leads to an increase in capital density. This indicates a positive relationship between σ and S, formally expressed as:

$$\frac{\partial S}{\partial \sigma} = \kappa \frac{\partial r}{\partial \sigma} > 0 \tag{31}$$

where κ represents the impact of change in land price on capital input, a substitution effect between capital and land. In fact, $\kappa = (\partial MRTS/\partial S\,|_{\pi=0}^{-1})\frac{1}{n}$, where $MRTS$ is the marginal rate of technology substitution, and $MRTS \equiv \frac{H_L}{H_K}$.[25] Since it is assumed that $h_S > 0$ and $h_{SS} < 0$, and $MRTS \equiv \frac{H_L}{H_K} = \frac{h - Sh_S}{h_{SS}}$, it is easy to have $\partial MRTS/\partial S > 0$. Thus κ is intrinsically a positive number.

Replacing h in (12) with (19) and totally differentiating (12) with respect to σ yields:

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[25] $\kappa = (\partial MRTS/\partial S\,|_{\pi=0}^{-1})\frac{1}{n} = [\frac{\partial(h/h_S)}{\partial S} - 1]\,|_{\pi=0}^{-1} \frac{1}{n} = \frac{1}{n}\frac{\delta}{1+\delta}\frac{1}{1+\rho}S^{-\rho}\,|_{\pi=0} > 0$

$$\frac{\partial^2 r}{\partial x \partial \sigma} = \frac{\partial h}{\partial \sigma}\frac{\partial p}{\partial x} = (h_S \frac{\partial S}{\partial \sigma} + h_\sigma)\frac{\partial p}{\partial x} < 0 \tag{32}$$

Inequality (32) holds because $\frac{\partial p}{\partial x} < 0$ by (4), $h_S > 0$ as assumed property of the production function, $\frac{\partial S}{\partial \sigma} > 0$ by (31), and $h_\sigma > 0$ by (20). Inequality (32) indicates that an increase in σ leads to a steeper land price curve. It is also shown that σ affects the distance gradient of land prices by affecting the housing output per unit of land ($\frac{\partial h}{\partial \sigma}$).

For the impact of σ on distance gradient of capital density, totally differentiating (31) with respect to *x* yields:

$$\frac{\partial^2 S}{\partial x \partial \sigma} = \kappa \frac{\partial^2 r}{\partial x \partial \sigma} < 0 \tag{33}$$

Inequality (33) indicates that an increase in σ also leads to a steeper capital density curve.

As mentioned above, the impact of σ on *h* is composed of two parts, since σ affects *h* as a parameter in producing housing services and by affecting *S*:

$$\frac{\partial h}{\partial \sigma} = h_S \frac{\partial S}{\partial \sigma} + h_\sigma > 0 \tag{34}$$

Inequality (34) holds because $h_S > 0$ as assumed property of the housing production function, $\frac{\partial S}{\partial \sigma} > 0$ by (31), and $h_\sigma > 0$ by (30). Inequality (34) indicates that as σ increases, the housing output per unit of land increases at any location within the urban area.

Intuitively, since σ positively affects land prices and the distance gradient of land prices but does not affect housing prices in the open city case, an increase in σ leads to steeper land price curve and thus positively affects λ, the degree that land prices are more elastic with respect to distance from the CBD than housing prices. Here is the proof. In the solution of λ by (24), if $\frac{p\gamma\delta}{n} > 1$, it is easy to have:[26]

$$\frac{\partial\lambda}{\partial\sigma} > 0 \tag{35}$$

In the open city case, the capital-land substitution also affects the city size in terms of territory (denoted by $\bar{x}$ as the city boundary) and population (denoted by *N*). Following Brueckner (1987), the spatial equilibrium of the urban space requires two conditions. One is that at the city boundary $\bar{x}$, the urban land price equals to agricultural land price r_a; and the other is that all of the residents *N* fit exactly into the urban boundary with their housing demand met by housing provision. By specifying the housing production function in the CES form, these two conditions are written as follows:

$$r(p(\bar{x}, y, t, u), n, \gamma, \delta, \sigma) = r_a \tag{36}$$

$$\int_0^{\bar{x}} \frac{h(S(p(x, y, t, u), n, \gamma, \delta, \sigma), \gamma, \delta, \sigma)}{q(x, y, t, u)} \theta x dx = N \tag{37}$$

where $D(x, y, t, u, n, \gamma, \delta, \sigma) = \frac{h(S(p(x, y, t, u), n, \gamma, \delta, \sigma), \gamma, \delta, \sigma)}{q(x, y, t, u)}$ is the population density, θ is a constant parameter of radius of land that are available for housing services production.

---

[26] Since usually p>>n, so $\frac{p\gamma\delta}{n} > 1$ is easy to hold.

The utility level u and agricultural land price r_a are exogenously determined. Assuming all other parameters are constant (including y, t, u, n, γ, δ), keeping only the interested variables and parameters, (36) and (37) can be simplified as:

$$r(\bar{x}, \sigma) = r_a \tag{38}$$

$$\int_0^{\bar{x}} \frac{h(S(x,\sigma),\sigma)}{q(x)} \theta x dx = N \tag{39}$$

Recursively solving (38) and (39) yields the solutions for $\bar{x}$ and N, respectively. To investigate the impact of σ on $\bar{x}$, totally differentiating (38) with respect to σ yields:

$$\frac{\partial r}{\partial \bar{x}} \frac{\partial \bar{x}}{\partial \sigma} + \frac{\partial r}{\partial \sigma} = 0 \tag{40}$$

Given that $\frac{\partial r}{\partial \sigma} > 0$ by (30) and $\frac{\partial r}{\partial x} < 0$ by (12), and $\bar{x}$ is only affected by σ in (38) as all other parameters are constant, so it can be inferred from (40) that:

$$\frac{d\bar{x}}{d\sigma} > 0 \tag{41}$$

Totally differentiating (39) with respect to σ yields:

$$\frac{h(S(x,\sigma),\sigma)}{q(x)} \theta x \frac{\partial \bar{x}}{\partial \sigma} + \int_0^{\bar{x}} \frac{\theta x}{q(x)} (h_S \frac{\partial S}{\partial \sigma} + h_\sigma) dx = \frac{dN}{d\sigma} \tag{42}$$

Given that $\frac{\partial \bar{x}}{\partial \sigma} > 0$ by (41), $h_S > 0$ as assumed property of housing production function, $\frac{\partial S}{\partial \sigma} > 0$ by (31) and $h_\sigma > 0$ by (20), it can be inferred from (42) that:

$$\frac{dN}{d\sigma} > 0 \tag{43}$$

Therefore, inequalities (41) and (43) indicate that an increase in σ leads to increases in both the city's geographical size $\bar{x}$ and its population *N*.

To sum up, under the competitive market in the open city case, the elasticity of capital-land substitution does not affect housing price and housing consumption, but positively affects the land price ($\frac{\partial r}{\partial \sigma} > 0$) and capital density ($\frac{\partial S}{\partial \sigma} > 0$) at any location within the urban area, negatively affects distance gradients of land prices and capital densities ($\frac{\partial^2 r}{\partial x \partial \sigma} < 0$ and $\frac{\partial^2 S}{\partial x \partial \sigma} < 0$), positively affects the housing output per unit of land ($\frac{\partial h}{\partial \sigma} > 0$), positively affects the ratio of the two distance elasticities ($\frac{\partial \lambda}{\partial \sigma} > 0$), and positively affects the city's geographical size and population size ($\frac{d\bar{x}}{d\sigma} > 0$ and $\frac{dN}{d\sigma} > 0$).

These impacts of a change in the elasticity of capital-land substitution can be intuitively interpreted as follows. As σ increases, it eases substitution between land and capital and raises housing output at each location. Increases in output in turn raise the residual land prices under the competitive market. Moreover, since housing prices (output prices) decline with distance from the CBD, increases in the residual land prices are higher at locations closer to the CBD as compared with in suburbs, and so the land price curve becomes steeper. Further, as land becomes more expensive, capital investment rises to substitute for land, and relatively more capital is invested at central locations where land prices increase more, and so the capital density curve also rises and becomes steeper. The gaps between the declining housing and land prices also increase, for the land price curve becomes steeper with the housing price curve held unchanged. The urban boundary expands, as a consequence of the higher urban land price curve, and the population increases (migrant from other cities or rural areas) to fill in the surplus of housing output so as to maintain the utility level.

Chapter 5: Numerical Simulation

The purpose of numerical simulations is twofold. First, it verifies the predicted impacts of housing services production on urban spatial structure, particularly the derived impacts of capital-land substitution. Second, it examines the magnitudes of these impacts by a series of estimations and simulations. I estimate the housing production function (elasticity of capital-land substitution and other production parameters), spatial distributions of housing prices, land prices, capital densities, and the housing output per unit of land, and then I calculate the marginal impacts of capital-land substitution. The estimated impacts of a 1% change of the elasticity of capital-land substitution include effects on land prices, capital densities, the housing output per unit of land (or the FARs), the ratio of the two distance elasticities , the share of land cost in total property value, and the welfare implications in terms of aggregated values of land and housing output.

5.1 Impacts of Capital-Land Substitution

The impacts of σ on land price, capital density, housing output per unit of land (or the FAR), and the ratio of the two distance elasticities, implied by the partial derivatives of $\frac{\partial r}{\partial \sigma}$, $\frac{\partial S}{\partial \sigma}$, $\frac{\partial h}{\partial \sigma}$, and $\frac{\partial \lambda}{\partial \sigma}$, respectively, can be solved as explicit functions of $p, n, \gamma, \delta,$ *and* σ directly from the equilibrium solutions of *S*, *r*, *h*, and λ by (21), (22), (23), and (24) .

The impacts of σ on distance gradients of land prices and capital densities ($\frac{\partial^2 r}{\partial x \partial \sigma}$ and $\frac{\partial^2 S}{\partial x \partial \sigma}$) are examined by verifying signs of $\frac{\partial^2 r}{\partial p \partial \sigma} < 0$ and $\frac{\partial^2 S}{\partial p \partial \sigma} < 0$. This is based on the fact that *r* and *S* are linked to distance only through *p* by (11) and (12), and $\frac{\partial^2 r}{\partial x \partial \sigma}$ and $\frac{\partial^2 S}{\partial x \partial \sigma}$ can be written as:

$$\frac{\partial^2 r}{\partial x \partial \sigma} = \frac{\partial^2 r}{\partial p \partial \sigma} \times \frac{\partial p}{\partial x} < 0 \tag{44}$$

$$\frac{\partial^2 S}{\partial x \partial \sigma} = \frac{\partial^2 S}{\partial p \partial \sigma} \times \frac{\partial p}{\partial x} < 0 \tag{45}$$

The solutions for $\frac{\partial S}{\partial \sigma}$, $\frac{\partial r}{\partial \sigma}$, $\frac{\partial^2 S}{\partial p \partial \sigma}$, $\frac{\partial^2 r}{\partial p \partial \sigma}$, $\frac{\partial h}{\partial \sigma}$ and $\frac{\partial \lambda}{\partial \sigma}$ are very complicated (see Appendix I) and Mathematica is used to determine their signs with different combinations of parameters of $p, n, \gamma, \delta, \sigma$.

The value of *p* is chosen to change from 1,000 to 30,000, based on observations of housing prices from the Beijing data, in which the lowest housing price was 2,034 RMB per square meter, the highest was 19,478 RMB per square meter, and the mean was 6,888 RMB per square meter (see table 6-2). Capital price *n* is normalized to unity. Value ranges of the three production parameters γ, δ, σ are determined based on their theoretical values. Since γ is a positive scale parameter, its value should be irrelevant to the impacts of σ, and so the range of γ is taken from 0.1 to 3.0 for convenience without loss of generality. δ is a positive number less than unity in the CES function and so its range is taken from 0.01 to 0.99, and the value range of σ is also taken from 0.01 to 0.99 (correspondingly ρ varies from 0.01 to 99) (see Chapter 4).

There are constraints on values of $p, n, \gamma, \delta, \sigma$ that can be chosen implied in (21) and (22). These constraints ensure that *S* is a positive and *r* is not negative and they are:

$$(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta > 0 \tag{46}$$

$$r = p\gamma[(\delta[\frac{(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta}{1-\delta}]^{-1} + (1-\delta)]^{-\frac{\sigma}{1-\sigma}} - n[\frac{(\frac{n}{p\gamma\delta})^{-(1-\sigma)} - \delta}{1-\delta}]^{\frac{\sigma}{1-\sigma}} \geq 0 \tag{47}$$

Table 5-1 reports the summary of the simulated results. These results are as expected and consistent with what the theory predicts (see Chapter 4).

Table 5-1 Signs of Relevant Partial Derivatives by Simulation

	$\frac{\partial S}{\partial \sigma}$	$\frac{\partial r}{\partial \sigma}$	$\frac{\partial^2 S}{\partial p \partial \sigma}$	$\frac{\partial^2 r}{\partial p \partial \sigma}$	$\frac{\partial \lambda}{\partial \sigma}$	$\frac{\partial h}{\partial \sigma}$
p=1000,2000,3000,…,28000,29000,30000	>0	>0	>0	>0	>0	>0
n=1						
γ=0.1, 0.2,0.3,…,2.9,3.0						
δ=0.01,0.02,0.03,…,0.99						
σ=0.01,0.02,0.03,…,0.99						

A close examination of these simulated results reveals a non-linear relationship between σ and urban spatial structure variables such as *S*, *r*, and λ (Appendix II). For instance, for the chosen ranges of $p, n, \gamma, \delta, \sigma$, these partial derivatives increase exponentially along with σ when p, γ, δ are large. Holding γ, δ and σ unchanged and increasing *p*, impacts of σ on *S* and *r* also increase accordingly, and this is consistent with the positive signs of the secondary partial derivatives ($\frac{\partial^2 S}{\partial p \partial \sigma} > 0$ and $\frac{\partial^2 r}{\partial p \partial \sigma} > 0$). However, holding γ, δ and σ unchanged and increasing *p*, the impact of σ on λ decreases, and this is consistent with the theoretical result that as moving toward the city center λ decreases with *p*.

5.2 *Marginal Effects of Capital-Land Substitution*

The above simulated results reveal that the marginal effects of capital-land substitution on urban spatial structure can be substantial. This section will estimate these marginal effects based on the Beijing data. This is carried out by estimating the housing production function (elasticity of capital-land substitution and other production parameters), spatial distributions of housing prices, land prices, capital densities, and the housing output per unit of land, calculating the marginal impacts of the elasticity of capital-land substitution, and finally determining the welfare implication by estimating aggregated values of land and housing output.

5.2.1 Housing Price Distribution and Production Function

Using data from Beijing (see chapter 6 for detailed data description), housing prices are estimated as an exponential function of distance from the city center—Tiananmen Square.

$$p = \exp(9.234732 - 0.0400622x) \quad (48)$$

(36.94) (-13.00)

R-sq=0.3904, Obs.=266.

where p is the housing price per square meter floor space in RMB and x is the distance from Tiananmen Square in kilometers. Figure 5-1 illustrates this estimated housing price curve as compared to observations from the sample. The estimated housing price is 10,247 RMB per square meter at the city center and drops gradually with distance from the city center.

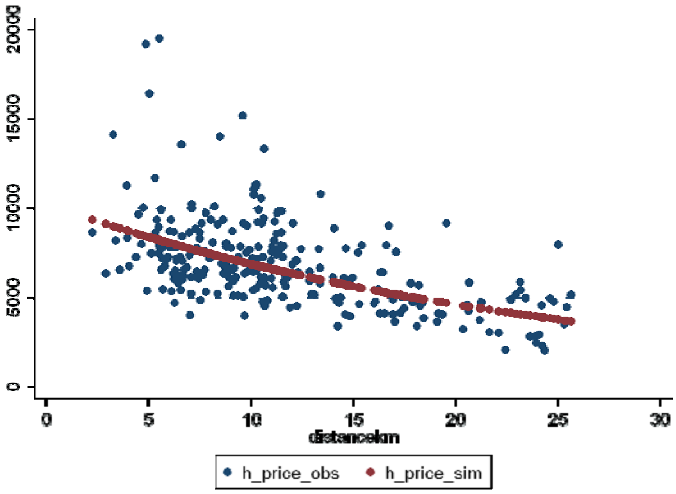

Figure 5-1 Estimated Housing Prices over Urban Space

To determine the CES housing production function, three parameters need to be determined. Among them, σ is the key parameter and is estimated by several approaches. The estimates suggest robust results ranging from 0.37 to 0.65 (see chapter 6 for more details). Based on these estimates, 0.5 is chosen for σ in the baseline scenario. With σ determined, the other two parameters γ and δ are then estimated by multiple approaches as well, and their estimates fall into the interval of 0.000316-0.000953 and 0.99975-0.99996 (see Appendix III for more details). Based on these estimates, γ and δ are taken 0.0005 and 0.99995, respectively, with consideration on the fitness of the simulated land prices and housing output per unit of land to the real observations.[27] It should be noted that land prices and housing output per unit of land generated by this simulation are respectively overestimated and underestimated to certain degrees when compared with real observations (figure 5-2 and figure 5-3). This is due to the gaps between the reality and the theoretical model. Nevertheless, these errors are regarded as acceptable, for this simulation focuses on demonstration of relative changes caused by 1% change in the elasticity of capital-land substitution rather than the absolute changes.

Estimations are carried out under the assumption that there is a 30% marginal profit in land development. This number makes the estimations fit better the data than a zero profit assumption. This assumption makes sense because of two reasons. First, although markets are emerging at a fast rate in China, specifically in Beijing, they are far from the competitive markets. Second, there is evidence suggesting that a substantial level of profits can be made from land development.[28]

[27] Ideally, the simulated land price and housing output per unit of land would both fit the real observations with the estimated housing prices and production parameters, if the analytical model can perfectly explain the reality. However, models are simplifications of the real world and rely on certain assumptions, and the analytical model used in this study is not exceptional. Therefore, simulations based on the analytical model cannot fully fit real data. In this case, many of the model assumptions may be not satisfied in Beijing, such as the competitive market, market equilibrium conditions, zero profit condition, unity capital price, constant return to scale, and market equilibrium. Due to the gaps between the reality and theoretical model, it is hard to find a pair of γ and δ to generate simulated land price and housing output per unit of land that both fit the data well. So the strategy used here is to pick up a pair of γ and δ from the ranges of estimates of these two parameters (see Appendix III) that generate acceptable simulated land price and housing output per unit of land.

[28] The 30% average profit ratio of sales is based on a survey of real estate profit done in China by the Ministry of Finance in 2005, which reported 26.79% profit ratio of sales of 39 real estate developers. Retrieved on July 13, 2010, from
http://finance.sina.com.cn/g/20061108/14573060647.shtml

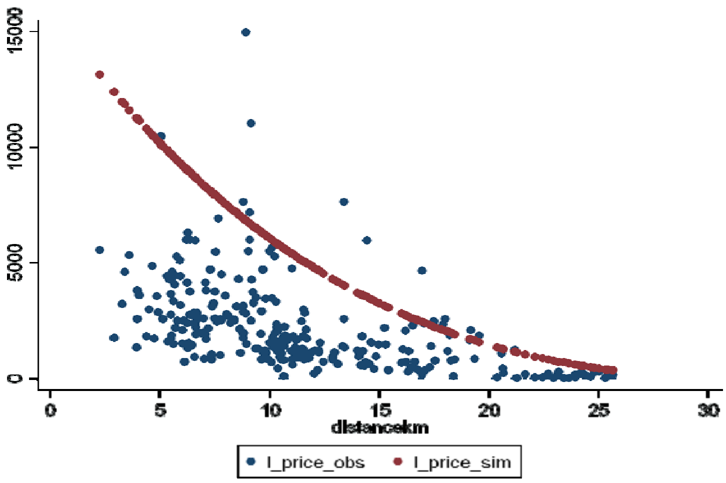

Figure 5-2 Simulated Land Prices over Urban Space

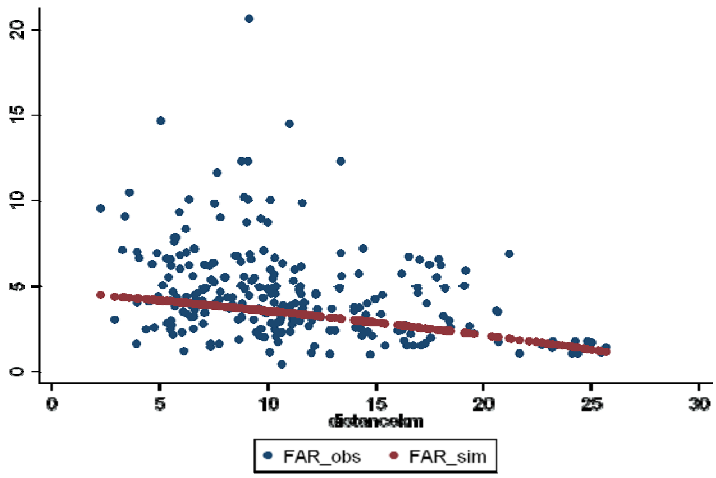

Figure 5-3 Simulated Housing Output per Unit of Land (FAR) over Urban Space

5.2.2 Marginal Impacts of Elasticity of Capital-Land Substitution

The baseline for estimating marginal effects of capital-land substitution is chosen as $\sigma_0 = 0.5$ and marginal effects are calculated by both a 1% increase and a

1% decrease in σ, respectively. That is, there is one baseline scenario and two simulated scenarios ($\sigma_1 = 0.505$ and $\sigma_2 = 0.495$).[29]

Table 5-2 reports simulations of variables of interest in the three scenarios at selected locations. Besides r, S, h, and λ that can be computed directly by (21), (22), (23), and (24), the share of land cost in total property value (includes both land and land improvements), denoted by α_L, and the city's geographical size $\bar{x}$ are also concerned.

In the baseline scenario, r drops from 15,978 RMB in the city center to 150 RMB per square meter at the city boundary $\bar{x}_0$ =27.73, where the urban land price intercepts the agricultural land price of 150 RMB per square meter (figure 5-4).[30] This simulated result of city size is reasonable, given that currently urban development in Beijing is expanding from the fifth ring road to the sixth ring road.[31] S drops from 17,876 RMB per square meter to 989 RMB per square meter and h (or the FAR) decreases from 4.72 to 0.47, from the city center to the urban fringe (figure 5-5 and figure 5-6). Compared with observations in the sample, capital density and the FAR are both underestimated to certain extents in this simulation.

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[29] In reality, it is unlikely that only σ changes with the other two parameters held. For example, advances in technology facilitate capital-land substitution as well as affect the other two production parameters γ and δ. This is why in this simulation analysis, a small change (one percent) in σ is manipulated. The production function will no longer generate reasonable results if σ changes too much.

[30] The agricultural land price is based on estimation of land acquisition projects in 2004 in Beijing provided by the Land & Resource Bureau and related policy documents on the minimum compensation. The land acquisition price was about 1.52 million per hectare (Zhao 2003, Thesis of Master degree).

[31] Beijing has five ring roads: while the second ring road is basically built on the ruins of the old city wall at about 3-5 kilometers from the city center, the other four rings are located respectively about 3-5 kilometers, 6-10 kilometers, 10-15 kilometers, 20-25 kilometers, 30-35 kilometers away from Tiananmen Square (as shown in figures 6-3 and 6-5).

Table 5-2 Simulated Impacts of Elasticity of Capital-land Substitution

	land price *r* (RMB per square meter)					capital density *S* (RMB per square meter)				
	S0	S1	% change	S2	% change	S0	S1	% change	S2	% change
0 km	15978	18946	18.6	13518	-15.4	17876	21486	20.2	14921	-16.5
5 km	10177	12027	18.2	8638	-15.1	14266	17080	19.7	11954	-16.2
10 km	6051	7122	17.7	5157	-14.8	11001	13109	19.2	9260	-15.8
15 km	3237	3790	17.1	2773	-14.3	8046	9533	18.5	6812	-15.3
20 km	1444	1679	16.3	1245	-13.8	5373	6318	17.6	4583	-14.7
25 km	437	502	15.0	381	-12.8	2955	3435	16.2	2549	-13.7
30 km	29	33	12.0	26	-10.6	768	869	13.2	680	-11.5
	housing output per unit of land *h* (FAR)					lamda (λ)				
	S0	S1	% change	S2	% change	S0	S1	% change	S2	% change
0 km	4.72	5.64	19.4	3.96	-16.0	2.12	2.13	0.7	2.10	-0.7
5 km	4.16	4.96	19.1	3.51	-15.8	2.40	2.42	0.8	2.38	-0.7
10 km	3.55	4.21	18.6	3.00	-15.5	2.82	2.84	0.8	2.80	-0.8
15 km	2.87	3.39	18.1	2.44	-15.1	3.49	3.52	0.8	3.46	-0.8
20 km	2.12	2.48	17.3	1.81	-14.5	4.72	4.76	0.9	4.68	-0.9
25 km	1.29	1.49	16.1	1.11	-13.6	7.77	7.84	0.9	7.70	-0.9
30 km	0.37	0.42	13.1	0.33	-11.4	27.05	27.32	1.0	26.79	-1.0
	share of land cost (α_L)					$\bar{x}$ (km)				
	S0	S1	% change	S2	% change	S0	S1	% change	S2	% change
0 km	0.33	0.33	-0.7	0.33	0.7	27.73	27.98	0.9	27.47	-0.9
5 km	0.29	0.29	-0.8	0.29	0.8					
10 km	0.25	0.25	-0.8	0.25	0.8					
15 km	0.20	0.20	-0.8	0.20	0.8					
20 km	0.15	0.15	-0.9	0.15	0.9					
25 km	0.09	0.09	-0.9	0.09	0.9					
30 km	0.03	0.03	-1.0	0.03	1.0					

Note: S0, S1, and S2 are respectively the scenarios with sigma=0.5, 0.505, and 0.495.

As expected, the simulated λ is larger than unity at any location, consistent with the analytical result and indicating that land prices decline faster than housing prices. Moreover, this simulation also indicates that λ increases with *x* (figure 5-7). The positive relationship between λ and *x* can be easily derived from the solution of λ by (23), noting that *p* is in the denominator and *p* decreases as *x* increases by (3).

The fact that σ is smaller than unity leads to a decreasing share of land cost in total property value towards the city edges.[32] This expected phenomenon is also supported by the simulated results (figure 5-8 and table 5-2). The simulated results show that the spatial variation of the share of land cost is remarkable. For example, land cost accounts for 33% of the total property value at the city center, but the number drops to 3% at the location 30 kilometers away (figure 5-8 and table 5-2). This implies profound policy implications, particularly for property taxation and assessment. In a two-rate property tax system in which land and improvements are imposed by different tax rates, the conventional method to determine land value often assumes a fixed share of land value in the total property (such as 20%) for all properties across the urban space. According to the above simulation, it has been demonstrated that a fixed portion of land value causes inaccurate assessment of land value and leads to efficiency loss.

The declining share of land cost in total property value (α_L) with distance from the CBD can be intuitively understood as the consequence of two different effects. One is the price effect and the other is the substitution effect. The price effect is related to the fact that land prices decline faster than housing prices with respect to distance and the substitution effect refers to the increasing intensity of land use as moving toward city edges due to the dropping land prices. Theory suggests that when $\sigma < 1$ the price effect overwhelms the substitution effect, and the simulation reveals consistent results.

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[32] α_L can be derived to be $\alpha_L = 1 - \frac{n}{p\gamma}(\frac{p\gamma\delta}{n})^{\sigma}$ and it is easy to derive that $\frac{\partial \alpha_L}{\partial x} < 0$ when $\sigma < 1$.

Now, look at the impacts caused by 1% change in σ by comparing the two simulated scenarios to the baseline scenario. First of all, results of the simulation suggest that land prices and capital densities are very sensitive to σ, particularly at the central locations. As σ increases (or decreases), both land price curve and capital density curve rise (or lower) and rotate clockwise (or counterclockwise), in accordance with the analytical results that σ positively affects land prices and capital densities and negatively affects their distance gradients (figure 5-4 and figure 5-5). At the city center, a 1% increase in σ leads to 18.6% increase (or 15.4% decrease) in land price and 20.2% increase (or 16.5% decrease) in capital density, at locations 30 kilometers away, the impacts of a 1% change in σ diminish to 10-13% change in land price and capital density (figure 5-4, figure 5-5, and table 5-2).

Second, housing output per unit of land (or the FAR) is also highly responsive to σ, particularly in the central locations, as illustrated by figure 5-6. A 1% change in σ leads to 19.4% increase or 16.0% decrease in the FAR at the city center, and the impacts decrease to 13.1% increase or 11.4% decrease at locations 30 kilometers away. This indicates that σ has considerable impacts on the urban housing structure at any location and it can be inferred σ must have large impact on the aggregated total housing output in the city.

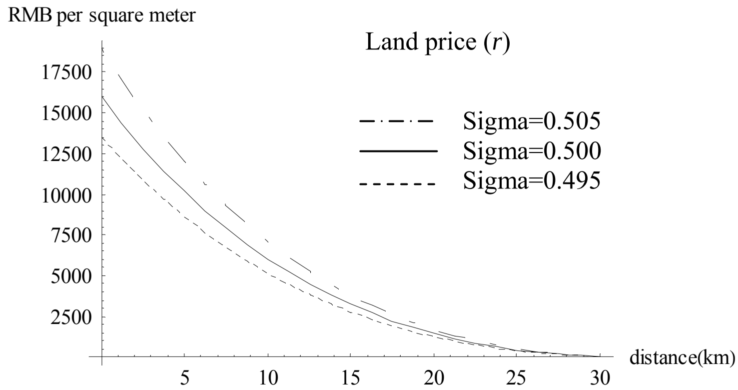


Figure 5-4 Simulated Land Prices in Three Scenarios

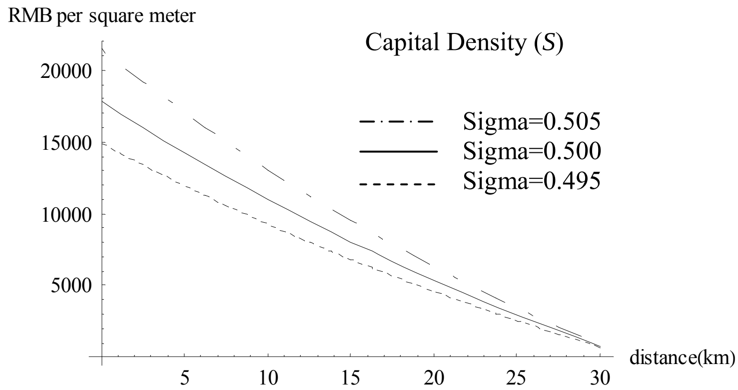
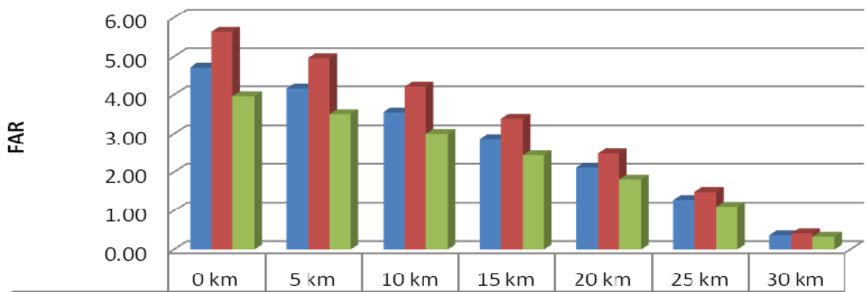


Figure 5-5 Simulated Capital Densities in Three Scenarios



	0 km	5 km	10 km	15 km	20 km	25 km	30 km
sigma=0.5	4.72	4.16	3.55	2.87	2.12	1.29	0.37
sigma=0.505	5.64	4.96	4.21	3.39	2.48	1.49	0.42
sigma=0.495	3.96	3.51	3.00	2.44	1.81	1.11	0.33

Figure 5-6 Simulated Housing Out Put per Unit Land (FAR) in Three Scenarios

Comparatively, λ, α_L, and $\bar{x}$ are less sensitive to σ. A 1% change in σ in general leads to less than 1% change in these three variables. The small impact of σ on $\bar{x}$ is easy to understand given the diminishing impacts of σ on urban land prices when moving towards the urban edges. The small impact of σ on λ is probably because λ is a ratio of the marginal changes already. Nevertheless, the directions of changes confirm the analytical results that σ positively affects λ and $\bar{x}$ (figure 5-7, figure 5-9 and table 5-2). In contrast, α_L is negatively affected by σ (figure 5-8 and table 5-2). To understand this intuitively, note that the larger σ implies the larger degree that land is substituted with capital, thus as σ increases, more capital is used and the share of land value decreases.

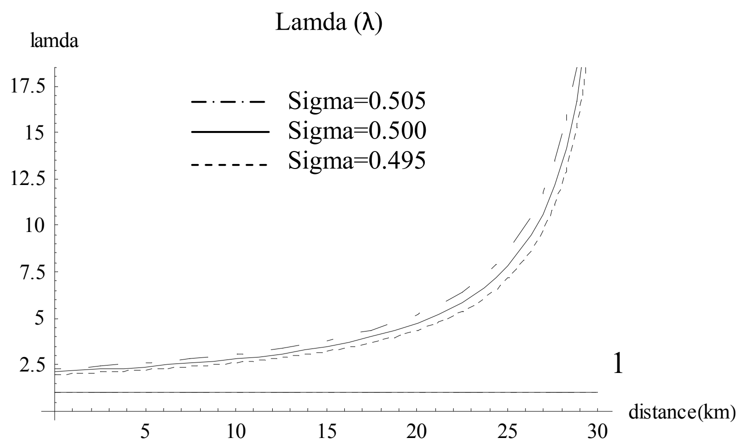
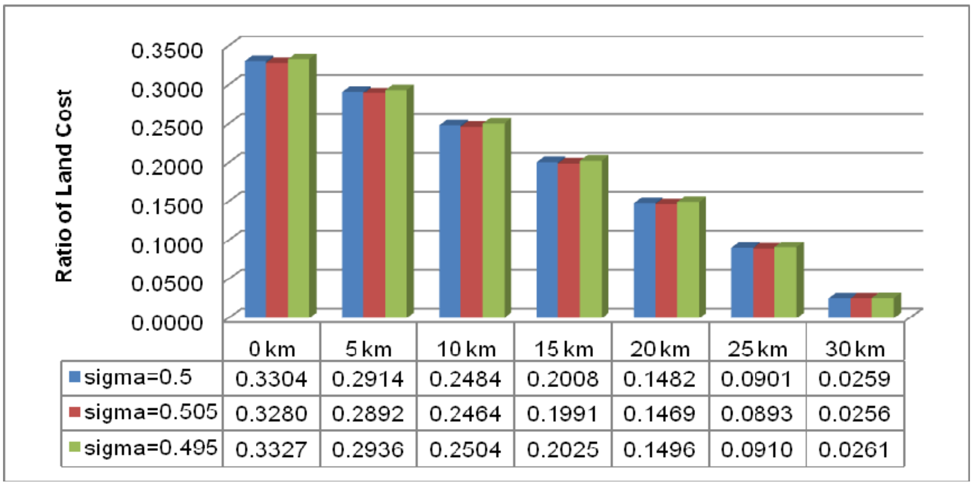


Figure 5-7 Simulated Ratios of the Two Distance Elasticities in Three Scenarios



	0 km	5 km	10 km	15 km	20 km	25 km	30 km
sigma=0.5	0.3304	0.2914	0.2484	0.2008	0.1482	0.0901	0.0259
sigma=0.505	0.3280	0.2892	0.2464	0.1991	0.1469	0.0893	0.0256
sigma=0.495	0.3327	0.2936	0.2504	0.2025	0.1496	0.0910	0.0261

Figure 5-8 Simulated Shares of Land Cost in Total Property Values in Three Scenarios

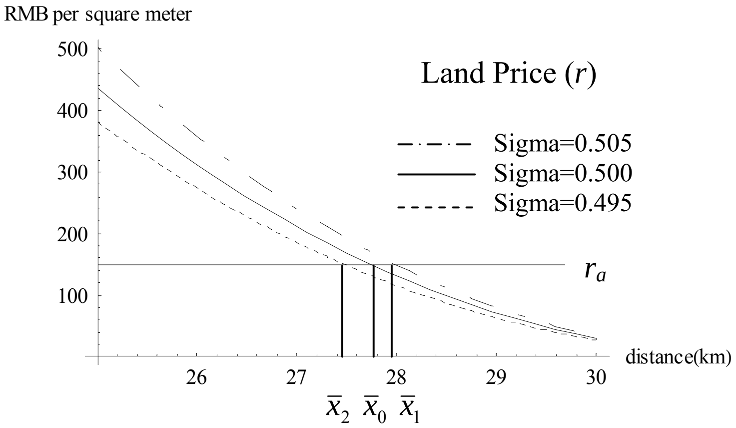


Figure 5-9 Simulated Urban Boundaries in Three Scenarios

To sum up, results of the simulated three scenarios suggest that σ has substantial impacts on land prices, capital densities, and the housing output per unit of land (a 1% change in σ leads to 10-20% change in r, S, and h). These impacts are larger at central locations and diminish with distance. Comparatively, σ has smaller impacts on the ratio of the two distance elasticities, the share of land cost in total property value, and the city size.

5.2.3 Social Welfare Impacts

Shift and rotation of the land price curve caused by a change in capital-land substitution have social welfare implications. Land is one of the important sources for local government to obtain revenue in China through collecting land leasing fees and in the United States through levying property (land) tax (Oates 2001, Ding & Lichtenberg 2010). The welfare impacts of capital-land substitution are also reflected in the overall changes in the aggregated housing output, housing value, and population scale.

The total impacts caused by 1% changes in σ, on the total land value, total housing output, total housing value, and total population capacity at the equilibrium of urban space are determined by the following equations, respectively:

$$TotalLandValue = \int_0^{\bar{x}} r(p(x), n, \gamma, \delta, \sigma) 2\pi x \varphi * 1{,}000{,}000 dx \tag{49}$$

$$TotalFloorSpace = \int_0^{\bar{x}} h(S(p(x); n, \gamma, \delta, \sigma); \gamma, \delta, \sigma) 2\pi x \varphi * 1{,}000{,}000 dx \tag{50}$$

$$TotalHouseValue = \int_0^{X} p(x) h(S(p(x); n, \gamma, \delta, \sigma); \gamma, \delta, \sigma) 2\pi x \varphi * 1{,}000{,}000 dx \tag{51}$$

$$TotalPopCapacity = \int_0^{\bar{x}} h(S(p(x); n, \gamma, \delta, \sigma); \gamma, \delta, \sigma) 2\pi x \varphi * 1{,}000{,}000 / \upsilon dx \tag{52}$$

where φ denotes the percentage of land that can be used for residential uses and is taken to be 0.3;[33] υ is the average personal occupied floor space, and is assumed to be 30 square meters per person;[34] and 1,000,000 is used to adjust the unit of area.

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[33] According to the *Urban Land Use Classification and Land for Construction Standards* by the Ministry of Housing and Urban-Rural Development of the China (previously the Ministry of Construction) in 1990, the share of urban constructive land for residential should be 20-32%. http://www.law110.com/lawserve/guihua/1800004.htm

[34] In fact, more strictly, housing consumption should be determined from the housing demand side problem and varies in urban space; however, for convenience here a constant consumption of housing

Table 5-3 presents the results. The total residential land value is estimated to be 1.94 trillion RMB, 2.28 trillion RMB, and 1.66 trillion RMB in the three scenarios, respectively. A 1% change in σ leads to 17.5% increase or 14.66% decrease in the total land value. These are remarkable impacts, as compared with the 0.2 trillion RMB total government revenue of Beijing in 2009.[35] Moreover, by integrating the land values for each annulus, it suggests that the central annulus witness larger impacts on land value brought by 1% change in σ.

Table 5-3 Simulated Total Impacts of Elasticity of Capital-land Substitution in the City

	land value (billion RMB)					housing output (million sq meter)				
	S0	S1	% change	S2	% change	S0	S1	% change	S2	% change
0-5 km	281.68	333.30	18.3	238.80	-15.2	102.58	122.28	19.2	86.33	-15.8
5-10 km	548.64	647.06	17.9	466.62	-14.9	270.52	321.51	18.9	228.33	-15.6
10-15 km	524.76	616.16	17.4	448.25	-14.6	376.03	445.10	18.4	318.66	-15.3
15-20 km	366.71	428.09	16.7	315.04	-14.1	409.33	481.87	17.7	348.75	-14.8
20-x bar	220.99	257.49	16.5	189.79	-14.1	500.63	594.51	18.8	421.33	-15.8
total	1942.77	2282.10	17.5	1658.50	-14.6	1659.08	1965.26	18.5	1403.40	-15.4
	housing value (billion RMB)					population capacity (million people)				
	S0	S1	% change	S2	% change	S0	S1	% change	S2	% change
0-5 km	2987.79	3560.75	19.2	2515.13	-15.8	3.42	4.08	19.2	2.88	-15.8
5-10 km	15556.84	18487.06	18.8	13132.58	-15.6	9.02	10.72	18.9	7.61	-15.6
10-15 km	29137.69	34487.13	18.4	24693.95	-15.3	12.53	14.84	18.4	10.62	-15.3
15-20 km	36294.56	42724.14	17.7	30924.10	-14.8	13.64	16.06	17.7	11.62	-14.8
20-x bar	46822.00	55600.65	18.7	39406.14	-15.8	16.69	19.82	18.8	14.04	-15.8
total	130798.87	154859.73	18.4	110671.90	-15.4	55.30	65.51	18.5	46.78	-15.4

Note: Assume 30 percent land for residential use, and 30 square meters housing consumption per person.
S0, S1, and S2 are respectively the scenarios with sigma=0.5, 0.505, and 0.495.

The impacts σ on the total housing output are also remarkable. This is as expected since the FAR is very responsive to σ (figure 5-6). One percent change in σ leads to 18.5% increase or 15.4% decrease in the total housing output of the city.

over the urban space is assumed to calculate population capacity. The 30-square-meter living space per person is targeted by the government of Beijing City's target by 2010: http://news.sina.com.cn/c/2010-03-12/092419848868.shtml.

[35] ChinaNews: http://www.chinanews.com.cn/cj/cj-gncj/news/2010/01-02/2050451.shtml

Also, the central locations experience larger impact when compared with the periphery areas.

Although housing price is unaffected by σ in the open city case, the total housing value changes with σ due to changes in housing output. The total housing value is simulated to be 131 trillion RMB, 155 trillion RMB, and 111 trillion RMB in the three scenarios, respectively. It suggests that a 1% change in σ leads to 18.4% increase or 15.4% decrease in the total housing value. In other words, a 1% change in σ could mean about 20 trillion RMB, which is a huge impact in the city's wealth.

The total population capacity of the city is estimated to be 55.3 million, 65.5 million and 46.8 million population in the three scenarios, respectively, by assuming an average floor space consumption of 30 square meters per person. These simulated numbers appear overestimated, given that currently 15.81 million permanent populations live in Beijing in 2006 within the administrative area of 16,400 square kilometers (BSB 2007).[36] However, considering that the Tokyo Metropolitan Area in Japan housed 33.4 million population in 2000 while occupying about 13,556 square kilometer land (about 65 kilometers radius), and China is experiencing rapid urbanization and massive rural-urban migration, some 50 million population might be a possible future if Beijing continues to grow.

To sum up, 1% changes in σ leads to 14-18% changes in the total land value, 15-19% changes in the total housing output, the total housing value, and the total population of the city. These numbers suggest that the total social welfare impacts caused by changes in capital-land substitution in housing services production are

[36] Permanent populations include migrants from other provinces that have stayed longer than six months but exclude temperate migrants staying less than six months.

substantial. These findings indicate that the opportunity cost of land development restrictions such as the building height caps and the FAR controls may be very high. Thus, policies and regulations that might constrain land development should be carefully examined before implementation.

Chapter 6: Empirical Evidence

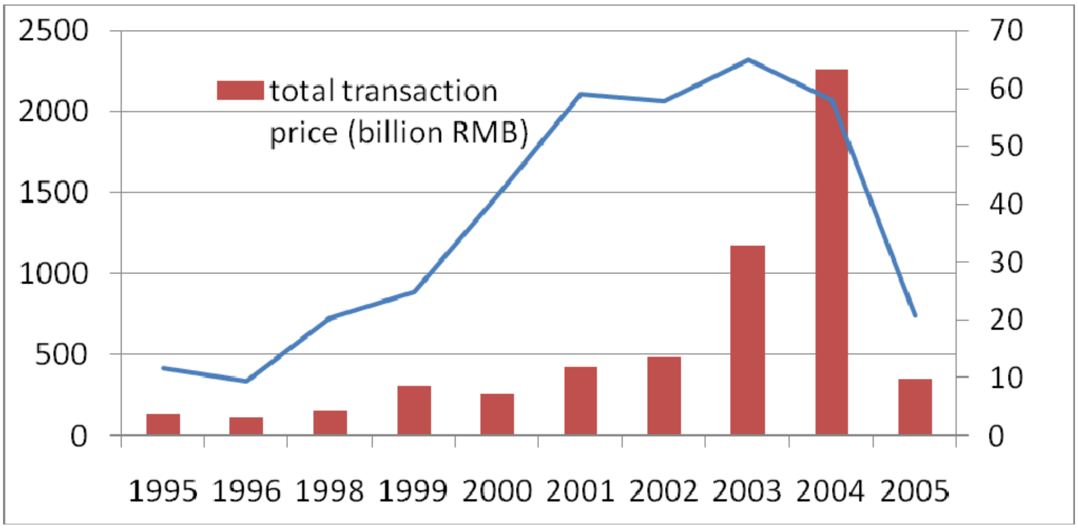
By using land development data from Beijing City, this chapter empirically examines the two research questions of this dissertation. After a brief introduction of the research area and data, I first test the classical predictions of the negative distance gradients of housing prices, land prices, capital densities, and the FARs. Then I examine the relationship between the distance elasticities of land prices and housing prices. Finally, I estimate the elasticity of capital-land substitution and examine its impacts by dividing the data into two sub-periods and comparing the changes of the estimated elasticity of capital-land substitution, distance gradients of land prices and capital densities, and the ratio of the two distance elasticities.

6.1 Research Area

Beijing is selected as a typical example of a prosperous city where land and housing markets have developed rapidly since the late 1980s. In 1995 there were only 419 land leasing transactions (1,219 hectares and 3.7 billion RMB in total), compared to 3147 free land assignments (5,006 hectares) (MLR 1996). However, the land leasing market grew quickly and began to play the dominant role in distributing urban land resources. In 2004, the number of land leasing transactions climbed to 2,073 (6225 hectares and 63.1 billion RMB in total), compared to only 89 cases of land grant for free (453 hectares) (figure 6-1) (MLR 2005).[37] The housing market in

[37] The sharp drop of land leasing transactions in 2005 (shown in figure 6-1) is due to a series of stringent policies on urban land supply to suppress the overheated real estate development and the

Beijing also developed rapidly, particularly after the year of 1998 when material housing distribution was formally prohibited. The annual sale of commodity housing rose from 1.42 million square meters in 1990 to 4.09 million square meters in 1998 and jumped to 28.03 million square meters in 2005, increasing at an annual growth rate of 14.1% during 1990-1998 and 31.6% during 1998-2005. Accordingly, the total value of annual sale shot up from 2 billion RMB to 176 billion RMB during this fifteen-year period at an impressive annual growth rate of 34.6% (BSB 2006) (figure 6-2).



Source: MLR 1996-2006, data of 1997 are unavailable

Figure 6-1 Land Leasing Market in Beijing: Total Number of Leases and Total Leasing Value, 1995-2005

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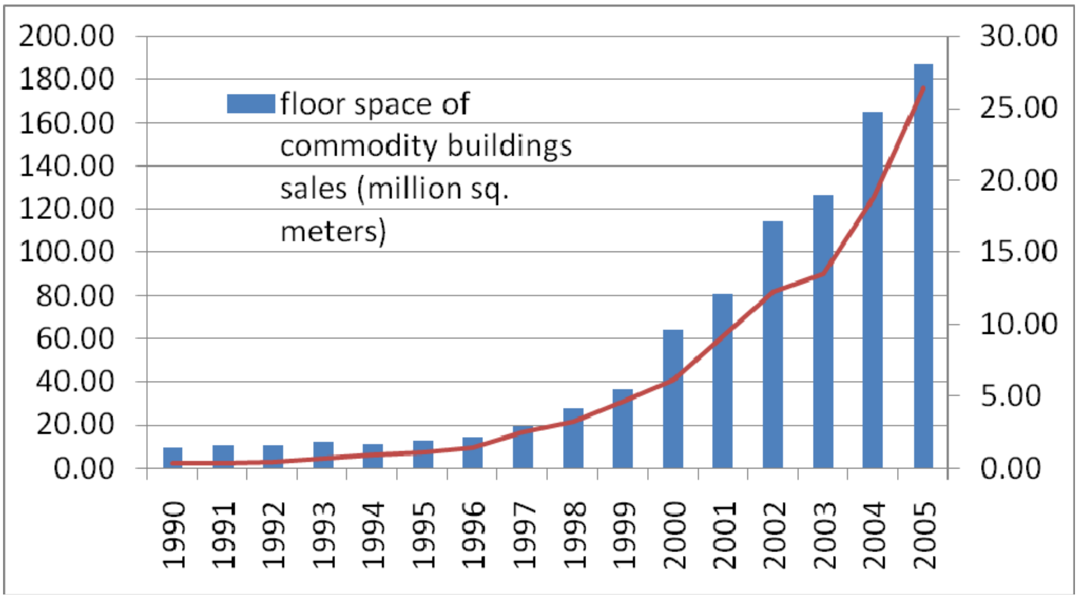
fever of special economic zones and industrial parks. The land leasing market in Beijing had been "frozen" during the second half of 2004 and the first half of 2005.

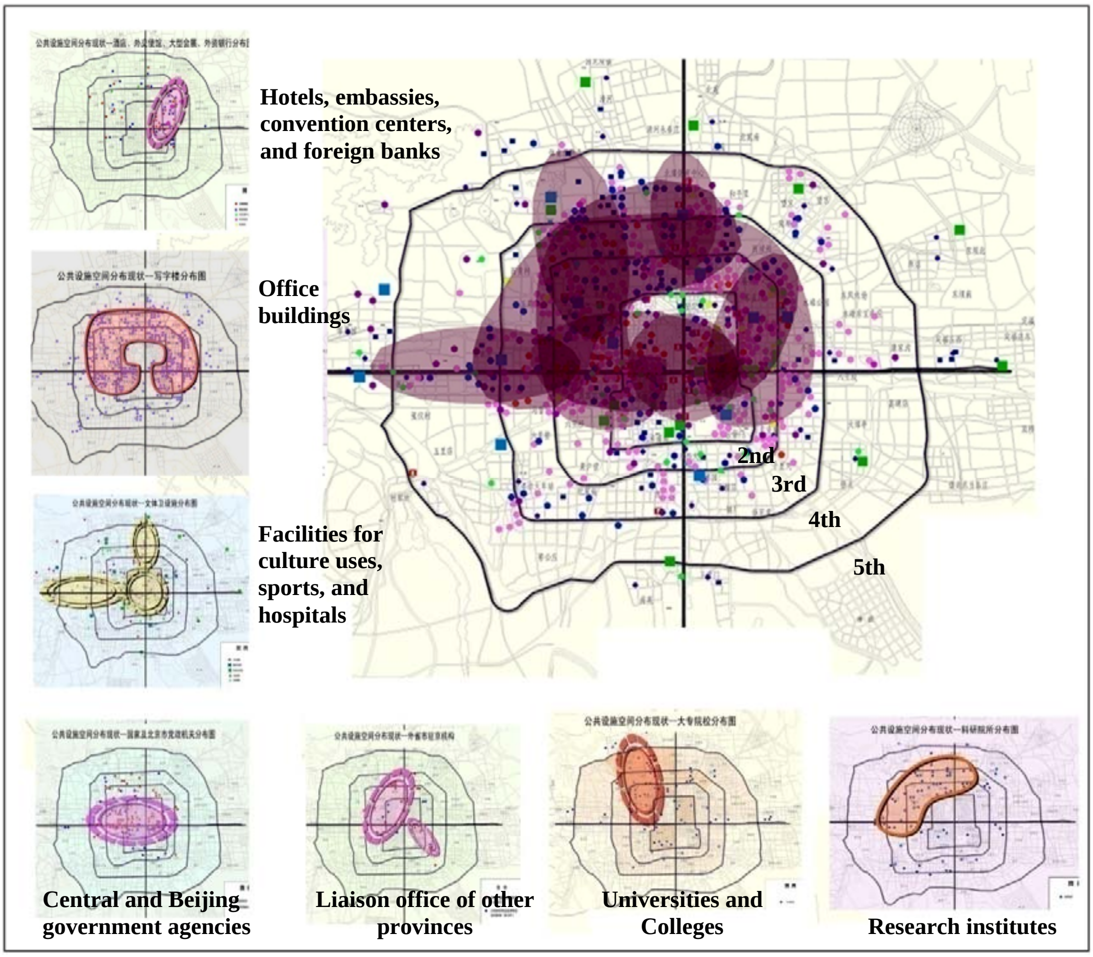


Source: BSB, Statistical Year Book of Beijing

Figure 6-2 Commodity Housing Market Development in Beijing: Floor Space and Value of Sales, 1990-2005

Combining with the advances in technology of construction, the emerging urban land and housing markets are reshaping Beijing's urban landscape. Before, Beijing was characterized with a flat skyline, resulting from the *danwei*-based urban landscape, lack of incentives to economize land, and strict planning regulations. After, one of the most salient changes in the urban landscape was the emergence of taller and taller buildings (figures 2-7, 2-8, and 2-9). Also, the spatial distribution of land uses evolved, manifested by the relocation of industries from the central locations to the suburbs and the concentration of business and commercial activities in the central region of Beijing.

Driven by the market forces, Beijing's urban landscape presents many similarities to Western cities. Figure 6-3 illustrates the spatial concentration of the functions in Beijing. Despite the preserved Forbidden City lying in the center of the city, the central locations are favored by various activities including business, commerce, administration, education and research, etc. For example, within the third ring road are located the three commercial centers and one commercial street (*Xidan*, *Wangfujing*, *Qianmen*, and *Jinrongjie*), offices for more than 20 central government departments, hundreds of city departments and about 250 government agencies (Ding et al. 2005).



Source: China Academe of Urban Planning & Design, Beijing Urban Spatial Development Research. 2003.

Figure 6-3 Spatial Concentration of City Functions

Population density declines with distance from the city center in Beijing. If dividing the city by its five ring roads, within the second ring road, population density was about 27,400 people per square kilometer in 2004, even higher compared with the central 23 wards in Tokyo, Japan;[38] within the third ring, population density was 24,000 people per square kilometer; and it decreased to 19,700, 12,600, 4,400, 2,000 and 840 for within the fourth ring, fifth ring, sixth ring, Beijing Bay, and the entire administrative area of Beijing, respectively (table 6-1).

Table 6-1 Distribution of Population Density in Beijing

	Current population density (10,000 pop/km^2)	Planned Population Capacity for 2020 (10,000 pop)
Within 2nd ring	2.740	124
Within 3rd ring	2.400	350
Within 4th ring	1.970	565
Within 5th ring	1.260	915
Within 6th ring	0.440	1235
Beijing Bay (exclude west and north mountainous area)	0.200	1650
Beijing	0.084	1750

Source: Beijing Municipal Institute of City Planning & Design, From Olympic Games to Future, 2004.

Empirical studies have also provided evidence for the distance decay phenomena of land and housing prices in Beijing. For example, Ding (2004) examined the revolution of urban spatial structure in Beijing using the land leasing data from 1993 to 2000. By comparing the land prices in different rings of the city by different land uses and estimating the price gradients and their changes, Ding's findings indicated that the distant gradients were all significantly negative and were dependent on land uses.

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[38] The population density of the 23 wards in Tokyo was estimated to be 13,660 people per square kilometer Tokyo Statistic Yearbook 2005: http://www.toukei.metro.tokyo.jp/tnenkan/2005/tn05qyte0510b.htm

The data set used in this dissertation also depicts a clear picture of spatial patterns of Beijing. By using the GIS software ArcScene, figure 6-4 presents the spatial distribution of the housing prices, land prices, and the FARs.

Nevertheless, it should be noted that despite growing markets, policies and planning regulations do play important roles in influencing the urban spatial structure of Beijing. For example, in 1989 the government of Beijing issued a policy—the *Decision on the Strict Control of High-rise Residential Building Provision* (Beijing [1989]42)—to control high-rise buildings, and this policy effectively curbed construction of high-rise buildings. The share of annually completed floor space of 10-and-above-floor buildings decreased from 40% in the late 1980s to less than 25% by 1992. This policy was later revised in 1994 and finally abolished in 2003. Afterward, the share of the 10-and-above-floor buildings rose again and currently reaches more than 40%.[39] It is true that developers often break land development requirements as subscribed to in urban plan and land leasing contracts (mostly the building height caps and the FAR controls) through bribing officials or even at the expense of paying the fines. However, this example illustrates that rigorous policy and plan implementation could serve as strict constraints on urban land development and significantly influence urban spatial structure, when stimulated by special incidences.

[39] High-rise Building Development in Beijing (in Chinese), retrieved on May 2010, from http://www.chinajsb.cn/gb/content/2005-01/06/content_120207.htm

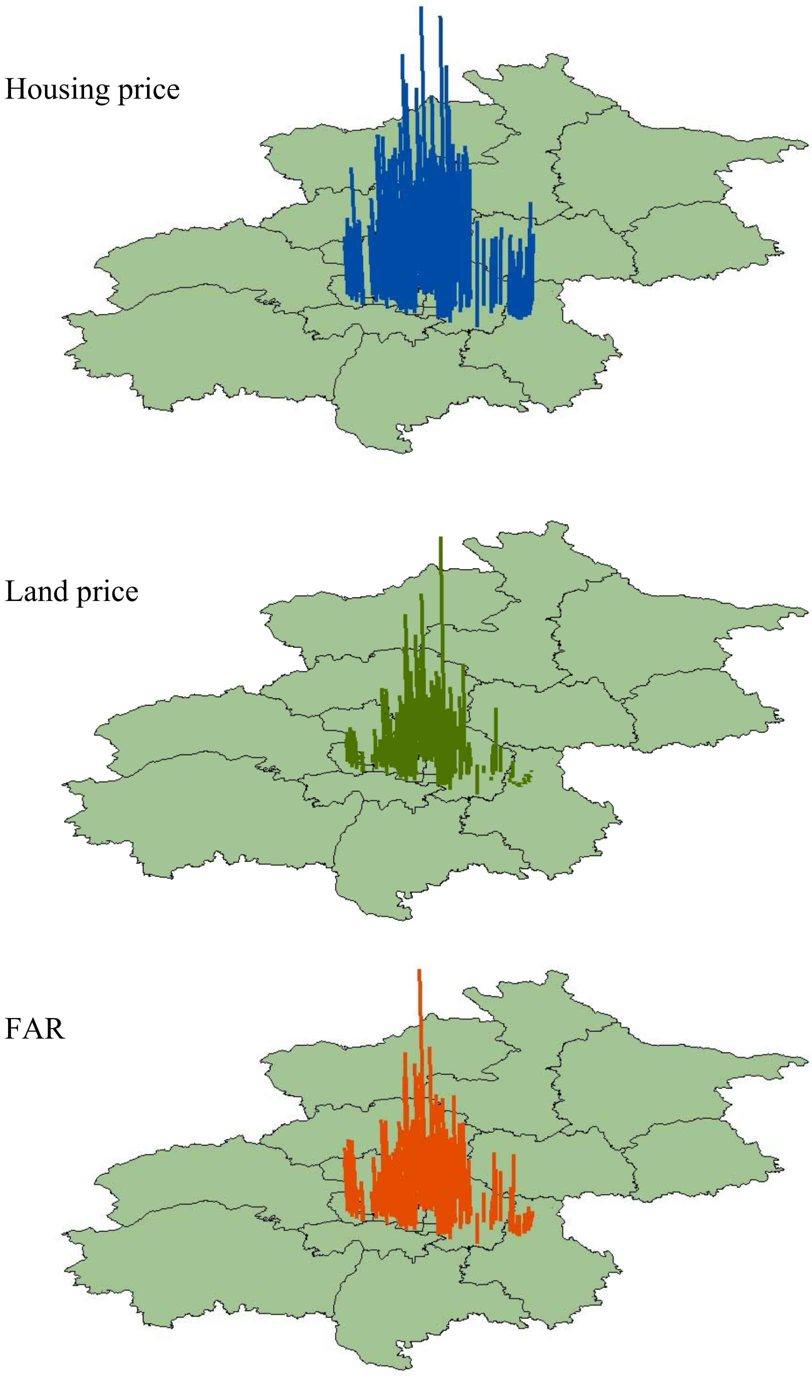

Figure 6-4 Housing Prices, Land Prices, and FARs in the Study Area

During the research period of 1999-2003, it is observed that stricter policy and planning implementation were introduced around the year 2002, partly for preparing for the 2008 Olympic Games and partly for controlling the overheated land development.[40] On the one hand, it was mandated that all state-owned urban land for profitable uses must be leased through open bid approaches (such as tender, auction, and listing) and no project should violate the plan, otherwise monetary penalty and even some jail time would be imposed. On the other hand, rigorous plan implementation was carried out and a great amount of illegal building structures were demolished.[41] The stringent policies could have probably constrained the market in allocating land and capital resources and limited the capital-land substitution in housing services production. The following estimations should take this into consideration.

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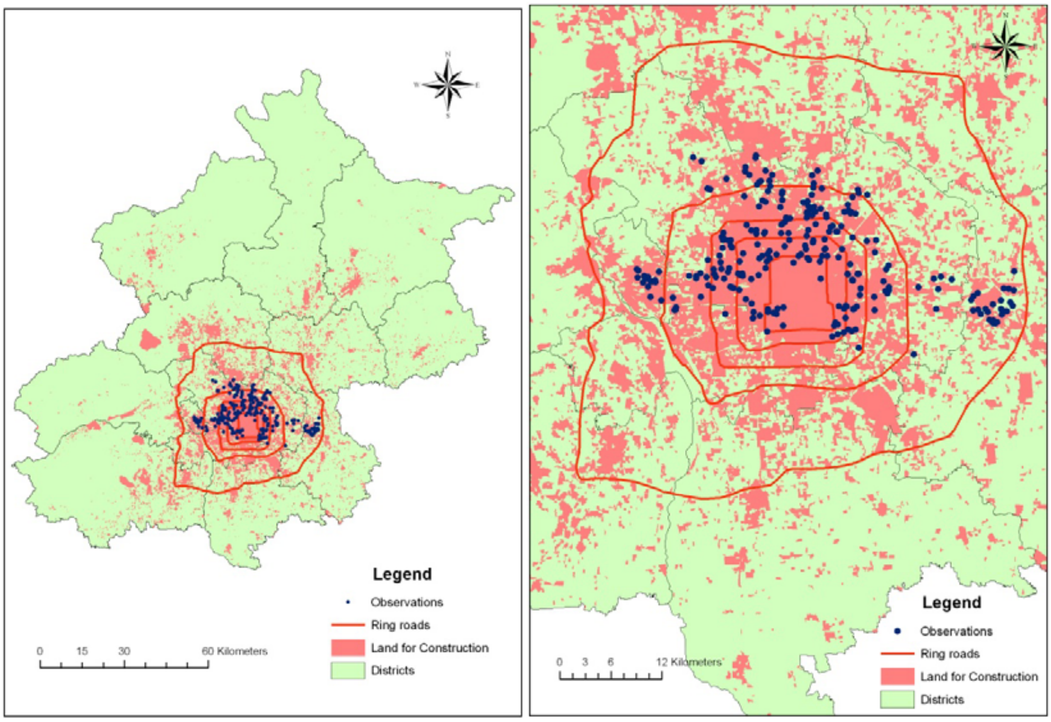
[40] The year 2002 was the first year that the Olympic Games Plan implementation was started. In tracking the policy documents issued in that year, several of them are important and deserve a note. On April 2002, the Ministry of Land and Resources announced the *Provisions of Tender, Auction, and Listing State-Owned Land Use Right*, requiring that urban land use rights for profitable uses (including commodity housing development and commercial and office real estate development) must be leased to private users through open bid approaches (tender, auction, or listing). Following this national document, the Beijing government issued *Provisions of Stop State-Owned Land Use Right Leasing to Profit Making Projects by Negotiation* on July 2002. At the same time, the Beijing government also issued *Measures on Violation of the Provisions of Land Management Administrative Responsibility*. In December of the same year, the Beijing government issued the *Notice of Adjusting State-Owned Land Use Right Benchmark Price*. These formally issued documents play important roles to tighten the urban land use management.

[41] Besides the tightening of land use policies and regulations, the citywide inspection of land use started in 2003 helped to reduce the number of cases of building permit violations. Furthermore, the successful bidding to the 2008 Olympic Games in 2001 triggered large-scale demolition of constructions that violated planning regulations zoning ordinances in the years after. For instance, a total 4.5 million square meters of building space were demolished in 2006. Source (In Chinese):
http://www.landscapecn.com/news/html/news/detail.asp?id=8074.
http://www.515home.com/commom/news_content.asp?id=32098.
http://huaxianews.cn/news/2006-3/27/2006327135600.htm.

6.2 Data

The data used in the empirical analysis of this dissertation include land price per square meter, housing price per square meter, total square meters of land lot, total square meters of floor space, the FAR, location information, and so on, for each observation of housing project. Both housings price and land prices are needed for the same land lots so as to estimate λ and σ, test the relationship of $\lambda > 1$, and examine the impacts of σ.

Housing price data were collected from the largest online housing information website (http://www.soufun.com) in China on March 2007. The housing data provided information of project name, starting date of sale, location, the average housing prices per square meter floor space, housing type, and if furnished or not. The housing data were then matched to the land leasing transaction data, which were obtained from the Beijing Land Resource and Management Bureau, by project name and location information. The land leasing data provided information on project name, land leasing date, location, total square meters of land lot, total planned square meters of floor space, and land price per square meter. Matching these records from both sources greatly reduced the number of usable observations. After excluding government-subsided affordable housing (*jingji shiyong fang*) projects, single detached dwellings, and observations located more than 30 kilometers from the city center as well as the very few observations in the remote suburban districts that were considered as outliers, a total of 266 observations were obtained. Figure 6-5 presents the spatial distribution of these observations.



Note: land for construction includes the urban & town land, single sites for industry, sites of special use, but excludes the sites for rural villages.
Source: Beijing Current Land Use Map of 2004, Beijing Land Resource and Management Bureau.

Figure 6-5 Administrative Area of Beijing and Research Area

Table 6-2 provides the descriptive statistics of the variables used in the following empirical analysis. The average land price per square meter was 2,211 RMB, which was about one-third of the average per square meter housing price. The housing structure floor space per unit of land or the FAR varied remarkably from 0.44 to 20.63, with the mean of 4.55. The capital density was estimated by $S = (pH * 0.7 - rL)/n$, based on the assumption that there was an average profit ratio of housing sales of 30% in urban housing market (as in the simulation analysis). The average capital density was 20,550 RMB per square meter of land in the sample. The mean location of observations was 11.4 kilometers away from the city center—

Tiananmen Square.[42] The years of land purchase varied from 1999 to 2003, and the starting years of housing sales varied from 1999 to 2007. There were time gaps between land purchases and housing sales, ranging from one year to seven years, which could be related to project scales. Usually it takes less time to finish smaller land development projects than larger ones. On average, the time lag was a bit more than one year. The total land area and total housing floor space varied dramatically among the observations, indicating the project scale had a large variance. About 38% of the housing projects had furnished the rooms. Tables 6-3 and 6-4 also provide information of the numbers of observations by district and housing type.

This data set has several advantages. First, each observation has matched housing and land prices that were directly observed from transactions. This is helpful to obtain better estimates, because measurement errors that are associated with systematically biased estimation of land prices are less likely to occur in this data set (McDonald 1981, Thorsnes 1997). Second, all of the observations were newly developed commodity housing projects, and thus this data set is not associated with the problem that old dwellings fail to continuously adjust land and capital input according to prices (Jackson et al. 1984). Moreover, rapid urban expansion and housing project development in Beijing offers spatially widely scattered observations, from the city center to the urban edges, as compared with the fact that in the developed countries new housing development are mostly clustered only in the suburbs.

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[42] Despite the Forbidden City, which only occupies 0.72-kilometer squares, the central areas of Beijing remain attractive to business, commercial, and administrative activities. In this study, Tiananmen Square is regarded as the city center, which is itself not an employment center but rather symbolic for the highly concentrated economic activities in Beijing.

Table 6-2 Descriptive Statistics

Variable		Obs	Mean	Std. Dev.	Min	Max
p	unit housing price per square meter structure space in RMB	266	6887.7	2481.0	2034.4	19477.9
r	unit land price per square meter land in RMB	266	2211.0	1939.1	30.8	14940.4
ln(p)	Logarithm of housing price	266	8.78	0.35	7.62	9.88
ln(r)	Logarithm of land price	266	7.26	1.12	3.43	9.61
h (or the FAR)	floor area ratio, measuring the housing output per unit land	254	4.55	2.69	0.44	20.63
ln(h)	Logarithm of housing output per unit of land	254	1.35	0.58	-0.82	3.03
S	capita density, estimated by subtracting total housing sale value with total land cost and divided by total land area	254	20549.9	15859.3	1348.7	157992.0
ln(S)	logarithmic capital density	254	9.70	0.71	7.21	11.97
x	distance from Tiananmen Square in kilometer	266	11.42	5.46	2.26	25.60
LY	land leasing year	266	2001.05	1.40	1999.00	2003.00
HY	housing sale year	266	2002.1	2.0	1999.0	2007.0
DIFF	Year difference between land purchase and housing sale	266	1.02	1.20	0.00	7.00
FA	total floor area of structure space for each observation in square meter	254	61594.0	101142.4	676.0	1433262.0
LA	total land area for each observation in square meter	266	17309.3	31209.4	248.0	427283.0
FUR	dummy variable: Furnish=1 if housing is furnished; otherwise Furnish=0	253	0.38	0.49	0.00	1.00
DT	dummy variables: districts	256				
TP	dummy variables: housing types	266				

Table 6-3 Numbers of Observations in Each District

Districts		Freq.	Percent
1	*Dongcheng*	10	3.76
2	*Xicheng*	7	2.63
3	*Xuanwu*	12	4.51
4	*Chaoyang*	109	40.98
5	*Haidian*	81	30.45
6	*Shijingshan*	21	7.89
7	*Tongzhou*	26	9.77
Total		266	100

Table 6-4 Numbers of Observations in Each Housing Type

Housing types		Freq.	Percent
1	Slab	10	3.76
2	Tower & Slab	7	2.63
3	Tower	12	4.51
4	Mid-rise	109	40.98
5	High-rise	81	30.45
6	Mid-to-high-rise	21	7.89
7	Slab & Mid-to-high-rise	26	9.77
Total		266	100

Note: these types are provided by the developers on the website, and they are not strictly exclusive to each other.

The data also bear several shortcomings. First, the observations were housing projects rather than single dwellings and the housing prices were the average prices of housing project. Compared with the prevalence of single-house dwellings in the developed countries, China's residential development is mostly high-rise compound buildings, each providing dozens to hundreds of apartment flats. The average housing price cannot reflect the structural differences (such as the floor number, number of bedrooms and bathrooms, layout, window directions) among housing apartment flats within one project. Second, the total structural space of each housing project and the FAR were from land leasing records, which were planned rather than completed. Therefore, they might be biased if the final housing output exceeded the planned structural space subscribed on the land leases. Finally, land prices were determined through the approach of negotiation, which is the most used approach but is often regarded as being associated with non-market factors.[43] Nevertheless, the way in which land prices are determined by negotiation is similar to that in the market, since

[43] During 1999-2003, there are totally 8,865 land leasing cases in Beijing, 8,738 of them were through negotiation, and the others were through tender, auction, and listing (MLR 2000-2004).

the final land leasing price is agreed to by both the city government and the developers and dependent on land use type, location, neighborhood characteristics, etc.

6.3 Urban Decaying Phenomenon

The first empirical question is to test the spatial decay functions. According to (4), (11), (12), (13), housing prices, land prices, capital intensities, and the housing output per unit of land (or the FARs) decline with distance from the city center. To estimate and test these negative distance gradients, the estimating equation is specified as:

$$\ln(O) = \theta_0 + \theta_1 x + \sum_{j=2} \theta_j A_j + \varepsilon \tag{53}$$

where O denotes the housing price p, land price r, capital density S, or housing output per unit land h (or the FAR); x denotes the distance from the city center; A_j denotes control variables, which vary with dependent variables; θ_0 is the intercept; θ_1 is the distance gradient, which is expected to be significantly negative; θ_j are coefficients of control variables; and ε is the error term.

Table 6-5 reports estimated results by ordinary least square (OLS).[44] The models present a moderate goodness-to-fit, with the R-squared ranging from 0.3 to 0.6. All of the distance gradients of housing prices, land prices, capital intensities and the FARs are significantly negative numbers, consistent with the model predictions of the urban decaying phenomenon.

[44] Stata is used in all estimations.

Table 6-5 OLS Estimations of Distance Gradients for Housing Prices, Land Prices, Capital Densities, and FARs

	ln(p)			ln(r)			ln(S)			ln(FAR)		
	obs=242,R-sq=0.5115			obs=266, R-sq=0.615			obs=242, R-sq=0.4047			obs=254, R-sq=0.3098		
	Coef.	t	sig.	Coef.	t	sig.	Coef.	t	sig.	Coef.	t	sig.
distance	**-0.0383**	**-6.30**	********	**-0.0943**	**-5.55**	********	**-0.05986**	**-4.37**	********	**-0.0272**	**-2.28**	******
district_2	-0.0359	-0.30		-0.0475	-0.13		-0.17693	-0.64		-0.1344	-0.54	
district_3	-0.2709	-2.46	**	-0.1809	-0.59		-0.09603	-0.37		0.0617	0.29	
district_4	-0.2263	-2.64	***	-0.0994	-0.40		-0.34127	-1.73	*	-0.0971	-0.56	
district_5	-0.1254	-1.41		-0.2025	-0.78		-0.31262	-1.53		-0.1772	-0.98	
district_6	-0.2738	-2.24	**	-0.0534	-0.15		-0.40446	-1.45		-0.0818	-0.34	
district_7	-0.2380	-1.61		-1.5336	-3.76	****	-0.70436	-2.08	**	-0.4784	-1.61	
type_2	0.0144	0.33					0.253581	2.54	**	0.2042	2.33	**
type_3	-0.0620	-1.52					0.205752	2.22	**	0.3346	4.17	****
type_4	-0.0506	-0.40					-0.61001	-2.11	**	-0.4413	-2.10	**
type_5	-0.1939	-2.14	**				0.188219	0.92		0.4569	2.97	***
type_6	0.0290	0.28					0.021759	0.09		-0.1373	-0.74	
type_7	-0.0219	-0.24					-0.18304	-0.88		-0.1111	-0.60	
FUR	0.0179	0.53					0.073118	0.95				
FA	0.0000	1.57										
HY_2000	-0.0037	-0.05										
HY_2001	-0.0624	-0.93										
HY_2003	0.0569	0.83										
HY_2004	0.1425	2.05	**									
HY_2005	0.2597	3.09	***									
HY_2006	0.2981	2.56	**									
HY_2007	0.4307	2.39	**									
LA				0.0000	-0.32							
LY_2000				-0.0248	-0.17							
LY_2001				-0.2229	-1.38							
LY_2002				0.1540	0.96							
LY_2003				0.0508	0.33							
DIFF							0.040743	1.30				
CONST	9.3609	88.68	****	8.6690	32.47	****	10.51319	53.26	****	1.6430	9.46	****

****99.9%, ***99%, **95%, * 90%

Calculating at the mean distance (11.4 kilometers), the distance elasticities of housing prices, land prices, capital densities, and the FARs were -0.44, -1.08, -0.68, and -0.31, respectively, suggesting that a 1% increase in the distance from the city center would decrease housing prices by 0.44%, land prices by 1.08%, capital densities by 0.68%, and the FARs by 0.31%, respectively. These results suggest that land prices behaved in a more elastic way with respect to distance, when compared to housing prices. To better understand the speeds of these declines, supposing that a one-kilometer move is made at the mean distance away from the city center in *Chaoyang* district, the housing type is slab and it is not furnished, the total floor space and land areas are taken by the means of the sample, and the land purchase year is 2001 and housing sale year is 2003, this move will make the housing price drop by 288 RMB per square meter, land prices drop by 142 RMB per square meter, capital densities drop by 637 RMB per square meter, and the FARs drop by 0.066.

Coefficients of the control variables suggest some interesting findings. First, effects of the district dummy variables are mixed compared with the expectation. Housing prices would be higher if it was located in *Chaoyang*, *Xuanwu*, and *Shijingshan*. This is reasonable given the development of *Chaoyang* CBD and the closeness to the city center of *Xuanwu* and *Shijingshan*. It is unexpected that *Haidian* did not have a positive influence on housing prices given the concentration of high-tech business and universities in *Haidian* district especially in its *Zhongguancun* area. A possible explanation is that *Haidian* is a large district and includes also less urbanized areas that offset its attractiveness. *Tongzhou* was the only district dummy variable that had significant and negative influence on land prices, probably due to the newly government-facilitated and to a certain degree subsidized land development (*Tongzhou* is among three of the key new cities in the 2004 master plan). Capital density was significantly higher in *Chaoyang* and lower in *Tongzhou*, suggesting difference in quality of residential development. No district dummy variable was significant for the FAR. Second, high-rise and tower housing buildings in general were associated with higher housing prices, capital intensities, and FARs, but not associated with land price. Third, the effects housing project scale and land development scale on housing prices and land prices were as expected but not significant.[45] Fourth, housing prices and land prices appeared to increase with time, consistent with economic growth, but the time effect on land prices was not significant. Finally, the time lag had a positive sign on capital density as expected but was not significant.

6.4 *Ratio of the Two Distance Elasticities*

According to (14), land prices are more elastic with respect to distance from the city center: $\lambda > 1$. To estimate λ , I employ two different approaches.

The first approach is to estimate λ by computing the ratio directly from the estimated distance gradients of land prices and housing prices. According to the definition of λ by (14):

$$\lambda = \frac{\frac{\partial r}{\partial x} \Big/ \frac{r}{x}}{\frac{\partial p}{\partial x} \Big/ \frac{p}{x}} = \frac{\frac{\partial r}{\partial x} \Big/ r}{\frac{\partial p}{\partial x} \Big/ p} = \frac{\frac{\partial \ln r}{\partial x}}{\frac{\partial \ln p}{\partial x}} = \frac{\theta_{1r}}{\theta_{1p}} \tag{54}$$

where θ_{1r} and θ_{1p} are respectively the estimated distance gradients of land prices and housing prices by (53). According to the OLS results shown in table 6-5, $\lambda = \frac{-0.0943}{-0.0383} = 2.46 > 1$.

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[45] Large housing projects are expected to positively affect housing prices for they provided better services and facilities. Larger land lots, however, are expected to negatively affect land prices because fewer developers were able to bid for large scale land development and thus they had more power to bargain with the government.

However, this simple computation from the independent OLS estimations cannot tell whether λ is statistically significant larger than unity. For the purpose of testing $\lambda > 1$, I also employ the seemingly unrelated regression (SUR) estimation. The SUR estimation jointly estimates the housing prices function and land prices function and yields more efficient estimates, for it takes into account the potential correlations between the error terms of the two equations. The SUR estimation makes sense in this case because both housing prices and land prices came from the same data set, and therefore the error terms of the two equations are likely to be correlated. More important, it can be tested whether the distance gradients from the two equations are significantly different from each other by conducting a cross-equation χ^2 test.

Table 6-6 reports the results of the SUR estimations. The estimated distance gradients are similar to those of the OLS, and both are significantly negative. Using these estimates, $\lambda = \frac{-0.0892}{-0.0382} = 2.34 > 1$. The χ^2 test reports that the null hypothesis of $\theta_{1r} = \theta_{1p}$ is rejected at a 99% level in favor of the alternative hypothesis that the two distance gradients are significantly different from each other, and this provides statistical evidence for $\lambda > 1$.[46]

[46] $Chi^2(1)=9.26$, $Prob>chi^2=0.0023$.

Table 6-6 SUR Estimations of Distance Gradients for Housing and Land Prices

	ln(p)			ln(r)		
	obs. 242, R-sq=0.5115			obs. 242, R-sq=0.4621		
	coef.	z	sig.	coef.	z	sig.
distance	**-0.0381691**	**-6.61**	********	**-0.0891899**	**-5.70**	********
district_2	-0.0345822	-0.30		-0.0230039	-0.07	
district_3	-0.2708801	-2.59	***	-0.0311796	-0.10	
district_4	-0.2271482	-2.79	**	-0.1085817	-0.48	
district_5	-0.1255459	-1.48		-0.2247626	-0.95	
district_6	-0.2753058	-2.37	**	-0.0054501	-0.02	
district_7	-0.2389175	-1.70	*	-0.8121863	-2.09	**
type_2	0.0156686	0.37				
type_3	-0.0596148	-1.54				
type_4	-0.0537071	-0.45				
type_5	-0.1897537	-2.20	**			
type_6	0.0300463	0.30				
type_7	-0.0230342	-0.26				
FUR	0.0177716	0.56				
FA	2.57E-07	1.70	*			
HY_2000	-0.0041231	-0.06				
HY_2001	-0.0624409	-0.98				
HY_2003	0.0569865	0.88				
HY_2004	0.1412889	2.13	**			
HY_2005	0.2587748	3.23	****			
HY_2006	0.294404	2.66	***			
HY_2007	0.4375647	2.55	**			
LA				-2.44E-06	-1.77	*
LY_2000				0.017005	0.12	
LY_2001				-0.1911381	-1.22	
LY_2002				0.079664	0.50	
LY_2003				0.0064016	0.04	
CONST	9.359147	93.21	****	8.636603	34.87	****

****99.9%, ***99%, **95%, * 90%

The second approach is to estimate λ based on its alternative representation as the housing price elasticity of land price. According to (15) and (26), λ can be estimated by the following equation:

$$\ln(r) = \alpha_0 + \lambda \ln(p) + \varepsilon \tag{55}$$

where r and p denote per square meter land price and housing price, respectively; and α_0 is the intercept. I use both OLS and instrumental variable (IV) estimations to estimate λ. The reason for using the IV estimation is that housing price is probably correlated with the error term, due to the uncontrolled factors that affect both housing and land prices such as the neighborhood effects. I choose the housing type (TP), housing sale year (HY), and whether the rooms are furnished (FUR) as instrumental variables since they are correlated with housing prices but are not apparently associated with land prices. I also include land leasing year (LY), land area (LA) and square of land area (LA_square) in the major function as control variables.

Table 6-7 reports the results of both the OLS and two stage least square (2sls) IV estimations. The OLS estimation yields $\lambda = 1.69$ with the T-statistics suggesting that λ is significantly larger than unity, and the IV-2sls estimation yields $\lambda = 2.75$, which is also significantly larger than unity.[47] It should be noted that although theoretically the IV estimation improves the estimation by correcting the endogenous problem, it is also associated with the problem of "weak" IV that impairs the precision of the estimates, especially in this case that the R-squared and the F-statistics of the first stage estimation that are quite small.

In conclusion, by using the Beijing data, different approaches and estimation methods yield considerably robust estimates of λ ranging from 1.69 to 2.75, and the statistical tests indicate that λ is significantly larger than unity, consistent with the theory that land prices are more elastic with respect to distance from the city center than housing prices.

[47] The T-statistics for $\lambda > 1$ is 4.28 for the OLS estimation, and 3.44 for the IV estimation, all significant at a 99.9% level.

Table 6-7 OLS and IV Estimations of the Ratio of the Two Distance Elasticities

OLS

	obs=266, R-sq=0.3878, lamda sig.>1****		
Dependent: ln(r)	coef.	t	sig.
ln(p)	**1.689699**	**10.49**	****
LA	-0.0000259	-6.55	****
LA_square	6.38E-11	5.95	****
LY_2000	-0.121649	-0.69	
LY_2001	-0.2867924	-1.45	
LY_2002	0.7089738	3.56	****
LY_2003	0.2098351	1.11	
CONST	-6.950496	-4.95	****

IV-2SLS

	First stage regression		
	obs=242, R-sq = 0.1709, F(21,220)=2.16		
Dependent: ln(p)	Coef.	t	sig.
LA	-5.81E-06	-2.75	**
LA_square	-8.31E-12	-1.87	*
LY_2000	0.14141	1.34	
LY_2001	0.1707963	1.37	
LY_2002	0.2860518	2.16	*
LY_2003	0.2187656	1.68	*
type_2	-0.0379462	-0.65	
type_3	-0.0797368	-1.50	
type_4	0.0506728	0.31	
type_5	-0.1342184	-1.17	
type_6	-0.1811546	-1.35	
type_7	-0.0388464	-0.33	
FUR	0.0520186	1.21	
HY_2000	-0.047188	-0.40	
HY_2001	-0.1908059	-1.40	
HY_2003	-0.1618301	-1.10	
HY_2004	-0.1428123	-0.96	
HY_2005	-0.0555139	-0.35	
HY_2006	0.0678337	0.34	
HY_2007	0.2445954	0.95	
FA	2.75E-06	3.93	****
CONST	8.722184	102.07	****
	Instrumental variables (2SLS) regression		
	obs=242, R-sq=0.4114, lamda sig.>1 ****		
Dependent: ln(r)	Coef.	t	sig.
ln (p)	**2.753689**	**5.40**	****
LA	-0.0000313	-7.68	****
LA_square	7.46E-11	6.81	****
LY_2000	-0.1783376	-0.90	
LY_2001	-0.2345336	-1.08	
LY_2002	0.6820098	2.89	**
LY_2003	0.431023	1.97	*
CONST	-16.07865	-3.61	****

****99.9%, ***99%, **95%, * 90%

6.5 *Elasticity of Capital-Land Substitution*

The elasticity of capital-land substitution is defined as the elasticity of the ratio of the factors with respect to the marginal rate of technical substitution between them, reflecting how sensitive the cost-minimizing factor input proportions is to changes in relative factor prices (McFadden 1978). Mathematically it is presented:

$$\sigma = \frac{d\ln(K/L)}{d\ln(r/n)} \tag{56}$$

where σ is the elasticity of capital-land substitution, K is the capital input (non-land input), L is the land input, r is the land price, and n is the capital price.

I employ three approaches to estimate σ. The first approach is to estimate σ directly from the CES function by (19). Given the non-linearity of the CES function, the non-linear least square (NLLS) estimation is employed and the estimating functions are:

$$h = \gamma[\delta S^{-\rho} + (1-\delta)]^{-\frac{1}{\rho}} + \varepsilon \tag{57}$$

$$\ln(h) = \ln(\gamma) - \frac{1}{\rho}\ln(\delta S^{-\rho} + (1-\delta)) + \varepsilon \tag{58}$$

where h is the housing output per unit of land (or the FAR), S is the capital density, γ, δ, ρ are production parameters, and $\sigma = \frac{1}{\rho+1}$ by (17). This approach is straightforward, and it yields estimates not only for σ but also for γ and δ. However, it should be noted that there are several drawbacks of this approach. First, direct estimation of the CES function is associated with the problem of multicollinearity between the inputs and the problem of simultaneous equation bias

(Caddy 1976). Second, since S is not observed but estimated by subtracting land cost and an average proportion of profit from the housing sale value, S tends to be correlated with the error terms. And finally, the NLLS estimation by Stata may not obtain the global best estimates but can only assure the local optimal estimates, for it starts with arbitrarily decided initials and iteratively solves the estimates to minimize the summation of squared residuals.

Table 6-8 reports the estimated results. While ρ and γ from the logarithmic equation by (58) are not significant, γ, δ, and ρ are all significant from the original form by (57) and σ is computed from ρ to be 0.49.

Table 6-8 NLLS Estimations of Housing Production Function

	h			ln(h)		
	R-sq=0.9187, Obs=254			R-sq=0.7691, Obs=254		
	parameter	t	sig.	parameter	t	sig.
γ	0.000307	6.62	****	0.0019933	0.62	
δ	0.9999906	23676.29	****	0.8376112	2.87	**
ρ	1.043628	2.38	**	0.0731662	0.33	
σ	0.4893			0.9318		

σ is calculated from the estimated ρ.

The second approach is to estimate σ from the equilibrium solution of h by (23), which describes also a non-linear relationship and NLLS is used. Assuming the 30% profit of housing sales, the estimating functions are:

$$h(p) = \gamma \left[\frac{1-\delta}{1-\delta\left(\frac{n}{0.7p\gamma\delta}\right)^{\frac{\rho}{1+\rho}}} \right]^{-\frac{1}{\rho}} + \varepsilon \tag{59}$$

$$\ln(h) = \ln(\gamma) - \frac{1}{\rho}\ln\left[\frac{1-\delta}{1-\delta(\frac{n}{0.7p\gamma\delta})^{\frac{\rho}{1+\rho}}}\right] + \varepsilon \tag{60}$$

The advantage of this approach is to avoid the endogenous problem as in the first approach; however, the function form is further complicated, which might impair the precision of the estimation. Table 6-9 reports the estimated results. Only the logarithmic equation by (60) yields significant estimate of ρ, and correspondingly σ is computed to be 0.37.

Table 6-9 NLLS Estimations of Housing Production Function

	h			ln(h)		
	R-sq=0.7448, obs=254			R-sq=0.0427, obs=254		
	parameter	t	sig.	paremeter	t	sig.
γ	0.0007836	1.87	*	0.0008514	2.22	**
δ	0.9999995	4.90E+05	****	0.9999996	6.40E+05	****
ρ	1.597259	1.4		1.674321	1.79	*
σ	0.385			0.374		

σ is calculated from the estimated ρ.

The third approach is to employ the market equilibrium conditions that the marginal factor output equals to the ratio of the factor price over the product price.

$$\frac{\partial H}{\partial K} = \frac{\delta}{\gamma^{\rho}}(\frac{H}{K})^{1+\rho} = \frac{n}{p} \tag{61}$$

$$\frac{\partial H}{\partial L} = \frac{1-\delta}{\gamma^{\rho}}(\frac{H}{L})^{1+\rho} = \frac{r}{p} \tag{62}$$

(61) and (62) yields:

$$\frac{\delta}{1-\delta}(\frac{K}{L})^{-\rho-1} = \frac{n}{r} \tag{63}$$

Taking the logarithm on both sides:

$$\ln(\frac{K}{L}) = \frac{1}{\rho+1}\ln(\frac{\delta}{1-\delta}) + \frac{1}{\rho+1}\ln(\frac{r}{n}) \tag{64}$$

Replace $S = \frac{K}{L}$ and suppose the capital price *n* is spatially invariant constant, then σ can be estimated the follow equation:

$$\ln(S) = a + \sigma \ln(r) + \varepsilon \tag{65}$$

where *S* is the capital density and *r* the land price. Compared with the above two approaches, the third approach is simple in equation form, and σ is a first-order parameter in the estimating function, increasing the possibility that σ is estimated with precision (Caddy 1976).

Nevertheless, this approach is also associated with the endogenous problem since *S* is estimated from *h*, *p* and *r* and there might be uncontrolled factors that both affect *r* and *S*. Therefore, besides using the OLS estimation, the IV method is also employed. I choose the land area (LA), the square of land area (LA_square), and the land leasing years (LY) as the instrumental variables, and I include the housing type (TP) and the time lag between land purchase and housing sale (DIFF) as control variables in the major equation.

Table 6-10 reports the results of OLS and IV-2sls estimations. The estimates of σ are 0.65 and 0.46 from the OLS and IV estimations, respectively, both significantly larger than zero and smaller than unity according to the T-tests, consistent with the theoretical analysis.[48]

To sum up, different approaches and estimation methods generate in general robust estimates of σ, ranging from 0.37 to 0.65. These values fall in the middle

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[48] The T-statistics for $\sigma < 1$ are 11.49 and 7.87 in the OLS and IV estimations, respectively, both significant at a 99.9 % level.

range of results reviewed by McDonald (1981). These values are also in accordance with Ding (2004)'s estimation of 0.32-0.74 in 1993-2000 by using also Beijing data.

Table 6-10 OLS and IV Estimations of Elasticity of Capital-land Substitution

OLS

	obs=254, R-sq=0.6877, sigma sig.<1****		
Dependent: ln(S)	coef.	t	sig.
ln(r)	**0.6468159**	**21.04**	********
type_2	0.1101075	1.56	
type_3	-0.0118449	-0.18	
type_4	-0.3490511	-2.03	**
type_5	-0.1441138	-1.16	
type_6	-0.2347224	-1.58	
type_7	-0.0687507	-0.46	
DIFF	0.0519092	2.32	**
CONST	4.861718	21.34	****

IV-2SLS

	First stage regression		
	obs=254, R-sq = 0.3465, F(13,240)=9.79		
Dependent: ln(r)	Coef.	t	sig.
LA	-0.0000274	-8.00	****
LA_square	6.49E-11	7.11	****
LY_2000	0.1382444	0.88	
LY_2001	0.0299359	0.17	
LY_2002	0.0125844	0.07	
LY_2003	0.1825713	1.08	
type_2	0.3615043	2.78	**
type_3	0.3553335	2.93	**
type_4	-0.4070911	-1.27	
type_5	0.706637	3.00	**
type_6	-0.3522217	-1.29	
type_7	-0.1189245	-0.42	
DIFF	-0.0342514	-0.80	
CONST	7.561267	47.33	****
	Instrumental variables (2SLS) regression		
	obs=254, R-sq=0.6403, sigma sig.<1 ****		
Dependent: ln(S)	Coef.	t	sig.
ln (r)	**0.4594759**	**6.69**	********
type_2	0.174936	2.23	**
type_3	0.0890905	1.15	
type_4	-0.4468925	-2.39	**
type_5	0.033356	0.23	
type_6	-0.3020863	-1.88	*
type_7	-0.0864005	-0.54	
DIFF	0.0367899	1.50	
CONST	6.217255	12.44	****

****99.9%, ***99%, **95%, * 90%

6.6 *Impacts of Elasticity of Capital-Land Substitution*

To examine the impacts of the elasticity of capital-land substitution on urban spatial structure, it first requires examining whether σ has changed. I expect a decrease in σ in the research period of 1999-2003, because of the stringent policies on urban land use around the year 2002. Technology of construction is regarded unlikely to have changed during this short period.

Further, if σ decreases, the land price and capital density curves will become flatter and λ will also decrease, according to the theoretical results by (31), (32), and (34), if the housing prices are held.

Therefore, by dividing the data into two sub-samples: 1999-2001, and 2002-2003, I examine the impacts of σ by comparing the changes in σ and the changes in distance gradients of land prices and capital densities as well as λ. If the changes are consistent with the theoretical results, it would provide certain evidence.

Table 6-11 reports the summary of the estimated results (for more details see Appendix IV). The findings in general provide consistent evidence to the theoretical results. The estimates of σ did decline during the research period: estimates from the OLS estimation were 0.71 and 0.62 for the first and the second sub-periods, respectively; estimates from the IV estimation were 0.56 and 0.44 for the two sub-periods, respectively. This is consistent to the expectation that the stringent policies on urban land use around 2002 suppressed capital-land substitution. The absolute values of distance gradients of land prices and capital densities both decreased (from -0.095 to -0.067 and from -0.066 to -0.059, respectively), indicating that both the two curves were flattened. The estimated λ also decreased according to the results from multiple approaches, indicating the gap between the decaying land and housing prices became smaller.

Table 6-11 Comparison between Estimates for Two Sub-Periods

		1999-2001	2002-2003	change	sig.
sigma	OLS	0.70	0.62	decrease	*
	IV	0.56	0.44	decrease	****
land price gradient	OLS	-0.095	-0.067	flatter	*
capital density gradient	OLS	-0.066	-0.059	flatter	***
lamda	OLS	1.89	1.52	decrease	not tested
	SUR	2.40	1.58	decrease	
	IV	3.25	2.07	decrease	****

****99.9%, ***99%, **95%, * 90%

Note: F-statistics are calculated to test the changes of the estimates in the two sub-periods

It should be noted that the above analysis is based on the assumption that housing price stayed unchanged. Estimated results suggest that the housing price curve became steeper during the research period (the estimated distance gradients of housing price were -0.035 to -0.039, respectively). However, this change is not statistically significant. So there must exist some forces that drove the land price and capital density curves to become flatter; and the decrease in σ was probably one of the reasons.

Chapter 7: Conclusion

The contribution of this dissertation to the literature is twofold. First, it investigates empirically the relationship between the distance elasticities of land prices and housing prices, and it provides evidence for what the urban economic theory predicts: as derived demand for land, land prices drop faster than housing prices towards the urban edges. Second, it investigates the impacts of the capital-land substitution, one of the most important properties of housing services production, on urban spatial structure through analytical exercise, numerical simulation, and empirical estimation. The findings suggest that an increase in the elasticity of capital-land substitution leads to increases in the land price, the capital density, and the housing output per unit of land at any location within the city, flattening of the land price and capital density curves, an increase in the ratio of the distance elasticity of land prices to the distance elasticity of housing prices, an expansion of the city boundary, and a growth in the population.

7.1 Policy and Planning Implications

The findings of this dissertation have three policy and planning implications. The first one links to the skyrocketing housing prices in Beijing and a few other cities in China. The climbing housing prices in cities, such as Beijing, are attributable to many sources; including the rapid urbanization, the historical shortages of housing stocks, the increase in income, the housing pre-sale system, and the rise in land prices.[49] Many developers and investors put the blame on the government for not controlling land prices and they claim the rising land prices are the primary reason for soaring housing prices.[50] However, the findings of this dissertation suggest an alternative explanation. By examining the spatial patterns of land and housing prices and revealing their relationships, this dissertation provides empirical evidence for the theory that land is an input factor in housing services production and the demand for land is a derived demand. Under the land use right system in China, it is mandated that land use rights of the state-owned urban land should be transferred to private developers through open bid process (such as an auction). Thus the final bid land price is determined by the expected housing prices in the future and other market conditions. Given that land is an input to produce housing services, developers who aim to maximize profit will hardly set housing prices lower than market prices, even if the governments reduce land prices. Therefore, based on the theory of housing services production and empirical findings, there is evidence to conclude that it is unlikely that the pace of housing prices increase in Beijing will be slowed down by controlling land prices in land markets, or the impact of land price declines on housing prices will be trivial if there will be any. The policy implication is that the problem of skyrocketing housing prices should be addressed through other approaches, for instance, improvement on the housing financing mechanism, taxes on

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[49] In the housing pre-sale system, developers sell housing properties to residents before buildings are constructed. This pre-sale system was adopted to boost China's urban housing market and solve the problem of lack of startup capital. However, this system favors sellers and push forward housing prices. It has been a hot topic in recent years whether or not to cancel the housing pre-sale system in China.

[50] Some examples (in Chinese) can be found from (retrieved on May, 2010)
http://www.sohochina.com/news/soho_news.aspx?id=13386
http://www.ln.xinhuanet.com/fcpd/2006-05/26/content_7104149.htm
http://lianghui.china.com.cn/zhibo/2009lh/2009-03/06/content_17384784.htm?show=t

vacant housing properties, taxes on income from speculative housing purchases, and provision of affordable public housing services for low-income households.

Second, the findings of this dissertation reveal that the share of land cost in the total value of the property declines with distance from the CBD to the urban fringes and this has important implication on land value assessment. Land tax is regarded as the best tax that does not distort resource allocation in markets. Land tax is also important as a widely used approach to improve social welfare by redistributing income and reducing poverty, according to Henry George (1879). The moral basis for levying tax on land is to collect the value increments of land that are not due to landowner actions, but due to the population growth of the city and the improvement of infrastructure by public expenditure (Nicholson 1998, Nechyba 1988). In comparison, a tax on land improvements is not as desirable, since it depresses investment and development. Therefore, economists favor the split-rate property tax, and argue that a switch from a single-rate property tax to a split-rate property tax would increase land use efficiency, minimize excess burden, stimulate economic development, preserve environment, reduce urban sprawl, and improve quality of life (Dye & England 2009, Cohen & Coughlin 2005). In the split-rate tax system, different tax rates are set for land and improvements and often, that for land is higher than improvements. Given the theoretical advantages of land tax over a general property tax, many local jurisdictions (such as two counties in Hawaii and sixteen Pennsylvania municipalities) apply split-rate property tax in order to improve efficiency and facilitate development (Kwak et al. 2009).

Currently, one of the greatest concerns of the split-rate property tax system lies in the property assessment. Without observed land value, land is typically assessed as a certain percentage of the total property value (such as 20%) regardless the location and land use intensity, and this leads to inaccurate land valuation. This dissertation finds that the share of land cost over the total housing property in the city of Beijing can be high as one-third at the central locations and drop to only 3% at 30 kilometers away from the city center. The findings of this dissertation can improve the accuracy of land value assessments and improve the efficiency of the split-rate property tax system, by adopting variant land value shares depending on locations instead of the fixed share of land value that is used currently in many local municipalities. Certainly, empirical and/or simulation studies are needed for specific cities to obtain more accurate and fitting parameters.

The third implication is associated with zoning ordinances and planning regulations on land use and land development. Given a certain level of technology, efficient land development requires capital-land substitution in housing services production. Regulative restrictions on building height and density not only affect housing output, but more important, they restrict capital-land substitution and thus affect the overall land value, which in turn influences the social welfare. The simulated results based on the Beijing data illustrate that a 1% change in the elasticity of capital-land substitution leads to 14-18% changes in the total land value and 15-19% changes in the total housing output. These numbers suggest remarkable opportunity cost and social welfare impacts that may be caused by planning regulations on land use and development intensity. Therefore, careful examination on the potential impacts is indeed needed before imposing any restriction on land development for environment justice and land use externalities.

7.2 Recommendation for Future Studies

One direction to extend this dissertation is to build longer period data for housing and land development data to document changes in urban spatial structure and capital-land substitution over time. Empirical studies can also be improved by collecting more detailed data including housing units' characteristics and neighborhood features to better control the estimation of spatial variant housing prices.

Also, this dissertation can be extended to study locational differences of the marginal effects brought by policies and planning regulations. As demonstrated in this dissertation, numerical simulations suggest that the impacts of changes in capital-land substitution differ considerably across locations, suggesting that constraints on land use will cause different opportunity costs and social welfare impacts at different places. Therefore, examination of the locational variant influences of the same policy or regulation will have practical significance for policy assessment.

Third, a formal model can be developed as an extension of this dissertation to investigate the impacts of the expected growth of housing prices on land prices over the urban space. This will be helpful in understanding land market behaviors and developing land use policies and planning regulations.

Finally, the research can be extended to introduce a VES housing services production function, in which the elasticity of capital-land substitution depends on the ratio of land and capital inputs and varies with location. Numerical simulations and empirical studies can be conducted to link the variant elasticity of capital-land substitution to urban land development and urban spatial structure.

Appendices

Appendix I: Solutions of Impacts of Elasticity of Capital-Land Substitution

$$\frac{\partial S}{\partial \sigma}$$

$$\frac{\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\left(\frac{\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{\sigma^{2}}+\frac{(-1+\sigma)\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)\sigma}\right)}{\left(-1+\frac{1}{\sigma}\right)^{2}}$$

$$\frac{\partial r}{\partial \sigma}$$

$$\begin{aligned}
&-\frac{n\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\sigma^{2}\left(\frac{\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{\sigma^{2}}+\frac{(-1+\sigma)\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)\sigma}\right)}{(-1+\sigma)^{2}}-\frac{1}{(-1+\sigma)^{2}}\left(p\gamma\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{\sigma}{-1+\sigma}}\right.\\
&\sigma^{2}\left(\frac{\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\left(-1+\frac{1}{\sigma}\right)\left(\frac{\frac{\sigma\,\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{-1+\sigma}+\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right]}{\sigma^{2}}+\left(-1+\frac{n}{n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}}\right)\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)}{1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta}+\right.\\
&\left.\left.\frac{\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]}{\sigma^{2}}\right)\right)
\end{aligned}$$

$$\frac{\partial h}{\partial \sigma}$$

$$-\frac{1}{(-1+\sigma)^2}\gamma\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{\sigma}{-1+\sigma}}\sigma^2$$

$$\left(\frac{\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\left(-1+\frac{1}{\sigma}\right)\left(\frac{\frac{\sigma\,\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{-1+\sigma}+\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right]}{\sigma^2}+\left(-1+\frac{n}{n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}}\right)\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)}{1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta}+\right.$$

$$\left.\frac{\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]}{\sigma^2}\right)\Bigg)$$

$$\frac{\partial\lambda}{\partial\sigma}$$

$$\Bigg(n\,p\,\gamma\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}(-1+\delta)\left(1+\delta\left(-1+\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\right)\right)^{\frac{\sigma}{-1+\sigma}}$$

$$\Bigg(-\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{1}{\sigma}}\sigma\Bigg(\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]+$$

$$p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}(-1+\sigma)\,\sigma\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]+\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]\Bigg)+$$

$$n\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{1-\sigma}}\Bigg(-(-1+\sigma)\,\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right]+\sigma\,\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]\Bigg)\Bigg)\Bigg)\Bigg/$$

$$\Bigg(\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\left(\delta\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{\sigma}{1-\sigma}}-(-1+\delta)\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{\sigma}{1-\sigma}}\right)^{\frac{1}{\sigma}}\right)$$

$$\left(n\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}-p\gamma\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{\sigma}{-1+\sigma}}\right)^{2}(-1+\sigma)^{2}\sigma\Bigg)$$

$$\frac{\partial^2 S}{\partial p\,\partial\sigma}$$

$$-\frac{1}{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)^{2}(-1+\sigma)^{2}}\Bigg(\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}$$

$$\Bigg(\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\sigma\,\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]+(-1+\sigma)\left(n(-1+\sigma)\left(1+\sigma\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\left(1-\sigma+\sigma^{2}\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)\right)\Bigg)\Bigg)$$

$$\frac{\partial^2 r}{\partial p \partial \sigma}$$

$$\frac{n\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}}{p\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)}+\frac{p\gamma^2\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\delta\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(1+\delta\left(-1+\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\right)\right)^{\frac{1}{-1+\sigma}}}{-n+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}}-$$

$$\frac{n\gamma\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{1}{-1+\sigma}}}{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)(-1+\sigma)}-$$

$$\frac{p\gamma^2\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\delta\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(1+\delta\left(-1+\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\right)\right)^{\frac{1}{-1+\sigma}}}{\left(-n+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)(-1+\sigma)}+\frac{n\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\sigma\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{p\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)}+$$

$$\frac{p\gamma^2\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\delta\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(1+\delta\left(-1+\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\right)\right)^{\frac{1}{-1+\sigma}}\sigma\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{-n+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}}+$$

$$\frac{n\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\sigma\left(\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\left(1-3\sigma+2\sigma^2\right)\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)}{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)^2(-1+\sigma)^2}-$$

$$\frac{1}{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)^2(-1+\sigma)^2}\left(p\gamma^2\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\delta\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(1+\delta\left(-1+\left(\left(\frac{\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\delta}{n(-1+\delta)}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\right)\right)^{\frac{1}{-1+\sigma}}\sigma\right.$$

$$\left.\left(\left(n-p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\right)\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]+p\gamma\left(\frac{n}{p\gamma\delta}\right)^{\sigma}\left(1-3\sigma+2\sigma^2\right)\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]\right)\right)-\frac{1}{\left(\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta\right)\left(-1+\frac{1}{\sigma}\right)\sigma^2}\left(\gamma\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\right.$$

$$\left.\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}\delta\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{1}{-1+\sigma}}(-1+\sigma)\left(\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right]-\frac{\sigma\left(\frac{\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{\sigma^2}+\frac{(-1+\sigma)\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)\sigma}\right)}{\left(-1+\frac{1}{\sigma}\right)^2}\right)\right)-$$

$$\frac{1}{\left(\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta\right)\left(-1+\frac{1}{\sigma}\right)}\left(\gamma\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}\delta\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{1}{-1+\sigma}}(-1+\sigma)\right.$$

$$\left.\left(\frac{\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\left(\frac{\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right]}{\sigma^2}+\frac{(-1+\sigma)\left(\frac{\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{\sigma^2}+\frac{(-1+\sigma)\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)\sigma}\right)}{\left(-1+\frac{1}{\sigma}\right)^2\sigma}\right)}{\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)(-1+\sigma)}-\frac{\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]}{(-1+\sigma)^2}\right)\right)-$$

$$\frac{1}{\left(-1+\frac{1}{\sigma}\right)^2}\left(\gamma\left(1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right)^{\frac{\sigma}{-1+\sigma}}\right.$$

$$\left.\left(\frac{\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\left(-1+\frac{1}{\sigma}\right)\left(\frac{\mathrm{Log}\left[\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right]}{\sigma^2}+\frac{(-1+\sigma)\left(\frac{\mathrm{Log}\left[\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right]}{\sigma^2}+\frac{(-1+\sigma)\,\mathrm{Log}\left[\frac{n}{p\gamma\delta}\right]}{\left(-1+\left(\frac{n}{p\gamma\delta}\right)^{1-\sigma}\delta\right)\sigma}\right)}{\left(-1+\frac{1}{\sigma}\right)^2\sigma}\right)}{1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta}+\frac{\mathrm{Log}\left[1-\delta+\left(\left(\frac{\left(\frac{n}{p\gamma\delta}\right)^{-1+\sigma}-\delta}{1-\delta}\right)^{\frac{1}{-1+\frac{1}{\sigma}}}\right)^{\frac{-1+\sigma}{\sigma}}\delta\right]}{\sigma^2}\right)\right)$$

Appendix II: Simulated Impacts of Capital-Land Substitution

(Selected parameter values)

p	n	γ	δ	σ	$\frac{\partial S}{\partial \sigma}$	$\frac{\partial^2 S}{\partial p \partial \sigma}$	$\frac{\partial r}{\partial \sigma}$	$\frac{\partial^2 r}{\partial p \partial \sigma}$	$\frac{\partial \lambda}{\partial \sigma}$	$\frac{\partial h}{\partial \sigma}$
1000	1	0.1	0.1	0.1	3.0702	0.00160289	8.16207	0.0112323	0.0297317	0.00407306
1000	1	0.1	0.1	0.5	8.5754	0.00807346	14.8503	0.0234257	0.0776473	0.00756336
1000	1	0.1	0.1	0.9	27.0033	0.0388654	30.7643	0.0577676	0.215826	0.0130116
1000	1	0.1	0.5	0.1	7.56249	0.00239554	82.0227	0.0895852	0.059599	0.354941
1000	1	0.1	0.5	0.5	80.0829	0.0593352	325.38	0.405463	0.32032	2.38584
1000	1	0.1	0.5	0.9	5897.16	9.80324	6660.91	12.5581	3.01938	184.284
1000	1	0.1	0.9	0.1	14.7907	0.00357154	348.17	0.362961	0.0728364	1.20111
1000	1	0.1	0.9	0.5	1102.53	0.726286	6446.27	7.54881	0.521065	41.9717
1000	1	0.1	0.9	0.9	2.52334×10^{9}	5.73211×10^{6}	1.66521×10^{9}	4.18856×10^{6}	14.2214	1.32485×10^{8}
1000	1	0.5	0.1	0.1	6.03828	0.00210748	57.242	0.0632802	0.0116386	0.00407306
1000	1	0.5	0.1	0.5	32.6895	0.0246564	136.194	0.168884	0.056923	0.00756336
1000	1	0.5	0.1	0.9	227.374	0.282051	446.451	0.673825	0.304314	0.0130116
1000	1	0.5	0.5	0.1	11.9472	0.00308436	446.524	0.458471	0.0193153	0.354941
1000	1	0.5	0.5	0.5	244.529	0.160731	2141.31	2.38584	0.186194	2.38584
1000	1	0.5	0.5	0.9	72215.5	105.932	112069.	184.284	3.13397	184.284
1000	1	0.5	0.9	0.1	21.273	0.00452759	1809.16	1.83043	0.0226749	1.20111
1000	1	0.5	0.9	0.5	3021.69	1.81863	38950.	41.9717	0.28267	41.9717
1000	1	0.5	0.9	0.9	6.83001×10^{10}	1.27341×10^{8}	6.41848×10^{10}	1.32485×10^{8}	11.4111	1.32485×10^{8}
1000	1	2	0.1	0.1	9.32596	0.00265411	250.727	0.260053	0.00450764	0.0194279
1000	1	2	0.1	0.5	88.2102	0.0604291	695.819	0.784029	0.0380003	0.0494516
1000	1	2	0.1	0.9	1194.21	1.38486	3248.49	4.4427	0.352157	0.122496
1000	1	2	0.5	0.1	16.7242	0.00383249	1827.25	1.84397	0.00690516	1.4232
1000	1	2	0.5	0.5	591.682	0.367349	9635.46	10.2271	0.112759	10.2271
1000	1	2	0.5	0.9	508607.	689.408	993658.	1502.26	3.08228	1502.26
1000	1	2	0.9	0.1	28.245	0.00556523	7308.21	7.33645	0.0079473	4.808
1000	1	2	0.9	0.5	6834.28	3.94992	168606.	175.44	0.165971	175.44
1000	1	2	0.9	0.9	7.70159×10^{11}	1.26678×10^{9}	9.3813×10^{11}	1.70829×10^{9}	9.65307	1.70829×10^{9}

p	n	γ	δ	σ	$\frac{\partial S}{\partial \sigma}$	$\frac{\partial^2 S}{\partial p \partial \sigma}$	$\frac{\partial r}{\partial \sigma}$	$\frac{\partial^2 r}{\partial p \partial \sigma}$	$\frac{\partial \lambda}{\partial \sigma}$	$\frac{\partial h}{\partial \sigma}$
10000	1	0.1	0.1	0.1	7.58745	0.000236694	121.193	0.0128781	0.00732189	0.00476872
10000	1	0.1	0.1	0.5	54.3388	0.00388134	313.857	0.0368196	0.0469867	0.0115105
10000	1	0.1	0.1	0.9	528.367	0.0631233	1233.88	0.176225	0.331021	0.0265717
10000	1	0.1	0.5	0.1	14.2061	0.000343962	905.975	0.0920181	0.0116126	0.355702
10000	1	0.1	0.5	0.5	382.763	0.0243658	4583.62	0.496639	0.145392	2.52874
10000	1	0.1	0.5	0.9	195371.	27.4798	341423.	53.6794	3.11999	328.137
10000	1	0.1	0.9	0.1	24.5793	0.000502068	3641.02	0.36656	0.0134835	1.2019
10000	1	0.1	0.9	0.5	4563.03	0.268363	81554.7	8.61178	0.21689	43.557
10000	1	0.1	0.9	0.9	2.38207×10^{11}	4.15457×10^{7}	2.55898×10^{11}	4.94105×10^{7}	10.4722	3.43121×10^{8}
10000	1	0.5	0.1	0.1	11.9488	0.000307995	642.429	0.0654378	0.0023156	0.00476872
10000	1	0.5	0.1	0.5	163.003	0.0107059	1914.31	0.207731	0.0280428	0.0115105
10000	1	0.5	0.1	0.9	3397.2	0.381827	11049.3	1.44465	0.372798	0.0265717
10000	1	0.5	0.5	0.1	20.4967	0.000441408	4595.55	0.461604	0.0034248	0.355702
10000	1	0.5	0.5	0.5	1037.26	0.0627822	25231.	2.62682	0.0798291	2.52874
10000	1	0.5	0.5	0.9	1.71458×10^{6}	222.702	3.84798×10^{6}	556.256	3.00682	328.137
10000	1	0.5	0.9	0.1	33.7053	0.000636975	18316.3	1.835	0.00390521	1.2019
10000	1	0.5	0.9	0.5	11551.2	0.656336	434479.	44.6031	0.115947	43.557
10000	1	0.5	0.9	0.9	3.30391×10^{12}	5.08062×10^{8}	4.70361×10^{12}	8.00752×10^{8}	8.71811	3.43121×10^{8}
10000	1	2	0.1	0.1	16.7265	0.000383686	2610.87	0.26276	0.000812889	0.0201421
10000	1	2	0.1	0.5	396.454	0.0248785	8371.75	0.876821	0.0170724	0.0600061
10000	1	2	0.1	0.9	15675.	1.69975	64539.5	8.02144	0.391165	0.190667
10000	1	2	0.5	0.1	27.308	0.000544475	18451.3	1.84786	0.00115706	1.42398
10000	1	2	0.5	0.5	2371.4	0.139629	105338.	10.7709	0.0465157	10.5514
10000	1	2	0.5	0.9	9.87896×10^{6}	1215.71	2.69567×10^{7}	3683.56	2.85785	2391.24
10000	1	2	0.9	0.1	43.4907	0.000779114	73377.1	7.34206	0.00130544	4.80882
10000	1	2	0.9	0.5	25207.4	1.40748	1.78601×10^{6}	181.122	0.0666186	178.872
10000	1	2	0.9	0.9	2.54366×10^{13}	3.59465×10^{9}	4.50591×10^{13}	7.04957×10^{9}	7.54982	3.58966×10^{9}

p	n	γ	δ	σ	$\frac{\partial S}{\partial \sigma}$	$\frac{\partial^2 S}{\partial p \partial \sigma}$	$\frac{\partial r}{\partial \sigma}$	$\frac{\partial^2 r}{\partial p \partial \sigma}$	$\frac{\partial \lambda}{\partial \sigma}$	$\frac{\partial h}{\partial \sigma}$
30000	1	0.1	0.1	0.1	10.4386	0.0000945261	381.01	0.0130483	0.00336718	0.00509018
30000	1	0.1	0.1	0.5	116.123	0.00259874	1094.05	0.040339	0.0333144	0.0165721
30000	1	0.1	0.1	0.9	1904.38	0.072533	5622.17	0.250885	0.362239	0.0634334
30000	1	0.1	0.5	0.1	18.328	0.000136026	2749.6	0.0922644	0.00507222	0.356054
30000	1	0.1	0.5	0.5	759.87	0.0155356	14786.6	0.518215	0.096899	2.68204
30000	1	0.1	0.5	0.9	876420.	38.8278	1.8226×10^{6}	89.9672	3.0519	835.914
30000	1	0.1	0.9	0.1	30.5706	0.000196963	10977.	0.366918	0.00581214	1.20227
30000	1	0.1	0.9	0.5	8630.52	0.164904	256728.	8.84528	0.141716	45.1723
30000	1	0.1	0.9	0.9	1.48495×10^{12}	7.89247×10^{7}	1.94056×10^{12}	1.14184×10^{8}	9.22063	1.51698×10^{9}
30000	1	0.5	0.1	0.1	15.6472	0.000122257	1954.11	0.0656587	0.00101332	0.00509018
30000	1	0.5	0.1	0.5	330.731	0.00697447	6188.55	0.217309	0.0189805	0.0165721
30000	1	0.5	0.1	0.9	11462.6	0.417058	45064.4	1.88423	0.388456	0.0634334
30000	1	0.5	0.5	0.1	25.7749	0.000173824	13831.8	0.46192	0.00145228	0.356054
30000	1	0.5	0.5	0.5	2001.07	0.0394679	78460.1	2.68204	0.052115	2.68204
30000	1	0.5	0.5	0.9	6.92104×10^{6}	286.844	1.81564×10^{7}	835.914	2.89118	835.914
30000	1	0.5	0.9	0.1	41.2952	0.000249145	55022.3	1.83545	0.0016417	1.20227
30000	1	0.5	0.9	0.5	21461.6	0.400654	1.33371×10^{6}	45.1723	0.0748222	45.1723
30000	1	0.5	0.9	0.9	1.68843×10^{13}	8.08228×10^{8}	2.86252×10^{13}	1.51698×10^{9}	7.77177	1.51698×10^{9}
30000	1	2	0.1	0.1	21.3223	0.000151579	7869.71	0.263034	0.000346094	0.0204723
30000	1	2	0.1	0.5	782.583	0.0159449	26184.5	0.898903	0.0112601	0.0726075
30000	1	2	0.1	0.9	50904.6	1.80008	247499.	9.94679	0.39706	0.356777
30000	1	2	0.5	0.1	33.8065	0.000213637	55413.5	1.84824	0.000481744	1.42434
30000	1	2	0.5	0.5	4504.19	0.0870066	322291.	10.8932	0.0299319	10.8932
30000	1	2	0.5	0.9	3.7259×10^{7}	1474.73	1.17601×10^{8}	5162.01	2.72328	5162.01
30000	1	2	0.9	0.1	52.761	0.000303897	220226.	7.34262	0.000540042	4.80919
30000	1	2	0.9	0.5	46409.7	0.855602	5.42379×10^{6}	182.34	0.0425317	182.34
30000	1	2	0.9	0.9	1.15054×10^{14}	5.12785×10^{9}	2.39564×10^{14}	1.18206×10^{10}	6.78348	1.18206×10^{10}

Appendix III: Estimation of CES Housing Production Function

Supposing it is already known that $\sigma = 0.5$, the other two parameters γ and δ of the CES housing production function can be estimated by the following approaches.

The first approach is to substitute $\sigma = 0.5$ in the production function by (19) and it can be written:

$$h^{-1} = \gamma^{-1}\delta S^{-1} + \gamma^{-1}(1-\delta) \qquad (66)$$

where *h* is the housing output per unit of land and *S* is the capital intensity per unit of land. Thus γ and δ can be estimated by the following linear function:

$$h^{-1} = b_1 S^{-1} + b_2 + \varepsilon \qquad (67)$$

where $b_1 = \gamma^{-1}\delta$, $b_2 = \gamma^{-1}(1-\delta)$, and ε is the disturbance term. h is measured by the floor space in square meters; S is the capital density, estimated by $S = (ph * 0.7 - r)/n$ where n is assumed to be unity and 0.7 comes from the assumption of the 30% average profit ratio of sales. Once b_1 and b_2 are estimated, γ and δ can be easily to be calculated. Table III-1 reports the estimated results and the estimated γ and δ are respectively 0.000315719 and 0.999957485.

Table III-1

	h^{-1}		
	Obs=254, R-sq=0.573		
	Coef.	t	Sig.
b1	3167.237	18.39	****
b2	0.1346622	10.22	****
delta	0.999957485		
gama	0.000315719		

****99.9%, ***99%, **95%, * 90%

The second approach is to substitute $\sigma = 0.5$ in (57) or (58) and apply the non-linear least square method, where γ and δ can be estimated by treating h as the dependent variable and p as the independent variable. Table III-2 reports the estimated results and the estimated γ and δ are 0.0016509 and 0.9997479, 0.0009533 and 0.999854, respectively.

Table III-2

	h			ln(h)		
	Obs=254, R-sq=0.7456			Obs=254, R-sq=0.8513		
	Coef.	t	Sig.	Coef.	t	Sig.
gama	0.0016509	1.42		0.0009533	3.29	****
delta	0.9997479	4631.85	****	0.999854	16649.77	****

****99.9%, ***99%, **95%, * 90%

Based on the above estimation, γ and δ should fall into the intervals of 0.99975-0.99996 and 0.000316-0.000953, respectively.

Appendix VI: Estimation of Two Sub-Periods

Sigma:

OLS: 0.70→0.62

	1999-2001			2002-2003		
	obs=151, R-sq=0.7265			obs=254, R-sq=0.6877		
Dependent=ln(S)	coef.	t	sig.	coef.	t	sig.
ln(r)	0.7022315	17.49	****	0.6178752	13.34	****
type_2	0.0428595	0.42		0.0970794	1.02	
type_3	0.008564	0.11		0.0141701	0.12	
type_4	-0.2547021	-1.52		(dropped)		
type_5	-0.1526961	-1.18		0.1513824	0.36	
type_6	-0.1404384	-0.78		-0.4004511	-1.63	
type_7	0.0267254	0.18		(dropped)	0	
DIFF	0.0137849	0.54		0.1116875	2.7	**
CONST	4.402439	14.74	****	5.092465	14.73	****

****99.9%, ***99%, **95%, * 90%

IV: 0.56→0.44

	1999-2001			2002-2003		
	First stage regression			First stage regression		
	obs=151, R-sq = 0.3912, F(11,139)=8.12			obs=103, R-sq = 0.3227, F(8,94)=5.6		
Dependent: ln (r)	Coef.	t	sig.	Coef.	t	sig.
LA	-0.0000445	-2.74	**	-0.0000217	-4.82	****
LA_square	1.97E-10	0.58		5.28E-11	4.59	****
LY_2000	0.0613893	0.41		(dropped)		
LY_2001	0.0387226	0.23		(dropped)		
LY_2002	(dropped)			-0.1150343	-0.63	
LY_2003	(dropped)			(dropped)		
type_2	0.5002565	2.7	**	0.308107	1.62	
type_3	0.2794933	1.97	*	0.5283118	2.34	**
type_4	-0.3259073	-1.07		(dropped)		
type_5	0.5889165	2.47	**	0.9566668	1.16	
type_6	-0.3797841	-1.17		-0.2855733	-0.58	
type_7	-0.074253	-0.28		(dropped)		
DIFF	-0.009061	-0.19		-0.1078504	-1.18	
CONST	7.761807	39.56	****	7.685078	43.32	****
	Instrumental variables (2SLS) regression			Instrumental variables (2SLS) regression		
	obs=151, R-sq=0.7008			obs=254, R-sq=0.6403		
Dependent: ln(S)	Coef.	t	sig.	Coef.	t	sig.
ln (r)	0.5556762	6.87	****	0.4415493	3.97	****
type_2	0.1054098	0.95		0.1596857	1.48	
type_3	0.0720154	0.81		0.144792	1	
type_4	-0.3374698	-1.88	*	(dropped)		
type_5	-0.0225876	-0.15		0.3480703	0.76	
type_6	-0.1892699	-1		-0.4563119	-1.72	*
type_7	0.0022114	0.01		(dropped)		
DIFF	0.009637	0.36		0.0781371	1.62	
CONST	5.467817	9.24	****	6.375571	7.84	****

****99.9%, ***99%, **95%, * 90%

Distance gradients:

Land price gradient:

OLS: -0.095→-0.067

Dependent: ln(r)	1999-2001			2002-2003		
	obs=159, R-sq=0.6479			obs=107, R-sq=0.6186		
	Coef.	t	sig.	Coef.	t	sig.
distance	-0.095465	-4.11	****	-0.0667709	-2.56	***
district_2	-0.4776704	-1.02		0.1628664	0.28	
district_3	-0.1774067	-0.52		-0.2120427	-0.35	
district_4	-0.0023648	-0.01		-0.4940625	-1.05	
district_5	-0.0365615	-0.12		-0.6162681	-1.25	
district_6	0.055358	0.13		-0.6907258	-1.13	
district_7	-1.490193	-2.86	***	-2.125974	-3.09	****
LA	-0.0000163	-3	****	5.92E-07	0.36	
LY_2000	-0.0930291	-0.68		(dropped)		
LY_2001	-0.1248155	-0.81		(dropped)		
LY_2002	(dropped)			0.1782791	1.16	
LY_2003	(dropped)			(dropped)		
CONST	8.78168	29.21	****	8.737746	19.27	****

****99.9%, ***99%, **95%, * 90%

Capital density gradient:

OLS: -0.066→-0.059

Dependent: ln(S)	1999-2001			2002-2003		
	obs=139, R-sq=0.3935			obs=103, R-sq=0.5141		
	Coef.	t	sig.	Coef.	t	sig.
distance	-0.0661747	-3.3	***	-0.0588481	-2.99	**
district_2	-0.607306	-1.5		-0.0312926	-0.08	
district_3	0.0048936	0.02		-0.2796232	-0.63	
district_4	-0.2657346	-1.08		-0.5325892	-1.54	
district_5	-0.2230217	-0.88		-0.5377934	-1.49	
district_6	-0.1732663	-0.46		-0.748735	-1.67	
district_7	-0.7576845	-1.51		-0.8589035	-1.66	*
type_2	0.2532012	1.6		0.2199796	1.66	*
type_3	0.2213518	1.82	*	0.3006749	1.99	**
type_4	-0.4055043	-1.31		(dropped)		
type_5	0.2127154	0.92		0.3718363	0.67	
type_6	0.1092993	0.31		-0.169886	-0.51	
type_7	-0.0641873	-0.29		(dropped)		
FUR	0.0996064	1.01		0.0757755	0.58	
DIFF	0.0114207	0.29		0.0970926	1.72	*
CONST	10.40865	41.45	****	10.73471	32.47	****

****99.9%, ***99%, **95%, * 90%

Housing price gradient:

OLS: -0.035→-0.039

Dependent: ln(p)	1999-2001			2002-2003		
	obs=139,R-sq=0.5937			obs=103,R-sq=47660.5115		
	Coef.	t	sig.	Coef.	t	sig.
distance	-0.0350837	-4.6	****	-0.0386754	-3.83	****
district_2	-0.1205275	-0.79		0.1353335	0.65	
district_3	-0.3313874	-2.83	***	-0.1954402	-0.87	
district_4	-0.280393	-3.05	****	-0.0955313	-0.54	
district_5	-0.184606	-1.95	*	0.0069479	0.04	
district_6	-0.303356	-2.14	***	-0.1573831	-0.69	
district_7	-0.5480769	-2.91	***	0.00145	0.01	
type_2	0.0006714	0.01		-0.0159167	-0.23	
type_3	-0.059781	-1.32		-0.0875994	-1.13	
type_4	-0.0487966	-0.42		(dropped)		
type_5	-0.2066416	-2.36	***	-0.1974976	-0.69	
type_6	-0.0311322	-0.23		0.0200667	0.12	
type_7	-0.0033267	-0.04		(dropped)		
FUR	-0.0042606	-0.11		0.0942277	1.38	
FA	8.71E-07	1.53		1.40E-07	0.72	
HY_2000	-0.006265	-0.1		(dropped)		
HY_2001	-0.0789065	-1.33		(dropped)		
HY_2003	-0.0052702	-0.07		-0.216687	-1.71	*
HY_2004	-0.0170736	-0.19		-0.1243462	-1.02	
HY_2005	-0.1262459	-0.79		0.0120849	0.09	
HY_2006	0.0686494	1.25		0.0638622	1.13	
HY_2007	0.2157619	0.98		0.2450864	0.8	
CONST	9.385247	85.25	****	9.523182	45.29	****

****99.9%, ***99%, **95%, * 90%

<u>Lamda:</u>

OLS: 1.886→1.519

(according to above OLS estimates)

SUR: 2.400→1.584

	SUR 1999-2001						SUR 2002-2003					
Dependent:	ln (p)			ln (r)			ln (p)			ln (r)		
	obs=139, R-sq=0.5937			obs=139, R-sq=0.5370			obs=103, R-sq=0.4761			obs=103, R-sq=0.5158		
	coef.	t	sig.	coef.	t	sig.	coef.	t	sig.	coef.	t	sig.
distance	-0.035033	-5	****	-0.0839871	-4.27	****	-0.038257	-4.18	****	-0.060597	-2.62	***
district_2	-0.120029	-0.86		-0.4213375	-1.09		0.1403827	0.74		0.1666664	0.33	
district_3	-0.331745	-3.09	***	0.0348868	0.11		-0.195436	-0.95		-0.158523	-0.29	
district_4	-0.280464	-3.33	****	-0.0601065	-0.25		-0.098352	-0.62		-0.501811	-1.21	
district_5	-0.184784	-2.13	***	-0.0346842	-0.14		0.0066776	0.04		-0.664141	-1.53	
district_6	-0.303437	-2.33	***	0.1701211	0.46		-0.163482	-0.79		-0.811953	-1.51	
district_7	-0.548974	-3.17	***	-0.3674741	-0.77		-0.00042	0		-1.654584	-2.7	***
type_2	0.0011134	0.02					-0.008698	-0.14				
type_3	-0.059166	-1.42					-0.071213	-1.01				
type_4	-0.049894	-0.47					(dropped)					
type_5	-0.205077	-2.56	**				-0.174516	-0.67				
type_6	-0.032229	-0.26					0.0303399	0.2				
type_7	-0.003806	-0.05					(dropped)					
FUR	-0.004111	-0.12					0.0921512	1.49				
FA	8.97E-07	1.71	*				1.57E-07	0.89				
HY_2000	-0.006195	-0.11					(dropped)					
HY_2001	-0.079076	-1.45					(dropped)					
HY_2003	-0.005365	-0.07					-0.199691	-1.74	*			
HY_2004	-0.01825	-0.22					-0.111332	-1				
HY_2005	-0.127976	-0.87					0.0288473	0.24				
HY_2006	0.08542	1.21					0.058776	0.98				
HY_2007	0.2184223	1.08					0.2981786	1.07				
LA				-0.0000283	-5.88	****				-8.28E-07	-0.56	
LY_2000				-0.0714568	-0.57					(dropped)		
LY_2001				-0.038906	-0.28					(dropped)		
LY_2002				(dropped)						8.638426	21.54	****
LY_2003				(dropped)						(dropped)		
CONST	9.383475	92.91	****	8.801487	34.85	****	9.49856	49.78	****	8.673336	21.76	****

****99.9%, ***99%, **95%, * 90%

IV: 3.25→2.07

Dependent: ln(p)	1999-2001			2002-2003		
	first stage regression			first stage regression		
	obs=139, R-sq=0.1559, F(18,120)=1.23			obs=103, R_sq=0.1673, F(13,89)=1.38		
	coef.	P>t	sig.	Coef.	t	sig.
LY_2000	0.1059809	1.01		(dropped)		
LY_2001	0.1297779	1.02		(dropped)		
LY_2002	(dropped)			0.0615543	0.85	
LY_2003	(dropped)			(dropped)		
LA	-5.46E-06	-0.62		-3.47E-06	-1.21	
LA_square	-9.22E-11	-0.58		-9.20E-12	-1.63	
type_2	0.0089699	0.1		-0.0736675	-0.86	
type_3	-0.0694731	-1.09		-0.0870994	-0.89	
type_4	0.0712955	0.45		(dropped)		
type_5	-0.1391959	-1.15		-0.1035485	-0.3	
type_6	-0.2103704	-1.15		-0.1406371	-0.68	
type_7	0.0006209	0.01		(dropped)		
FUR	0.0122603	0.23		0.1480448	1.87	*
HY_2000	-0.020139	-0.18		(dropped)		
HY_2001	-0.1603289	-1.2		(dropped)		
HY_2003	-0.0610789	-0.39		-0.2219412	-1.35	
HY_2004	-0.1647709	-0.99		-0.1604551	-1.04	
HY_2005	-0.1216464	-0.52		-0.06413	-0.37	
HY_2006	(dropped)			(dropped)		
HY_2007	0.0195644	0.06		0.3192789	0.83	
FA	3.17E-06	2.56	**	2.12E-06	2.17	**
CONST	8.731107	87.21	****	8.954684	52.39	****
	Instrumental variable (2SLS) regression			Instrumental variable (2SLS) regression		
	obs=139, R-sq=0.1765, lamda>1 ***			obs=103, R_sq=2193, lamda>1 *		
dependent: ln(r)	coef.	t	sig.	coef.	t	sig.
ln (p)	3.252312	4.44	****	2.070356	3.35	***
LY_2000	-0.2689838	-1.29		(dropped)		
LY_2001	-0.2278908	-1		(dropped)		
LY_2002	(dropped)			-0.2373032	-1.37	
LY_2003	(dropped)			(dropped)		
LA	-0.0000871	-3.85	****	-0.0000271	-5.92	****
LA_square	1.18E-09	2.39	**	6.48E-11	5.46	****
CONST	-20.02213	-3.15	**	-10.51844	-1.92	**

****99.9%, ***99%, **95%, * 90%

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