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The Effect of Land-Use Controls on Urban Sprawl

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
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TABLE OF CONTENTS

LIST OF TABLES

THE EFFECT OF LAND-USE CONTROLS ON URBAN SPRAWL

Marin Geshkov

ABSTRACT

Chapter 1 provides a discussion of definitions, criticisms, and measurements of urban sprawl. Land-use controls are surveyed in Chapter 2. In Chapter 3, we present the monocentric urban model, followed by a discussion of extensions of that model to include land-use controls. Chapter 4 is a survey of previous empirical analysis of the monocentric model, while Chapters 5 and 6 present our own empirical work.

In general, our empirical results support the theoretical predictions as well as providing support for policies to control sprawl. In particular, the results support the use of maximum lot-size zoning, urban growth boundaries, and density restrictions in the form of minimum building heights, minimum square-footage limits, maximum building permits, and minimum persons per room.

The importance of this dissertation lies in the fact that it presents the first empirical analysis of the effects of land-use controls on urban sprawl. For this reason, the findings should be of interest to urban planners in their efforts to control urban sprawl. Because we test theoretical hypotheses found in the urban economics literature, the results should also be of interest to academic economists. Finally, the data on land-use controls gathered for the empirical analysis should be of importance to researchers in urban economics

CHAPTER 1: INTRODUCTION

Urban sprawl is a contentious issue, involving various and conflicting views on such fundamental matters as its definition, measurement, and causes. Economists' contributions to this literature emphasize the theoretical and empirical analysis of the causes of urban sprawl. This dissertation follows in that tradition with an empirical analysis of the effect of land-use controls on urban sprawl, drawing on testable hypotheses found in the theoretical literature.

As will be discussed later, many empirical studies have been performed on the effect of land-use controls on housing prices, but no study has examined their effect on urban sprawl. This dissertation therefore makes a unique contribution to the literature on urban sprawl by documenting the effect of land-use controls on the spatial size of the urban area. Such information should be useful to urban planners who are trying to curb sprawl.

In addition, this dissertation tests theoretical hypotheses on the effect of land-use controls on the spatial size of urban areas. These theoretical hypotheses have not previously been empirically tested. As such, this dissertation adds to the positive literature on urban economics.

DEFINITION, CRITICISM, AND MEASUREMENT OF URBAN SPRAWL

Definition

In general, economists distinguish two types of statements. *Positive* statements are descriptive. They describe the world the way it is. *Normative* statements are prescriptive. They make a claim about the way the world ought to be. In the urban economics literature, we find both positive and normative definitions of urban sprawl. According to the normative definition, urban sprawl is the *excessive* decentralization of population and employment from the central city to the suburbs (Mills, 1999; Brueckner, 2000). According to the positive definition, urban sprawl is simply the decentralization of population and employment from the central city to the suburbs. This process is also called decentralization and suburbanization (Mills and Hamilton, 1994, p. 81).

There are other definitions of urban sprawl in the urban economics literature as well. Glaser and Kahn (2004) view urban sprawl as relatively low-populated residential and employment areas combined with low-density suburbanization in the urban fringe. Nechyba and Walsh (2004) interpret urban sprawl as planned communities that have their own downtowns near a lake or a park, or as interspersed residents among rural areas.

In this dissertation, we use the positive definition, except that, since our data are for population only, we define urban sprawl as the decentralization of population from the central city to the suburbs.

Criticism

Over the years, urban sprawl has generated a great deal of criticism from economists and planners. According to British urban planning advocate, John Osborn, as discussed in Williams, Burton, and Jenks (2000), urban sprawl has two downsides: it is economically wasteful and socially disadvantageous. It is economically wasteful because transportation improvements have allowed city residents to move farther from the city center, at the expense of long and costly daily commutes, as opposed to the situation in more compact cities. Economists argue that this problem is caused by congestion externalities and subsidization of the auto (for a review of auto externalities, see Parry, Walls and Harrington, 2007). Urban sprawl is socially disadvantageous because movement of city residents to the suburbs worsens local community life by making access to the countryside more difficult for those people who are left in the central city (see also Nechyba and Walsh, 2004).

Others criticize sprawl on different grounds. For example, Brueckner (2000) names three major drawbacks of urban sprawl: loss of open space, traffic congestion, and racial segregation. As a result of sprawl, open space is gradually replaced by urban structure. Recent studies in urban economics (Geoghegan, Wainger, and Bockstael, 1997; O'Sullivan, 2006) find that the market price of a house increases at a decreasing rate with the amount of open space. Therefore, open space is most valued in direct proximity to the house and less valued farther from the house. Acharyi and Bennett (2001) show theoretically that in suburban residential areas, the price of housing increases as the amount of open space surrounding the house increases. Therefore, households value open space, and the loss of open space is a negative consequence of urban sprawl.

Another consequence of urban sprawl is that people live farther out and drive more often and for longer distances. By using their automobiles more frequently, residents of the urban area create traffic congestion (Kahn, 2000).

Finally, sprawl exacerbates income segregation because different income groups cannot travel equal distances. Low income groups live in areas closer to downtown which is served by public transportation. Higher income groups live in areas farther from downtown which are only accessible by the automobile. This income segregation exacerbates racial segregation because lower income groups are predominately black.

Bertaud (2004) claims that urban sprawl is a reason for inadequate transportation systems. He examines the issue of providing mass transit in low density cities. Bertaud compares Barcelona, Spain, to Atlanta, Georgia—two cities almost equal in population but highly different in their concentration of people (Barcelona has a population density of 171 people per hectare compared to 6 people per hectare for Atlanta). According to him, "to duplicate the accessibility and ridership of the Barcelona system, Atlanta would have to build an additional 3,400 kilometers of metro tracks and 2,800 stations," while "in contrast, the Barcelona system has just 99 kilometers of tracks and 136 stations" (O'Sullivan, 2006, p. 149). Bertaud's conviction is that urban sprawl makes it impossible to create a well functioning mass transportation system. A local example confirms Bertaud's conclusions. The Hartline bus system in Tampa is much less effective than the Metro rail system in Washington, DC. Hartline covers only certain parts of the Tampa area, and its buses arrive every 30 minutes to an hour (www.hartline.org). The Washington Metro system trains arrive almost every three minutes, and the Metro system in Washington covers almost the entire area of Washington, DC, and surrounding communities (www.wmata.com).

Measurement

Urban sprawl is often measured by the density gradient, which represents the percentage decrease of population density with distance from the urban area center**.** Over time or cross-sectionally, a smaller density gradient means greater decentralization**.** Mills (1972, p. 35) finds that the density gradients of U.S. urban areas in his sample decreased significantly from 1880 to 1963, which indicates that urban sprawl has been occurring for many years.

Another measure of urban sprawl is the spatial size of the urban area: other things equal, the bigger the urban area, the lower the average population density, and the greater the sprawl. Regarding spatial size, O'Sullivan (2006, p. 145) notes, "between 1950 and 1990 the amount of urbanized land in the United States increased by 254 percent while the urban population has increased by only 92 percent."

CAUSES OF URBAN SPRAWL

The first general equilibrium analytical model of urban structure is Wheaton (1974). Wheaton derives many properties of his model, among which is that the spatial size of the urban area is directly related to the urban area's mean income and population and inversely related to the cost of travel within the urban area and to the value of rural land adjacent to the urban-rural boundary. Wheaton's model does not contain a housing sector, but Brueckner (1987) synthesizes the simulation models of Mills (1972) and Muth (1975), which do contain a housing sector, with the theoretical model of Wheaton, and obtains the same results.

Population growth and rising real income increase the demand for housing, and a greater quantity of housing is a better buy farther out. The land price decreases with distance from the center of the urban area because of the demand for accessibility to the central business district (CBD). For a given quantity of housing, then, housing price also falls with distance from the CBD. People choose where to live in an urban area by trading off the decrease in housing expenditure against the increase in commuting cost with distance. As long as the decrease in housing expenditure (the marginal benefit of distance) is greater than the increase in commuting cost (the marginal cost of distance), households will move farther from the CBD. When these quantities are equal, the household has found the optimal distance. Increased demand for housing upsets this equilibrium because it induces the household to purchase more housing, which, since housing price falls with distance, is a better buy farther out. This causes the urban area to expand spatially.

Lower real transportation cost allows people to commute longer distances at the same total cost, which also encourages suburban living. According to Glaser and Kahn (2004), automobiles have been the primary reason for urban sprawl throughout much of the twentieth century. Nechyba and Walsh (2004) show that, for the period 1910–1920, the number of car registrations increased dramatically, from half a million to more that eight million. Glaser and Kahn (2004) point out that by 1952 a majority of U.S. residents had at least one car. From 1964 to 2000 the number of people commuting to work increased by 24 percentage points, from 64 percent in 1964 to 88 percent in year 2000. Undoubtedly, the rise of automobile transportation is an important reason for sprawl.

Finally, higher rural land values impede urban development because urban land use must command a higher value to allow buyers to outbid rural land users. These predictions have empirical support (Brueckner and Fansler, 1983; McGrath, 2005).

In addition to the fundamental causes discussed above, economists identify market and government failures as contributing sources of urban sprawl. The following is a brief discussion of them.

Failure to Account for the Social Costs of Road Congestion (Brueckner, 2001). Auto commuters pay the private cost of operating and maintaining their cars, and they pay partial costs of road use through taxes. They do not, however, pay the full cost of congestion. That induces households to occupy residences farther from the CBD than they would if they paid the full costs of commuting, which leads to excessive spatial expansion of urban areas.

Failure to Account for the Social Value of Open Space (Brueckner, 2001). As already noted, households value open space, but open space, such as parks within urban areas and rural land outside of urban areas, is a public good, and, as such, exhibits the free-rider problem. Thus, a household chooses to live at the urban fringe, causing a conversion of open space to urban use, and does not consider the effects of its action. Consequently, too much open space is converted to urban use.

Failure to Account Fully for the Infrastructure Costs of New Development (Brueckner, 2001). When a new residential area is developed, the cost of public infrastructure, such as roads, sewer systems, schools, and recreation centers, is mostly paid through the property tax. This results in a government failure because developers and home buyers do not bear the full cost of converting the open space into land available for urban use. The infrastructure cost imposed on home owners by local governments through the property tax generally does not cover the marginal infrastructure cost but the average, which is generally less than the marginal. Homeowners with equal assessed values pay the same tax regardless of whether the house is located in newly developed areas or in already developed areas. As a result, developers would bid higher prices for undeveloped land than normally, which leads to converting more rural land into urban use. Thus, people living in high density, already developed areas subsidize residents living in low-density, suburban areas. This is an argument for impact fees, which have become more prevalent as well as higher in recent years (Brueckner, 1997).

Transportation Subsidies (Brueckner, 2005a). Brueckner points out that for transportation and location decisions to be efficient, residents should pay the full cost of transportation. In reality, however, individuals do not bear the full cost of transportation because of transportation subsidies. The fact that residents underpay the cost of traveling allows residents to commute longer distances and seek living in city suburbs, thus contributing to sprawl. Su and Desalvo (2008) empirically test the effect of transportation subsidies on urban sprawl, showing that the urban area contracts with public transit subsidies and expands with auto-subsidies.

Mortgage Subsidies. Mortgage interest is deductible from income for the purpose of federal and state income taxes, which lowers the cost of home ownership, and which, for reasons discussed above, encourages people to locate in the suburbs of urban areas. Williams, Burton, and Jenks (2000) argues that, through their generous mortgage insurance and loan programs, both the Federal Housing Administration (FHA) and the Veterans Administration (VA) create incentives for urban sprawl. For example, the FHA provides federal guarantees to private mortgage lenders by lowering the minimum down payment to just 10 percent and extending the pay-back period from 20 to 30 years. The VA offers low-interest mortgages without down payment to all qualified veterans.

The Property Tax. Brueckner and Kim (2003) advance the idea that the property tax is a source of sprawl. Property taxes are usually lower in the suburbs than in their central cities. Therefore, land in the suburbs is developed less intensively than land in the central city, which contributes to the spatial expansion of the city. Brueckner and Kim provide numerical examples that confirm the suggestion that the property tax may encourage urban sprawl. O'Sullivan (1985) analyzes the spatial effect of property taxes using a model including both business and residential property, finding that an increase in property taxes reduces employment in both central and suburban sectors causing the urban area to shrink in size. Arnott and MacKinnon (1997) use general equilibrium simulation of the spatial effects of the property tax and find that an increase in the property tax shrinks the size of the urban area. The results are disputed by Pasha and Ghaus (1995) who note that they might not hold in a more general model. Most recently Song and Zenou (2006) and Su and DeSalvo (2008) find empirically that property taxes contracts the urban area.

Federal Spending. Persky and Kurban (2003) contend that spatially dispersed federal spending could lead to urban sprawl. In Chicago, they find that government spending to alleviate poverty and support the elderly affects residential location decisions. In fact, they show that land use in the outer fringe of Chicago increased by 20 percent because of federal spending.

Land-Use Controls. Cities and counties employ a variety of land-use controls, including minimum lot-size zoning, maximum lot-size zoning, population density controls, rent control, building height restrictions, urban land-use boundaries, land-use management districts, watershed protection policies, land-purchase programs, differential property tax assessments, transferable property rights, etc. These land-use controls are intended to achieve various, and sometimes conflicting, goals, such as reducing or eliminating urban sprawl (e.g., urban land-use boundaries, maximum lot-size zoning, population density controls), ensuring adequate housing for the poor (e.g., rent control), aesthetics (e.g., building height restrictions), environmental improvement (e.g., watershed protection), etc.

As will be discussed later, many empirical studies have been performed on the effect of land-use controls on housing prices, but no study has examined their effect on urban sprawl. This dissertation therefore makes a unique contribution to the literature on urban sprawl by documenting the effect of land-use policies on the spatial size of the urban area. Such information should be useful to urban planners who are trying to curb sprawl.

In addition, this dissertation tests theoretical hypotheses on the effect of land-use controls on the spatial size of urban areas. These theoretical hypotheses have not previously been empirically tested. As such, this dissertation adds to the positive literature on urban economics. Finally, the data set on land-use controls should be of great use to urban researchers.

CONCLUSION AND PLAN OF THE DISSERTATION

This chapter familiarizes the reader with the nature of urban sprawl and analyses some of its causes. Since urban sprawl is widely believed to be a problem for a large number of U.S. cities, local governments develop measures intended to restrict the spatial size of the urban area. Chapter 2 provides a description of land-use controls. Chapter 3 surveys papers that provide empirically testable hypotheses on the effect of land-use controls on urban sprawl. Chapter 4 surveys empirical analyses of the monocentric urban spatial model. Chapter 5 discusses the data we use in our empirical analysis. Chapter 6 supplies an empirical analysis of the effect of land-use controls on urban sprawl. Chapter 7 provides a summary and conclusions.

CHAPTER 2: DESCRIPTION OF LAND-USE CONTROLS

As a response to urban sprawl and for the other reasons, local governments adopt various kinds of land-use controls. The theoretical urban literature argues that some of these land-use controls prevent or restrain urban sprawl while some facilitate urban sprawl. There have been virtually no empirical tests of these theoretical predictions, however. This dissertation estimates the magnitude and direction of the effect of land-use controls on urban sprawl. The next chapter reviews the basic model of urban structure without land-use controls and incorporates theoretical extensions of that model to include land-use controls. Theoretical hypotheses about the effect of land-use controls on urban sprawl are drawn from the literature. This chapter, however, provides a description of the various land-use controls.

ZONING[1]

The urban regulation used most by local governments is zoning. Fischel (1985, p. 21) defines zoning as "the division of a community into districts or zones in which certain land-use activities are prohibited and others are permitted." There are two types of zoning: cumulative and prescriptive. Cumulative zoning assigns a hierarchy of land-use restrictions to zones within the city, starting with the least restricted zones and moving toward the most restricted zones. This hierarchy is usually justified by a negative exter-

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[1] This section draws heavily on O'Flaherty (2005, pp. 170–197), Bogart (1998, pp. 207–223), and Fischel (1985, pp. 21–37).

nality that some buildings or activities could impose on the surrounding environment. Prescriptive zoning determines the allowable use of land for each parcel of property. A special permit must then be requested to use land in areas of the city not zoned for that activity, even when the desired use is ranked higher in the hierarchy.

A zoning code specifies the kind of buildings permitted or prohibited in different districts of the city. For example, residential zoning permits the presence of residential buildings; commercial zoning permits commercial and entertainment buildings; and industrial zoning permits factories and other industrial buildings. What was just described may be called "traditional" zoning. More recently, however, zoning codes have expanded to cover many other kinds of restrictions.

The zoning code may also set limits on building size, location, lot size, maximum height, and even color. It may also restrict the number and size of off-street parking spaces and even the number and size of trees. Zoning may also determine the number of buildings in particular zones and the amount of land they occupy. Some of these land-use controls are discussed more fully later.

Even though zoning codes are very strict, some exceptions are possible. For example, local government might allow one building to be higher than the maximum height restriction in a zone. The local government issues special permits to some activities that generally are not allowed in any zone. Drugstores, fast food restaurants, and gas stations are examples of activities that require a local government permit in order to be located in particular city zones.

A zoning term frequently encountered is "nonconforming land use." The term refers to the situation in which activities located in conformity to a zoning code become nonconforming under a new zoning code. In such cases, local government allows the affected buildings to continue their existence, usually with the proviso that they are not to expand nor change dramatically.

Finally, local government has the right to change the boundaries of the zones and the rules that apply to them. In order to obtain variances or special permits, individuals and businesses must apply to a zoning or planning board. The board usually consists of people appointed by the local government and is empowered to approve or disapprove a submitted application. The board is not usually required to provide reasons for its approval or disapproval. Adversely affected firms and individuals may object to the board decisions in a special hearing. In most cases, the board acts in the interest of those citizens who live near the land under consideration for a variance. If the neighbors do not object, then the board usually approves the request; if there are objections, then the board usually does not approve the request.

HISTORY OF ZONING[2]

Today, many U.S. cities have adopted zoning as a common measure of land-use control. The initial purpose of zoning, as noted earlier, was to put different enterprises into different zones to reduce transmission of smoke, dust, noise, etc., from one sector to another.

The second decade of the twentieth century marked the beginning of U.S. zoning. The first comprehensive zoning plan was developed in New York City in 1916. Eight other cities adopted zoning in the same year. Before introduction of comprehensive zoning, many cities used ordinances to monitor and exercise land-use control in specific

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[2] This section draws heavily on O’Sullivan (2006, pp. 185–204) and Fischel (2004, pp. 317–340).

areas of the city. For example, cities regulated the height of tall buildings in response to concerns that tall buildings could block the view of shorter buildings. After 1916, more and more cities started to adopt zoning as a measure of land-use control. By 1936, zoning had been introduced by more than 1,300 cities.

The state of urban transportation technology in the late 19th and the early 20th century is viewed as the main cause for not implementing zoning before 1916. Back then, manufacturers transported their output on horse-drawn wagons, which was a slow and expensive mode that required firms to be located near a port or railroad terminal, which were generally at or near the city center. At that time, the main form of public transportation was the hub-and–spoke street car system. Low income households lived in apartments close to the city center or along the spokes of a street-car system. Almost all commercial activities and apartments were located along the route of the street-car system, a locational pattern that generated neighborhoods of mixed land use. Single-family homeowners, on the other hand, lived a few blocks from the street-car route and away from industry, commerce, and apartments. Homeowners valued their quiet, convenient, low-density neighborhoods off the street-car route and made efforts to prevent extension of the street-car route toward their communities, since possible extension would have disturbed their peace.

Introduction of intercity truck transportation in 1910 allowed firms to move away from the city's central export node and closer to their suburban workers. Before introduction of the intercity truck, the externalities generated from industrial firms were confined to the central part of the city where such firms were predominately located. With the existence of intercity truck transportation, firms moved away from the central part of the city, thus spreading pollution, noise, dust, etc., into residential areas. That provided the city government with a reason to introduce industrial zoning. The primary goal of industrial zoning was to separate business, industrial, and commercial activities from residential areas.

At the same time, the innovation of mass transit increased mobility of workers. The motorized passenger bus, invented in 1920, allowed workers to live away from the factory and inhabit apartments closer to the homeowners. Local governments responded with the introduction of residential zoning. The role of residential zoning was to keep apartments out of homeowners’ neighborhoods.

In time, U.S. city and, later, county governments gradually developed a large number of other types of land-use controls, such as population land-use limitations, minimum lot-size zoning, maximum lot-size zoning, urban land-use boundaries, building-height limitations, square-footage limitations, impact fees, and density controls. The main reason for these land-use controls was to limit expansion of the urban area. There were also other reasons for implementation of land-use controls by local governments. For example, minimum lot-size zoning requires more space between houses, which protects one building from negative externalities produced by neighboring houses. Maximum density controls prevented overpopulation in certain areas of the city. Building-height limitations generated a smoother skyline and ensured that taller buildings would not block either the view or the sunlight of shorter ones. Fire and occupancy codes were also used for these purposes. Lastly, rent control was designed to ensure that the poor could afford housing in the city.

LAND-USE CONTROLS: THEIR PURPOSE, DESCRIPTION, AND EFFECT ON SPRAWL

Minimum Lot-Size Zoning

As Bates and Santerre (1994, pp. 253–254) note, “there are two contrasting theories regarding why communities adopt zoning requirements. According to the public interest theory, zoning laws are implemented to reduce or eliminate the impact of negative externalities.... Alternatively, the special interest group theory argues that zoning laws are designed to promote the fiscal and exclusionary objectives of the entrenched residents of a community.” By the public-interest theory, minimum lot-size zoning would reduce population density, thereby mitigating negative externalities thought to be associated with high density, such as disease, fire, crime, and traffic congestion. By the special-interest theory, minimum lot-size zoning, as well as other population-density restrictions, as Mills (2005, p. 572) puts it, “may be intended to exclude low-income and/or minority people from high-income suburbs.” Both of these views imply that the urban area expands under minimum lot-size zoning, but that is an empirical question.

Pasha (1992a) discusses minimum lot-size zoning as a type of land-use control and analyzes two cases. In the first case, the central city is regulated, but the suburbs are not. In the second case, the central city is not regulated, but the suburbs are. This theoretical paper, to be discussed thoroughly in the next chapter, produces mixed results. In one version of his model, Pasha finds that the urban area expands under minimum lot-size zoning. In another version, the result is ambiguous. In a later paper, in which minimum lot-size zoning was binding on the rich but not on the poor, Pasha (1996) finds that minimum lot-size zoning expands the urban area. According to Pasha, this finding indicates that implementing minimum lot-size controls in suburbs might be a major factor contributing to urban sprawl.

Maximum Lot-Size Zoning

Maximum lot-size zoning is used to minimize the amount of land used for urban infrastructure in the city (Pasha, 1992b). Developing countries use maximum lot-size zoning to keep the price of land low in certain areas of the city so that the poor can afford to live there. If binding, maximum lot-size zoning makes lots smaller than otherwise, and a smaller lot, other things equal, is a cheaper lot. Pasha (1992b) studies maximum lot-size zoning in a model in which maximum lot-size restrictions are not binding on the poor but are binding on the rich. Under these conditions, he finds that no matter whether the rich live in the suburbs and the poor live in the central city, which is the case in most developed countries, or the rich live in the central city and the poor live in the suburbs, which is the case in most developing countries, applying maximum lot-size restrictions leads to a contraction of the spatial size of the urban area.

Building-Height Limitations

Local governments introduce building-height limitations for several reasons. One reason is to achieve a smooth and aesthetic skyline. Another reason is to prevent tall buildings from blocking the view of shorter buildings and the sunlight from reaching them. Thus, building-height restrictions protect shorter buildings from being overshadowed by taller buildings. Like minimum lot-size restrictions, building-height limitations may lower population density, which could lead to expansion of the urban area. On the other hand, as noted by Brueckner and Kim (2003) in discussing the effect of the property tax on the spatial size of urban areas, building-height limitations may reduce the size of dwelling units in a building, possibly increasing population density.

The first theoretical work on building-height limitations is that of Arnott and MacKinnon (1997). The authors use a model designed to simulate Toronto. They demonstrate that, in the presence of building-height limitations, the residential land-rent function is higher than it would be without those restrictions. It therefore equals rural land rent farther from the CBD. Thus, building-height restrictions increase the spatial size of the urban area. The major drawback of Arnott and MacKinnon's analysis is the use of a simulation model with specific functional forms and parameters, which limit the model's generality.

Recently, Bertaud and Brueckner (2005) obtain the same results as those of Arnott and MacKinnon in a more general model. Instead of building-height limitations, Bertaud and Brueckner use the floor-area ratio, which is the ratio of the floor area of the building to the land area on which building is located. Generally, the greater the floor-area ratio, the taller the building. In other words, a binding restriction on the floor-area ratio means a restriction on building height.

Population-Density Restrictions

Another form of land-use control is population density restrictions. Maximum population density restrictions may be used to avoid the negative externalities discussed above in the context of minimum lot-size zoning. Also, as noted there, they may also be used as exclusionary devices. Although not necessarily the purpose, maximum population density restrictions might cause an urban area to expand relative to an urban area without density controls. Minimum population density restrictions, on the other hand, are intended to avoid excessive spread of population over the urban area.

As already discussed, most urban economists working on the relation between density controls and sprawl have modeled population density indirectly in terms of lot-size and building-height restrictions in general equilibrium models. Peiser (1989) and Heikkila and Peiser (1992) explicate the differences in population density resulting from continuous vs. discontinuous (or leapfrogging) development. Peiser (1989) concludes that policies that restrict discontinuous development may reduce efficiency in the land market and lead to lower, rather than higher, urban density. Heikkila and Peiser (1992) find that if the planner opts for a continuous, rather than discontinuous, development pattern, the result is lower densities but higher property values. The researchers conclude that planning efforts to limit sprawl are more consistent with tax-base considerations than with concerns over density. These articles show how population density may be affected by continuous vs. discontinuous development, but they do not explicitly address the effect of population density restrictions on urban sprawl.

Impact Fees and In-Kind Exactions

When an urban area expands in both spatial and population size and when a new development takes place within the urban area, local governments provide public services, such as roads, rights of way to electricity and telephone companies, water mains, sewers, etc. Historically, local governments make capital expenditures that are usually supported by bond sales. The carrying cost of the bonds is covered by property taxes imposed on existing and future residents. In other words, old residents contribute to the cost of development for new residents.

Considering this policy inequitable, some local governments place the additional capital cost on developers. This additional cost may be in the form of in-kind exactions on the developers, who are expected to provide parks, roads, and schools, along with other necessary local infrastructure. This additional cost may also be in the form of impact fees on developers to pay for additional infrastructure (Brueckner, 1997).

In-kind exactions and impact fees raise the direct cost of development, which may postpone development and slow the spatial and population growth of the urban area. Brueckner (1997) claims this to be an important reason for the increasing use of in-kind exactions and impact fees by local governments. In a theoretical model, Brueckner finds that the effect of impact fees on new development depends strongly on the time needed to implement the impact fees and on how development costs and infrastructure costs vary with the urban area population. Brueckner shows that under usually assumed cost conditions the timing of the shift from bond financing to impact fees affects the timing of development and the rate of growth of the spatial size and population of the urban area. In some cases, the urban area will continue to develop the same way with or without impact fees, but impact fees cause urban expansion gradually to slow down. In other cases, the imposition of impact fees causes an immediate slow-down of development in the areas that are affected by impact fees. Brueckner's conclusion is that impact fees on balance cause a slowdown in the expansion of urban spatial size and of urban population.

Although Brueckner's article is insightful and informative, it does not provide the kind of comparative static model we seek. In fact, we have been unable to find such a model. For this reason, in Chapter 2, we will present the model of Song and Zenou (2006). Although a model of the property tax, it is nevertheless useful for our purpose.

Urban Growth Boundary

Local government imposes an urban growth boundary (UGB) by establishing a radius around the city and outlawing any development beyond the radius. The urban growth boundary was first implemented in 1958 in Kentucky. Since then the use of urban growth boundaries has grown rapidly. By its nature, the urban growth boundary restricts the spatial size of the urbanized area. In a theoretical model, to be discussed more fully in the next chapter, Quigley (2007) and Quigley and Swoboda (2007) show that, in the presence of a binding urban growth boundary, the spatial size of the urban area is lower than otherwise. In reality, however, cities with UGB's may expand the radius of the UGB to accommodate development, so it is unclear what effect UGB's have on urban sprawl empirically.

Population-Growth Limitations

Another type of land-use control used by local governments is the population-growth limitation. Population-growth limitations include direct population caps, building-permit limitations, and maximum density restrictions. The purpose of population-growth limitations is to prevent growth, which is associated with overcrowding and sprawl. Maximum population density restrictions were discussed earlier, and their likely effect to slow population growth was noted. So far, no U.S. city has adopted direct population caps although some California cities are considering them (Groening, 2008). Most

U.S. cities use building-permit limitations to control population growth. Local governments issue a fixed number of building permits per year. If the number of permits issued is less than the number demanded, the result may be to restrict the amount of new development that would otherwise take place. The restriction on the number of new buildings may therefore retard growth in the spatial size of the urban area. On the other hand, if building permits do not impose a minimum lot-size, it is conceivable that the urban area could expand spatially. No theoretical or empirical research showing the effect of building-permit limitations on the spatial size of the urban area has as yet been done.

Square-Footage Limitations

Local governments adopt both minimum and maximum square-footage limitations on the size of offices and apartment in urban areas. In urban areas, population density (say, in persons per square mile), housing density (say, in square feet of floor space per acre), and structural density (say, in number of floors per acre), and land rent all decrease at decreasing numerical rates with distance from the CBD. Hence, when a binding maximum square-footage limitation is established, buildings near the CBD are required to have a smaller square footage per acre than would otherwise be chosen, while at some distance from the CBD, beyond which the limitation is no longer binding, buildings will have square footage per acre equal to or lower than the maximum. For a given population, this lowers density near the center causing higher density away from the center, which raises land rent and expands the spatial size of the urban area.

For a minimum square-footage limitation, the reverse is the case. Near the CBD, where the limitation is not binding, densities will be equal to or greater than the minimum, while farther out, where the limitation is binding, the desired densities will be smaller than the required minimum. This causes those living farther out to live at higher densities than they would prefer and, given population, would cause the urban area to contract.

In a theoretical paper, to be discussed thoroughly in the next chapter, Bertaud and Brueckner (2005) investigate the effect of square-footage limitations on the size of an urban area and show that they have the effects described above. No empirical studies have been performed to test these theoretical predictions.

Rent Control[3]

Rent control is another land-use control adopted by local governments. Rent control is a price ceiling established on apartment rents. The main purpose of rent control is to ensure affordable housing for the poor, but it may also induce low-income households to live in the city, which might limit spatial expansion of the urban area. On the other hand, it might contribute to sprawl if rich and middle-income households move to the suburbs to avoid the poor.

Rent control was imposed in the United States just after the U.S. entered World War II, the first city with rent control being New York. The war required massive relocation of labor, with consequent pressure on many local housing markets. The type of rent control imposed at that time was called first-generation rent control. First-generation rent

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[3] This subsection draws heavily on Roistacher (1992), Arnott (1995), and Ho (1992).

control was a rent freeze. Later, local governments allowed some provisions in the mechanism of setting rents, which led to second-generation rent control.

Second-generation rent control was more flexible than first-generation rent control. For example, second-generation rent control commonly permitted the landlord to increase rent each year, with the percentage increase equal to the annual inflation rate. The local government could also allow the landlord to justify rent increases based on cost increases other than inflation. An example is a cost-through provision, which permits the landlord to apply for a rent increase above the inflation rate when the landlord has a justifiable cost increase associated with the apartment. Another type of allowable increase is called a hardship provision, which allows discretionary increases to assure that the landlord does not have a cash-flow problem. Finally, there is a rate-of-return provision, which permits discretionary increases in rent to ensure that the landlord receives a reasonable return. In some jurisdictions, second-generation rent control permits vacancy decontrol, i.e., the unit becomes decontrolled once it is vacated. Other local governments apply inter-tenancy decontrol, in which rent control is imposed during a given tenancy with an allowable rent increase during the inter-tenancy period. Another type of second-generation rent control is rent-level-decontrol. In this case the apartment is decontrolled but becomes re-controlled if rent exceeds a certain level.

Although much theoretical and empirical research has been performed on rent control (for a summary, see Roistacher, 1992; Arnott, 1995, and Ho 1992), only one study deals with the effect of rent control on urban sprawl (Skelly, 1998), which finds that the imposition of rent control contracts the urban area. Pasha (1995) develops a model of rent control but draws no conclusion as to its effect on the spatial size of the urban area.

CONCLUSION

This chapter has discussed various kinds of land-use controls that have been applied by local governments. "Traditional" zoning is clearly the most commonly used kind of land-use control, but many others have arisen over time. Several land-use controls have been incorporated into theoretical urban models. Little or no empirical research has been performed that tests the predictions of these models regarding the effect of land-use controls on urban sprawl.

In the next chapter, we review the theoretical models, drawing out their implications for the effect of land-use controls on urban sprawl. With this task completed, we then turn to empirical tests of the theoretical predictions. The urban areas in our data set do not employ all of the land-use controls discussed above, and all have "standard" zoning and building permits. Consequently, in the next chapter, we concentrate on only those kinds of land-use controls whose effects we can estimate in our sample of urban areas.

CHAPTER 3: THEORIES OF URBAN FORM WITH LAND-USE CONTROLS

The purpose of this chapter is to exposit the standard monocentric urban model (Brueckner, 1987) and the extensions of it that urban economists have made to derive the effect of land-use controls on urban form, in particular, for our purpose, on the size of the urban area. From the extensions, we draw empirically testable hypotheses concerning the effect of land-use controls on urban form, which form the basis for the empirical work to follow. Some papers in the area of land-use controls do not use the static monocentric model. We shall discuss these papers if they shed light on the size of the urban area. We begin, however, with a review of the development of the monocentric urban model and a justification for our use of it to study urban sprawl.

DEVELOPMENT OF THE MONOCENTRIC URBAN MODEL

The beginnings of the monocentric urban model occurred in the 1960's, starting with Alonso (1964). Alonso adapted von Thünen's (1966 [1826]) agricultural land-use model to urban areas. He applied the concept of bid-rents, whereby land users bid against one another to obtain land for urban use. Under the assumption that all employment occurs in the CBD and that commuting cost rises with distance from the CBD, the demand for land near the CBD is great but attenuates with distance. The bidding for land results in high land rent near the CBD and declining land rent with distance from the CBD. Because of the ability of households to substitute land for other non-commuting expenditures, land rent falls at a decreasing numerical rate with distance from the CBD. A spatial equilibrium is established when all land users are unwilling to relocate within the urban area because those located close to the CBD are “penalized” for their low commuting cost by high land rents, while those living farther away from the CBD are “compensated” for their high commuting costs with low land rents.

Alonso tested his prediction that residential land rent falls with distance from the CBD by regressing land expenditures per family (the product of land price per square foot and the number of square feet per family) on family median income and distance from the CBD, using data for Philadelphia for 1950. Based on the regression results, Alonso concluded that the value of land per family increased with income and decreased with distance from the CBD (Alonso, 1964, pp. 168–172).

Although Alonso recognized that a complete model of an urban area had to involve a housing market with households and housing producers as well as a residential land market and that it required conditions ensuring that all households were housed in the urban area, he never developed a successful general equilibrium model. That came with Wheaton (1974). In addition, the comparative static results of Alonso’s partial equilibrium theory of urban consumer choice were all ambiguous.

The ambiguity of the model’s comparative static results was due to Alonso’s inclusion of distance from the CBD as an argument of the household utility function, assuming that the marginal utility of distance was negative. Alonso’s rationale for this assumption was to capture the time cost of commuting. Muth (1969) dropped that assumption, arguing that it was unclear empirically whether utility increased or decreased with distance from the CBD. Consequently, Muth assumed that distance did not enter the utility function but affected location by operating through the cost of commuting in the budget constraint. This slight change of assumption allowed Muth to obtain a number of empirically testable hypotheses. DeSalvo (1977) provided the complete set of comparative static results of Muth's model.

Like Alonso, Muth started his research by defining and deriving the conditions for household equilibrium in urban space. Next, Muth added housing producers to the model and obtained equilibrium conditions for housing producers, but, as with Alonso, he did not successfully develop a general equilibrium model of a monocentric urban area. He nevertheless did provide much empirical evidence on urban areas.

Muth found that housing price (the flow price per unit of housing space) fell at slightly less than 2 percent per mile in some cities (Muth, 1969, p. 192) but at 1 percent per mile in a more detailed study of Chicago (Muth, 1969, p. 309). Subsequently, others generally confirmed the finding that housing price falls at a numerically decreasing rate with distance from the CBD (e.g., Evans, 1973; Wieand, 1973; Coulson, 1991). As will be seen later, this pattern of housing prices produces a decline in population density also at a decreasing numerical rate. Muth confirmed this hypothesis by estimating negative exponential population density functions for forty-six urban areas in 1950 (Muth, 1969, pp. 141–145). By regressing the natural log of population density on distance from the CBD, he produced estimates of the parameters, central density (i.e., population density extrapolated to the CBD) and the density gradient (i.e., the percentage decline of density with distance). A decrease in the density gradient unambiguously means decentralization of population, while an increase means centralization. To investigate the determinants of population density, Muth regressed his estimated density gradients on characteristics of households, finding that the density gradient falls with income and population, meaning that urban areas decentralize as income rises, but rises with commuting cost (Muth, 1969, pp. 153–158). In the U.S., the real income of urban residents and urban population have risen over time, while real transport costs have fallen, which are the major factors explaining decentralization of population.

Although the early work of Alonso and Muth was extremely important, it did not succeed in producing a general equilibrium model. A few years later, however, Mills (1972, pp. 96–108) developed the first general equilibrium urban monocentric simulation model; working independently, Muth (1975) did so as well. Altmann and DeSalvo (1981) showed that these two models were essentially identical, provided some tests of the Mills-Muth model, and extended it in directions that resulted in more accurate predictions of urban development. Wheaton (1974) produced the first general equilibrium analytical urban monocentric model and derived a number of comparative results.

In addition to developing his simulation model, Mills (1972, pp. 34–58) also estimated population and employment density functions and, as did Muth, estimated the determinants of density gradients. Mills used a different approach from regression analysis which allowed him to use data further back in time than others had heretofore done. His main finding on population density was that population had been decentralizing at least since 1880. To investigate the determinants of density, he regressed his estimated population and employment density gradients on population, income, and transportation costs, with results similar to those of Muth.

Wheaton (1974) produced an analytic general equilibrium model, but without a production sector. Finally, Brueckner (1987) combined the work of Muth, Mills, and

Wheaton into an analytic general equilibrium monocentric urban model with a production sector. From here on, when we refer to the monocentric urban model, we are referring to Brueckner's synthesis.

RATIONALE FOR USING THE MONOCENTRIC URBAN MODEL TO STUDY SPRAWL

As will be fully exposited later, the monocentric urban model explains urban structure in terms of housing consumption, housing price, population density, structural density (housing capital per unit of land), housing density (the amount of housing per unit of land), land rent, and the spatial size of the urban area. All of these, except for the spatial size of the urban area, are functions of distance from the CBD. In one variant of the model, called the closed city model, it also determines the spatial equilibrium household utility level, given population, while in another variant, called the open city model, it determines the urban population, given the spatial equilibrium utility level. These endogenous urban structure variables are determined by the exogenous variables, population (in the closed city model), the spatial equilibrium utility level (in the open city model), rural land rent, household income, and commuting cost.

The closed city version of the monocentric urban model, which is the version used most in both theoretical and empirical analysis, explains sprawl as the growth in the spatial size of the urban area under changes in population, household income, commuting costs, and rural land rent. Although the open city model can explain migration among urban areas, while the closed city model cannot, for reasons given in the next paragraph, we use the closed city model in our study of urban sprawl.

In the open city model, the assumption is that households will migrate from urban areas providing lower utility to urban areas providing higher utility until utility levels are equalized. If urban areas are homogeneous in the sense that there is no comparative advantage to living in one versus another, then urban areas in the open city model will have equal populations, land-rent functions, housing-price functions, transportation costs, etc. When land-use controls differ across urban areas in the open city model, however, one would observe differences in sprawl among urban areas even allowing for migration to equalize utility. In this case, each urban area in the open city model can be treated as closed with respect to the variation of land-use controls across urban areas.

Hence, the closed and open city models may be expected to produce similar results when studying the impacts of land-use controls if the urban areas are “imperfect competitors” because of differing land-use controls. (In our sample of urban areas, imperfect competition is further ensured by differences in climate, topography, water access, etc.) Because the open and closed city models will produce similar results with respect to land-use controls, we remain within the existing literature on sprawl and employ the closed city model.[4]

THE MONOCENTRIC URBAN SPATIAL MODEL

The Household Sector

The monocentric model has as a predetermined center, the central business district (CBD), to which all travel is made for work and other activities. Travel is along radial and dense transportation routes between the household’s residential location and the

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[4] We thank Professor Kenneth F. Wieand for providing this justification for the use of the closed city model.

CBD. A household's quasi-concave utility function, $v(c,q)$, is defined over housing consumption, q, which is a normal good, and non-housing, non-transportation expenditures, c. The household spends its exogenous income, y, on housing; non-housing, non-transportation goods; and transportation. Round-trip transportation cost is determined by distance between home and CBD, x, and the round-trip cost per mile of travel, t. Thus, the problem of the household is to maximize $v(c,q)$ subject to $y = c + pq + tx$, where p is the price per unit of housing. Upon eliminating c, this problem gives rise to the familiar first-order condition

$$\frac{v_q(y-tx-pq,q)}{v_c(y-tx-pq,q)} = p \tag{3.1}$$

where the price of the numéraire good is normalized to unity. All urban households are assumed identical with respect to utility function and income. Consequently, for them to be in spatial equilibrium in which no one wants to move, it is necessary for the following condition to hold

$$u = v(y-tx-pq,q) \tag{3.2}$$

where u is the urban-area-wide spatial equilibrium utility level. The, numéraire good, c, plays no role in the analysis and is therefore ignored.

The Housing Production Sector

Housing is produced via a constant-returns-to-scale concave production function defined over land, l, and non-land inputs, N, as follows

$$H = H(l,N) \tag{3.3}$$

but because of constant returns to scale, this may be rewritten as

$$\frac{H}{l} = H\left(\frac{N}{l},1\right) = H(S,1) = h(S), \text{ or } H = lh(S) \tag{3.4}$$

where S is the nonland-to-land ratio, called structural density. Profit per unit of land is given by

$$\pi = ph(S) - iS - r \tag{3.5}$$

where p is housing price, as before, i is the rental rate of the nonland input, and r is the rental rate of the land input. Setting π equal to zero, solving for r, and maximizing rent per unit of land produces the following first-order condition

$$ph'(S) = i \tag{3.6}$$

which is the familiar result that marginal revenue product equals factor price at the profit-maximizing S. Finally, the spatial equilibrium condition for housing producers is that land rent absorbs profit, so all housing producers are equally well off at any location

$$r = ph(S) - iS \tag{3.7}$$

Boundary and Population Conditions

To complete the model requires an urban-area boundary condition and an urban population condition. The urban boundary condition is

$$r\left(\bar{x}\right) = r_A \tag{3.8}$$

where $\bar{x}$ is the distance from the CBD at which the urban area ends and the rural area begins and r_A is rural land rent (or the opportunity cost of land). Urban households outbid rural land users between the CBD and $\bar{x}$, while rural land users outbid urban land users beyond $\bar{x}$. The urban population condition is

$$\int_0^{\bar{x}} \delta x \frac{h(S)}{q} dx = P \tag{3.9}$$

where δ is the number of radians in a circle available for urban residential use and P is the urban population, which is assumed to be the same as the number of urban households. The quotient is population density since it is the total quantity of housing per unit of land at any given x divided by per-household consumption of housing at that x. Integrating population density times residential land over all urban land gives total population. This condition ensures that the population of the urban area exactly fits inside the boundary of the urban area.

Closed City and Open City Solutions of the Model[5]

At this point in the development of the model, it is necessary to distinguish between the "open city" and "closed city" versions of the model because some authors use the open city version and others use the closed city version while conducting their theoretical analysis. In an open city, utility is exogenous while population is endogenous. The idea behind this is that if utility is higher in one urban area than in another, people will migrate to the first urban area from the second. This raises population and lowers utility in the first urban area while lowering population and raising utility in the second. Eventually, the utility level is the same in both urban areas and migration stops. In the closed city model, the reverse is the case. An exogenous increase in population lowers utility in the urban area, but no out-migration occurs. It is sometimes said that the closed city model is a "short-run" model, while the open city model is a "long-run" model. Since both versions are used, we shall present the solutions for both.

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[5] This subsection draws on DeSalvo (2008).

In both versions of the model, Equations. (3.1) and (3.2) are solved simultaneously for p and q, producing the reduced form equations

$$q = q(x,u,t,y) \tag{3.10}$$

and

$$p = p(x,u,t,y) \tag{3.11}$$

Also, in both versions of the model, Equations (3.6) and (3.7) are solved simultaneously for S and r, producing the reduced form equations

$$S = S(p,i)$$

and

$$r = r(p,i)$$

or, using Equations (10) and (11)

$$S = S\left[p(x,u,t,y),i\right] \tag{3.12}$$

and

$$r = r\left[p(x,u,t,y),i\right] \tag{3.13}$$

In the open city model, setting $r_A = r\left[p(x,u,t,y),i\right]$ and solving for x produces the reduced form urban-rural boundary equation

$$\overline{x} = \overline{x}(u,t,y,i,r_A) \tag{3.14}$$

Finally, using the above solutions for S, q, and p, the reduced form population equation may be obtained from Equation (3.9) as

$$P = P(\overline{x},u,t,y,i,\delta) \tag{3.15}$$

The recursive solution for the urban-rural boundary and population in the open city model is possible because the spatial equilibrium utility is exogenous. In the closed city model, however, this is not the case, and Equations (3.8) and (3.9) must be solved simultaneously, producing

$$\bar{x} = \bar{x}\left(P, t, y, i, r_A, \delta\right) \tag{3.16}$$

and

$$u = u\left(P, t, y, i, r_A, \delta\right) \tag{3.17}$$

Table 3.1 summarizes these results.

TABLE 3.1: Summary of Reduced Form Equations

Closed City	*Open City*
$q = q\left(x, u, t, y\right)$	
$p = p\left(x, u, t, y\right)$	
$S = S\left[p\left(x, u, t, y\right), i\right]$	
$r = r\left[p\left(x, u, t, y\right), i\right]$	
$\bar{x} = \bar{x}\left(P, t, y, i, r_A, \delta\right)$	$\bar{x} = \bar{x}\left(u, t, y, i, r_A\right)$
$u = u\left(P, t, y, i, r_A, \delta\right)$	$P = P\left(\bar{x}, u, t, y, i, \delta\right)$

Comparative Static Analysis: Closed City Model

Comparative static analysis of this model is quite complicated and has been provided by Brueckner (1987). We summarize his results in Table 3.2. Because our interest is in the effect of exogenous variables on the size of the urban area, $\bar{x}$, we only discuss the results for this variable, but see DeSalvo (2008) for a thorough discussion. Following Brueckner (1987), we suppress the variables for the radians of available residential land, δ, and the price of the non-land input, *i*. Suppression of these variables has become common practice although it is not clear why. The reasoning for suppressing the nonland input price is probably the assumption that it varies little among urban areas, for the interest rate, which is its primary component, is determined on a national market. Perhaps authors suppress the radians of available residential land, thinking that this is more an empirical than theoretical issue. These are simply speculations as no one to our knowledge has explained the suppression of these variables in comparative static analysis. These remarks apply also to open city models. In both models, equilibrium housing price and land rent are functions of distance from the CBD, i.e., $p = p(x)$ and $r = r(x)$. In the closed city model, both of these functions shift due to changes in population and rural land rent, but they also pivot due to changes in income and transportation cost; all functions of x only shift in the open city model. Therefore, in Table 3.2, x' is the distance at which the pivot occurs.

TABLE 3.2: Summary Comparative Statics: Closed City Model, Brueckner (1987)

Exogenous Variables		*Endogenous Variables*					
		q	p	S	r	$\bar{x}$	u
x		+	–	–	–	*NC*	*NC*
P		–	+	+	+	+	–
r_A		–	+	+	+	–	–
y	$x < x'$	+	–	–	–	+	+
	$x > x'$	?	+	+	+		+
t	$x < x'$	?	+	+	+	–	–
	$x > x'$	+	–	–	–		–

Note: Effects due to δ and i are omitted. *NC* means "no change."

The effect of exogenous variables on the size of the city, $\bar{x}$, may be seen from Table 3.2. Since $\bar{x}$ is a specific value of x, there is no comparative static effect of x on $\bar{x}$. An increase in population increases the demand for housing, which drives up housing price and land rent. At the urban-rural boundary, urban households now outbid rural households and the urban area expands. In contrast, a rise in rural land rent allows rural households to outbid urban households for land at the urban fringe, and the urban area contracts. If household income increases, households choose to locate farther from the CBD. An increase in income causes an increase in the demand for housing, and since housing price and land rent fall with distance from the CBD, more housing is a better buy farther out. Moving farther out raises housing price and land rent there and lowers them closer in. That is why these functions pivot at x'. The increase in land rent farther out allows urban households to outbid rural households at the urban fringe, thereby expanding the urban area. An increase in transport cost has effects opposite those of an income increase because an increase in transport cost lowers income available for all non-transportation expenditures, including housing.

Comparative Static Analysis: Open City Model

As for the previous version, comparative static analysis of this variant of the model is quite complicated and has been provided by Brueckner (1987). We summarize his results in Table 3.3.

TABLE 3.3: Summary Comparative Statics: Open City Model, Brueckner (1987)

Exogenous Variables	*Endogenous Variables*					
	q	p	S	r	$\bar{x}$	P
x	+	–	–	–	*NC*	*NC*
r_A	*NC*	*NC*	*NC*	*NC*	–	!
y	–	+	+	+	+	+
t	+	–	–	–	–	!

Notes: Effects due to δ, i, and u are omitted. *NC* means "no change."

Because our interest is only in the effect of exogenous variables on the size of the urban area, $\bar{x}$, we only discuss the results for this variable, but see DeSalvo (2008) for a thorough discussion. Table 3.3 shows that there is no effect of a change in x on $\bar{x}$ since $\bar{x}$ is a specific value of x. If rural land rent increases, this would allow rural households to outbid urban households for land at the urban fringe, which would contract the size of the urban area. An increase in household income causes the demand for housing to increase which increases housing price and land rent allowing the urban area to expand. An increase in transportation cost has effects opposite those of an increase in income. In this variant of the model, the land rent and housing price functions do not pivot because of in- and out-migration.

Other Variants of the Monocentric Urban Model

Although we refer to the preceding model as the "standard" monocentric urban model, others have presented variants of it that we feel should be mentioned here. Some researchers have used the indirect, rather than the direct, utility function, which leads to a slightly different solution process. Some have included two income classes as well as two modes of transportation. In the closed city version of models with either two income classes or two modes, some authors have designated the model as "semi-closed," meaning that the population, while fixed in total, may migrate within the area thereby changing the boundary between land occupied by higher and lower income households or by household using different transportation modes. Finally, in some cases, the housing production sector has been omitted to simplify the model if nothing substantive is thereby lost.

EXTENSIONS OF THE MODEL TO INCLUDE LAND-USE CONTROLS

Many urban economists have extended the standard monocentric urban model to incorporate land-use controls, deriving the effect of such controls on the size of the urban area. We survey those models here.

Minimum Lot-Size Zoning

Pasha (1996) analyzes the effect of minimum-lot size zoning on the size of the urban area, as well as on other urban variables. He uses the semi-closed version of the standard monocentric urban model with two income groups and no housing production sector. Pasha divides the city into two zones, central city and suburbs. He assumes that the rich, denoted by the subscript 2 on relevant variables, live in the suburbs and face a binding minimum lot-size constraint. The poor, denoted by the subscript 1, on the other hand, live in the central city and do not face a minimum lot-size constraint.[6] The author also assumes that all land is available for residential use, or $\delta = 2\pi$. The author starts his analysis with the suburbs, followed by the central city, and we shall follow his approach.

Suburbs. The utility function of suburban residents is defined as $v_2 = v\left(c_2, l_2\right)$, where $l_2 = \underline{l}$ and $\underline{l}$ is the minimum lot size, so the minimum lot size is exactly the amount each rich household consumes. (Pasha assumes all households, those residing in both the suburbs and the central city, have the same utility function, so we have omitted

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[6] In general, the determination of which income class lives in the suburbs and which in the central city depends on the relative magnitudes of the income elasticity of the demand for housing (or land) and the income elasticity of marginal transportation cost. It is not in general the case that the rich live in the suburbs either theoretically or empirically. The first person to recognize this point was Muth (1969, pp. 29–34). In Pasha's model, the income elasticity of marginal transportation cost is zero since it is not a function of income. Consequently, for any positive income elasticity of demand for housing (or land), higher income households will live farther from the CBD than will lower income households. Therefore, Pasha does not need to assume the pattern he wants.

the subscript on the functional operator, v.) Residents living in the suburbs face the following budget constraint

$$c_2 + r_2 \underline{l} = z_2 \tag{3.18}$$

where $z_2 = y_2 - tx$. The spatial equilibrium condition for suburban households is

$$u_2 = v\left(c_2, \underline{l}\right) \tag{3.19}$$

where u_2 is the spatial equilibrium level of utility. Since, $v = u_2$ and $l = \underline{l}$, c_2 is determined by Equation (3.19). Then given y_2 and t, r_2 is determined by Equation (3.18).

The suburban population condition is

$$2\pi \int_{x'}^{\overline{x}} \frac{x}{\underline{l}} dx = P_2 \tag{3.20}$$

where x' is the boundary between the central city and the suburbs and P_2 is the suburban population. (Previously, x' stood for the distance from the CBD at which the land rent and housing price functions pivot.) Equation (3.20) assumes, as noted earlier, that all rich households consume the minimum lot size. The urban-rural boundary, $\overline{x}$, is given by

$$r_2\left(\overline{z}_2, u_2, \underline{l}\right) = r_A \tag{3.21}$$

where $\overline{z}_2 = y_2 - t\overline{x}$.

Central City. In contrast to suburban residents, central city households do not face a minimum lot-size restriction. Therefore, these households choose values of c_1 and l_1 in the standard budget-constrained utility maximization problem

$$\max v_1 = v\left(c_1, l_1\right) \text{ s.t. } c_1 + r_1 l_1 = z_1 \tag{3.22}$$

where $z_1 = y_1 - tx$. Solution of the first-order conditions generates the demand functions

$$c_1 = c_1\left(z_1, r_1\right) \tag{3.23}$$

$$l_1 = l_1\left(z_1, r_1\right) \tag{3.24}$$

The indirect utility function, $V_1 = V(z_1, r_1)$, and the spatial equilibrium condition, $V = u_1$, combine to provide the solution for r_1

$$r_1 = r_1\left(z_1, u_1\right) \tag{3.25}$$

Substituting Equation (3.25) into Equation (3.24) gives the solution for l_1

$$l_1 = l_1\left(z_1, u_1\right) \tag{3.26}$$

The population condition for the central city is then

$$2\pi \int_0^{x'} \frac{x}{l_1} dx = P_1 \tag{3.27}$$

where P_1 is the central city population. The boundary between the central city and the suburbs, x', is determined endogenously from

$$r_2(z_2', u_{2,} \underline{l}) = r_1(z_1', u_1) \tag{3.28}$$

where $z_i' = y - tx'$, $i = 1,2$.

Comparative Static Analysis. Equations (3.20), (3.21), (3.27), and (3.28) represent a four-equation system that may be solved for the values of the main endogenous variables, $\bar{x}$, x', u_2, and u_1, given the exogenous variables, $\underline{l}$, P_2, y_2, P_1, y_1, t, and r_A. Once these endogenous variables are known, then c_2 may be obtained from Equation (3.19), r_2 from Equation (3.18), r_1 from Equation (3.25), c_1 from Equation (3.23), and l_1 from Equation (3.24). Note that while l_2 is fixed at $\underline{l}$, l_1 is determined endogenously, so, given r_A, $\bar{x}$ is determined endogenously as well.

Pasha conducts comparative static analysis of the effect of minimum lot-size zoning on the main endogenous variables. Since the mathematics is fairly complicated and is available in the article, we simply summarize the results in Table 3.4. The important conclusion for us is that an increase in a minimum lot-size constraint that is binding on suburban households expands the size of the city. Presumably this occurs because the binding minimum is greater than the lot size that would be chosen in the absence of the constraint although this is not stated explicitly by Pasha. Thus, the rich suburbanites consume more land than they otherwise would, which expands the urban area, and which also accounts for their becoming worse off. It is interesting to note that the central city boundary also expands, which, in this model, means that the poor also consume more land and become better off. The reduction in land rent paid by the poor produces these results.

TABLE 3.4: Minimum Lot-Size Comparative Statics, Pasha (1996)

Exogenous Variable	*Endogenous Variables*					
	u_1	u_2	r_1	r_2	x'	$\overline{x}$
$\underline{l}$	+	–	–	?	+	+

Other Research on Minimum Lot-Size Zoning. Turnbull (1991) examines the effect of minimum lot-size zoning on development in a dynamic monocentric open city model. There is no urban area size variable in his model. For comparison with the zoned urban area, Turnbull first discusses the unzoned urban area. The unzoned urban area may develop away from the CBD or toward the CBD depending on how developer profit changes over time with lot size. If profit increases or remains unchanged with lot size over time, development proceeds outward from the CBD with decreasing density at greater distances. If profit falls with lot size over time, development proceeds outward from the CBD at increasing, decreasing, or constant density. This case also includes the possibility that development proceeds inward toward the CBD with density decreasing with distance from the CBD. Under minimum lot-size zoning, development may proceed outward from the CBD, be postponed for a time, produce leapfrogging development, or even produce reverse leapfrogging development. Although this is a rich and interesting model, it provides no empirically testable implications on the effect of minimum lot-size zoning on the size of the urban area.

Bucovetsky (1984) finds that increasing a minimum lot-size restriction increases the price per unit of housing service and decreases the unit price of land. Although he does not deal directly with the size of the urban area, the preceding finding implies the urban area contracts with increases in minimum lot size. This follows because a decrease in urban land rent allows rural households to outbid the given number of urban households for land at the urban-rural fringe. This result is our conjecture since it is not derived explicitly in the model, nor, for that matter, is the number of households included in the model. If correct, this result contradicts that of Pasha.

In an unpublished paper by Henderson (1983), Bucovetsky notes, however, that his result depends on the assumption that the urban area is small and open, such that the interurban spatial equilibrium utility level is parametric. In the open city model, any land-use restriction will lower utility, in which case population will decline and the urban area will contract. Pasha's paper assumes a closed urban area, that is, one with fixed total population, and an endogenous spatial equilibrium utility level. In our opinion, Pasha's result is the more convincing.

Miceli (1992) and Bates and Santerre (1994) examine the fiscal advantages to local government of enacting minimum lot-size zoning. Gyourko and Voith (1997) show that minimum lot-size zoning results in sorting by income within the urban area with an increasing concentration of the poor in the central city. Lichtenberg, Tra, and Hardie (2007) showed that minimum lot-size restrictions induce developers to substitute private space for public open space in urban areas. Although exploring interesting topics, these papers say nothing about the effect of minimum lot-size zoning on the size of the urban area.

Maximum Lot-Size Zoning

Pasha (1992b) incorporates maximum lot-size zoning into the standard monocentric model. He assumes a monocentric city with two income classes as well as two modes of transportation, the auto for the rich and public transportation for the poor. In his analysis Pasha uses subscript 1 for the poor and subscript 2 for the rich. He also assumes that all land is available for residential use; therefore $\delta = 2\pi$.

The Poor. Pasha begins his analysis with the poor, who are assumed not to face a maximum lot-size constraint. The poor thus face the standard budget-constrained utility maximization problem

$$\max\ v_1 = v(c_1, l_1) \text{ s.t. } c_1 + r_1 l_1 = z_1 \tag{3.29}$$

where $z_1 = y_1 - t_1 x$. Pasha assumes both rich and poor have the same utility function. Thus there is no subscript on the utility function operator. Solution of the first-order conditions generates the demand functions

$$c_1 = c_1(z_{1,}, r_1) \tag{3.30}$$

$$l_1 = l_1(z_{1,}, r_1) \tag{3.31}$$

The indirect utility function, $V_1 = V(z_{1,} r_1)$, and the spatial equilibrium condition, $V_1 = u_1$, combine to provide a solution for r_1

$$r_1 = r_1 (z_{1,}, u_1) \tag{3.32}$$

Substituting Equation (3.32) into Equation (3.31) gives the solution for l_1 for the poor as follows

$$l_1 = l_1 (z_{1,}, u_1) \tag{3.33}$$

The Rich. Pasha assumes that the maximum lot-size constraint is operative for the rich. Hence the rich face the budget constraint

$$c_2 + r_2 \bar{l} = z_2 \tag{3.34}$$

where $z_2 = y_2 - t_2 x$ and where $\overline{l}$ is the maximum lot size. The spatial equilibrium condition is

$$u_2 = v(c_2, \bar{l}) \tag{3.35}$$

where u_2 is the spatial equilibrium level of utility. Since $v = u_2$ and $l = \bar{l}$, c_2 is determined by Equation (3.35). Then given y_2 and t_2, r_2 is determined by Equation (3.34). As in the model discussed in the preceding subsection, Pasha assumes that the rich consume exactly the maximum lot size.

To complete the model requires population and boundary conditions. We postpone stating these conditions because in this model, in contrast to his previous one, Pasha considers two cases, and the population and boundary conditions differ depending on which case is being considered.

Case I. The poor live in the central city and the rich live in the suburbs. The population condition for poor households is

$$2\pi \int_0^{x'} \frac{x}{l_1} dx = P_1 \tag{3.36}$$

where x' is the boundary between the central city and the suburbs and P_1 is number of poor households. Similarly

$$2\pi\int_{x'}^{\bar{x}}\frac{x}{\bar{l}}dx = P_2 \tag{3.37}$$

where $\bar{x}$ is the boundary between rural and urban area and P_2 is the population of rich households. The boundary between poor and rich is given by

$$r_1(z_1',u_1) = r_2\left(u_{2,}z_2',\bar{l}\right) \tag{3.38}$$

where $z_i' = y_i - t_i x'$, $i = 1,2$. Given fixed rural land value r_A, the urban-rural boundary, $\bar{x}$, is found where

$$r_2\left(u_2,\bar{z}_2,\bar{l}\right) = r_A \tag{3.39}$$

where $\bar{z}_2 = y_2 - t_2\bar{x}$.

In Case I, Equations (3.36) to (3.39) represent a four-equation system that may be solved for the endogenous variables, u_1, u_2, x', and $\bar{x}$. Once these variables are known, z_1' , z_2', $\bar{z}_1$, and $\bar{z}_2$ are known, and the remaining variables—c_1, c_2, l_1, r_1 , and r_2—may be obtained from Equations (3.30)–(3.34), given $\bar{l}$, P_1, y_1, P_2, y_2, t_1, t_2, and r_A.

Case II. The rich live in the central city, while the poor reside in the suburbs. In this case, the population condition for rich households is

$$2\pi\int_0^{x'}\frac{x}{\bar{l}}dx = P_2 \tag{3.40}$$

The population condition for the poor is

$$2\pi\int_{x'}^{\bar{x}}\frac{x}{l_1}dx = P_1 \tag{3.41}$$

The boundary between rich and poor, x', is given by

$$r_1(z_1', u_1) = r_2(u_2, z_2', \bar{l}) \tag{3.42}$$

where $z_i' = y_i - t_i x'$, $i = 1,2$. Finally, the urban-rural boundary is given by

$$r_1(u_1, \bar{z}_1) = r_A \tag{3.43}$$

where $\bar{z}_1 = y_1 - t_1 \bar{x}$. For Case II, Equations (3.40)–(3.43) may be solved simultaneously for u_1, u_2, x', and $\bar{x}$. Then the remaining endogenous variables—c_1, l_1, r_1, c_2, and r_2—may be obtained from Equations (3.30) and (3.32)–(3.35).

Comparative Static Analysis. Next Pasha conducts a comparative static analysis of the effect of maximum lot-size zoning on the main endogenous variables. The comparative static analysis is done separately for each case. We summarize the results in Table 3.5.

Comparative static results show that in both Case I and Case II, reducing the maximum lot size binding on the rich, i.e. reducing the amount of land that the rich may occupy, leads to contraction of the urban area. (We speak in terms of decreasing maximum lot size because this policy is usually intended to control the spread of the urban area.) Although this result seems intuitively acceptable, some of the other results are more difficult to explain, and some are puzzling.

TABLE 3.5: Maximum Lot-Size Comparative Statics, Pasha (1992b)

Exogenous	*Endogenous Variables*						
Variable $\bar{l}$	u_1	u_2	x'	$\bar{x}$	r_1	r_2	l_1
Case I	–	?	–	–	+	?	–
Case II	+	?	–	–	–	?	+

Note: Signs represent a *decrease* in maximum lot size.

In Case I, reducing a binding maximum lot-size constraint on the rich, who live in the suburbs, raises land rent for the poor, who live in the central city, and reduces their consumption of land, which explains why they are worse off and why the area they occupy contracts. The effects on the rich, who live in the suburbs, are ambiguous, however. A given number of rich now occupies less land, so one would expect that land rent for them would rise because land supply falls, which would make them worse off, but, instead, the results are ambiguous.

In Case II, reducing a binding maximum lot-size constraint on the rich, who now live in the central city, contracts the urban area as well as the size of the central city. This would seem to raise land rent for the rich because the same number of rich households now occupies a smaller area, which might be expected to lower their utility, but both of these result are ambiguous. For the poor, land rent falls and land consumption rises, which explains why they become better off. Land rent for the poor may fall because, although the urban area contracts, the area occupied by the rich also contracts, so the supply of land to the poor may increase.

Other Research on Maximum Lot-Size Zoning. Despite a diligent search, we have found no theoretical treatment of maximum lot-size zoning, other than that of Pasha (1992b), discussed at length above.

Urban Growth Boundaries and Similar Land-Use Restrictions

Urban areas often place some amount of land off-limits to development, for example, parks, wetlands, conservation areas, and so forth. The most severe form of land-use restrictions is the urban growth boundary (UGB), which defines an area from the downtown out to a given distance in which urban development is permitted and beyond which no urban development may occur. The UGB may also take the form of a “greenbelt," which consists of a belt of land surrounding the unrestricted area. Portland, Oregon, is the best known and most studied city in the U.S. with a UGB.

Much empirical work but little theoretical work has been performed on UGB's. Quigley (2007) and Quigley and Swoboda (2007) provide the best theoretical treatment. We follow the development in Quigley and Swoboda, as it is more thorough. The authors start with the standard monocentric model, Equations (3.1)–(3.9) above, but modify it to incorporate land-use restrictions and the UGB. Quigley and Swoboda define unrestricted or urbanized land as that land within the urban area that may be developed. They define the restricted area as the land that cannot be developed for urban use. Quigley and Swoboda also assume that there is no leapfrogging development beyond the restricted area.

Quigley and Swoboda assume that the restrictions affect k radian of an annulus of width $\hat{x}$ at the distance x^* from the CBD. The urban-rural boundary is, as before, $\bar{x}$, so $\hat{x} = \bar{x} - x^*$. Land use is unrestricted in the rest of the circular urban area.

To incorporate land-use restrictions into the standard monocentric model, Quigley and Swoboda modify the population condition, Equation (3.9), as follows

$$\int_0^{x^*} 2\pi x \frac{h(S(x))}{q(x)} dx + \int_{x^*}^{\bar{x}} \left(2\pi - k\right) x \frac{h(S(x))}{q(x)} dx = P \qquad (3.44)$$

where $2\pi - k$ are the radians of unrestricted land, and the remaining variables have the definitions noted above. Equations (3.1)–(3.8) and (3.44) represent the complete model with land-use restrictions.

Comparative Static Analysis. We summarize comparative static results Table 3.6. An increase in the radians of restricted land, k, at a given distance from the CBD, x^*, limits the supply of land available for development. Given a fixed population, this drives up the price of housing, p, and reduces its consumption, q. Although the increase in housing price reduces housing consumption, it increases structural density, S, as developers build taller buildings on the reduced supply of land. This drives up land rent, r, which expands the urban area not subject to the restriction, $\bar{x}$. Finally, the spatial equilibrium utility level, u, falls because of both the increase in housing prices and its reduced consumption. Decreasing the distance from the CBD at which the restriction takes effect, x^*, holding k constant, reproduces the qualitative effects of an increase in k.

TABLE 3.6: Comparative Statics of Land-Use Restrictions, Quigley and Swoboda (2007)

Exogenous Variable	*Endogenous Variables*					
	p	q	S	r	$\bar{x}$	u
k	+	–	+	+	+	–
x^*	+	–	+	+	+	–

Note: Results for x^* represent a *decrease* in distance from the CBD at which the restriction takes effect.

In addition to the preceding limited land-use restrictions, Quigley and Swoboda examine the more restrictive case where $k = 2\pi$. In this case, we have a UGB that outlaws any development beyond its inner boundary, which limits the size of the urban area to a circle with radius $\bar{x} = x^*$. Under the UGB, the urban-rural boundary is determined exogenously by the local government, and the model reduces to Equations (3.1), (3.2), (3.5), (3.6), and (3.7) above. The comparative static results are qualitatively the same as those given in the second row of Table 3.5, i.e., for a decrease in x^*, holding k constant at 2π, except for the effect on $\bar{x}$, which decreases along with x^*.

Other Research on Urban Growth Boundaries and Similar Land-Use Restrictions. The UGB has been widely studied. Researchers have investigated the effects of a UGB on urban development and the conversion of farm land to urban use (Cho, et al., 2007; Cunningham, 2007; Cho, et al., 2006; Jun, 2004; Turnbull, 2004; Abbott, 2002; Kline and

Alig, 1999); the effect of a UGB on agricultural land values (Marin, 2007); whether or not a UGB is a preferable substitute for a congestion toll (Anas and Rhee, 2006; Anas and Rhee, 2007; Brueckner, 2005b); the distributional effects of alternative anti-sprawl policies, including the UGB (Bento, Franco, and Kaffine, 2006); the effects of a UGB on urban housing and land prices (Downs, 2002; Lang, 2002; Nelson, 2002; Fischel, 2002; Phillips and Goodstein, 2000); and amenity and disamenity effects either caused by or mitigated by a UGB (Knaap and Nelson, 1988; Cho, 1997). Although many aspects of the urban land-use boundary have been studied, only the work of Quigley and Quigley and Swoboda, discussed at length above, deals directly with the effect of a UGB on the size of the urban area.

Cho (1997) and Knapp and Nelson (1998) discuss the effects of a UGB on land rent when the UGB produces an amenity or disamenity. Cho considers the case of an amenity effect on both sides of the UGB due to the desirability of residential location near a wooded area. According to Cho, a UGB causes land rent to rise throughout the urban area, except in the greenbelt created by the UGB, where it falls. This implies that the urban area expands. In addition, because of the amenity, land rent rises as one approaches the UGB from either side. Knapp and Nelson assume that the UGB confers an amenity near the inside of the greenbelt, that is, toward the CBD, but a disamenity on the outside. Their reason for the amenity is the same as Cho's. The reason for the disamenity is that Knapp and Nelson assume the land outside the UGB is agricultural and suffers adversely from closeness to the urban area. In this case, they argue that land rent falls from the CBD, rises as one approaches the UGB, drops discontinuously at the UGB, rises away from the UGB, and eventually begins to fall at some distance away from the UGB.

Since land is rural outside the UGB, urban development presumably stops at the inside boundary of the UGB although they do not discuss this.

Neither Cho nor Knaap and Nelson present a fully articulated model, nor do these authors derive their results mathematically within such a model. They nevertheless call attention to the importance of the *kind* of land use on the outside of a UGB. Quigley and Swoboda do provide a fully articulated model and perform a comparative static analysis of the effect of an land-use boundary. Moreover, the Quigley-Swoboda model can be interpreted in ways that make its results consistent with those of Cho and Knaap and Nelson. In the Quigley-Swoboda model, if urban land use is permitted beyond the radius at which the UGB begins, then the urban area expands. On the other hand, if rural land use begins on the outside of the UGB, then the UGB contracts the urban area over what it would otherwise have been. For our purpose, the presence or absence of amenity and disamenity effects are not of importance; the size of the urban area is.

Density Controls

Introduction. High urban population density contributes to traffic congestion, noise, and pollution as well as producing less aesthetic skylines, and local governments have used various techniques to control it. In addition, density controls, as Mills (2005, p. 572) noted, “may be intended to exclude low-income and/or minority people from high-income suburbs.” On the other hand, governments have sought to increase density to encourage use of transit, as opposed to the auto, increase neighborhood interactions, and reduce infrastructure cost.

We divide density controls into two categories, direct and indirect.[7] Direct density controls set a maximum or minimum number of people per unit of land. Indirect density controls can be grouped into two classes, housing density restrictions and structural density restrictions. Housing density restrictions set an upper or lower bound on the amount of housing per unit of land. Structural density refers to the amount of non-land inputs per unit of land and is reflected in building height restrictions and setback requirements.

To relate these ideas to the model of Section 1 of this chapter, recall the constant-returns-to-scale housing production function, given in Equation (3.3) above

$$H = H(l, N)$$

and its intensive form, given in Equation (3.4) above

$$\frac{H}{l} = h(S)$$

where H is the amount of housing at a given distance from the CBD, which is produced by land, l, and non-land, N, and where $S = N/l$. The quotient, h/q, is the total amount of housing per unit of land at any given distance from the CBD divided by per-household consumption of housing at that distance. Assuming single-person households, this is population density, D. The three density measures—housing density, h; structural density, S; and population density, D—are all directly related. Also, as seen from Table 3.2, S falls with distance from the CBD. Since $h'(S) > 0$, then h also falls with distance. Although not discussed in Section 1, population density also falls with distance. This may most easily be seen by rewriting h/q as $(H/l)/q$. Then, since H/l falls and q rises, popula-

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[7] In this, we partially follow Mills (2005), who related density controls directly or indirectly to structural density.

tion density falls with distance from the CBD. Because of these relationships, we shall use the model of Bertaud and Brueckner (2005), which deals with housing density in the form of a maximum floor-area ratio (*FAR*). Although we have not found studies dealing directly with structural density and population density restrictions, we assume Bertaud and Brueckner's findings can be applied to these kinds of restrictions. Some additional comments on this will be made later.

The Model. Bertaud and Brueckner provide an analysis of the effect of a *FAR* restriction on the spatial size of the urban area, urban residents' welfare, housing price, housing consumption, and land-rent. The *FAR* restriction is represented by the following expression

$$h(S) \leq \bar{h} \tag{3.45}$$

where $\bar{h}$ is the maximum *FAR* set by the local government. To incorporate this *FAR* restriction into the basic model requires that the following equation replace Equation (3.9)

$$\int_0^{\hat{x}} \delta x \frac{\bar{h}}{q} dx + \int_{\hat{x}}^{\bar{x}} \delta x \frac{h(S)}{q} dx = P \tag{3.46}$$

The first integral in Equation (3.46) represents the urban area population where the *FAR* is binding, called the restricted area, and the second integral represents the urban area population where the *FAR* is not binding, called the unrestricted area. Integrating both populations gives the total population of the urban area. Except for this change, this model is identical to that of the basic model.

Comparative Statics. Bertaud and Brueckner obtain the results summarized in Table 3.7.

TABLE 3.7: Maximum *FAR* Comparative Statics, Bertaud and Brueckner (2005)

Exogenous Variable	*Endogenous Variables*[a]					
	u	$\overline{x}$	h	p	q	r
$\overline{h}$	–	+	+	+	–	*NC*

[a]Results for $\overline{x}$ and u are general; the rest are obtained by simulation and are evaluated at $\overline{x}$.

If the urban area has a binding maximum *FAR*, then from the CBD out to some distance at which the restriction is no longer binding, the urban area will have lower population, housing, and structural densities inside the restricted area than it would have had in the absence of the *FAR* restriction. This lowers the utility of those living in the restricted area because the restriction is binding on them, i.e., they are forced to live at a lower density than they would prefer. Given an exogenous total population, the *FAR* restriction leads to population outflow from the restricted area to the unrestricted area, which expands the urban area and raises housing density in the unrestricted area. The increased population in the unrestricted area increases the demand for housing there, which raises housing price and reduces quantity demanded, which, in turn, reduces utility. Finally, at the urban boundary, land rent will be the same for an urban area with and without a *FAR* restriction because, in either case, urban land rent is equal to agricultural land rent, r_A , at the urban-rural boundary. Because of their direct relation to *h*, these results also apply to caps on structural density, $\overline{S}$, and population density, $\overline{D}$.

We found no theoretical analysis of minimum density restrictions, but we did find such restrictions in our data. Consequently, we interpret the results of Bertaud and Brueckner in terms of minimum density restrictions. Their argument for a positive effect of a maximum *FAR* on urban spatial size is that the urban population is constrained by the *FAR* up to the distance at which it ceases to be a binding constraint (since *FAR* will fall with distance in the unconstrained model). This causes households to seek locations beyond the distance at which the constraint is binding, which raises land rents beyond that distance, which, in turn, causes the urban area to expand.

Applying this logic to a minimum *FAR* means that the constraint will be non-binding up to some distance from the CBD. Beyond that distance and up to the urban-rural boundary, however, the unconstrained *FAR* would be lower than allowed by the minimum *FAR*, i.e., people are being required to live at a higher density than they would prefer. For a given population, this would reduce the spatial size of the urban area. Again, because of the direct relation among population, structural, and housing density, we conclude that minimum density restrictions, which we denote $\underline{h}$, $\underline{S}$, and $\underline{D}$, will all reduce the spatial size of the urban area.

Other Research on Density Restrictions. Arnott and MacKinnon (1977) are the first to examine structural density restrictions, in the form of building-height restrictions, in a general equilibrium simulation model. Although their purpose is to measure the costs of such restrictions, not to determined the effect of a building-height restriction on the urban-rural boundary, their results may nevertheless be interpreted as supportive of the results of Bertaud and Brueckner. Pasha (1992a, 1995) treats density restrictions as minimum lot-size restrictions, which we have analyzed earlier. Fu and Somerville's (2001) objective is to determine how variation in density restrictions within an urban area, due to different interests between different levels of government, affects the outcome of site-specific urban redevelopment. To accomplish this objective, they derive a relationship between land price per unit of buildable space and the building-height restriction. Estimating this relationship for Shanghai, China, they find, "concerns for congestion raise the restriction on redevelopment densities. However, higher resettlement cost and greater inefficiency in the existing land use tend to lower the restriction" (Fu and Somerville, 2001, p. 421)." This analysis, while interesting, does not shed light on our concern with the effect of density restrictions on the decentralization of urban areas. In an empirical study of Mumbai, India, similar to that of Fu and Somerville, Nallathiga (2006, p. 132) finds, "the impact of density regulation is highest on the already highly demanded space in the CBD; also, the impact is significant in the suburbs." Again, this type of analysis does not shed light on our concerns.

Impact Fees

Introduction. When new development occurs in an urban area, the local government (municipality or county) must provide infrastructure (roads, water mains, sewer lines, parks, schools, police and fire protection, etc.) to support that development. To pay for the infrastructure, local governments collect property taxes, which are the main source of local governmental revenues, but exactions, that is, non property-tax revenues, are also used. Only about 10 percent of localities in the U.S. used exactions before 1960, but by the mid 1980's, in contrast, 90-percent of localities were using exactions. Prior to 1960, most exactions were levied in-kind, such as the developer's provision of land for a park, but by the mid 1980's, about 60 percent of localities were using both in-cash and in-kind exactions (Altshuler and Gómez-Ibáñez, 1993). Such exactions are known as development or impact fees, and include, in addition to those noted above, fees in lieu of developer land contributions for parks and schools, and development excise taxes, also called privilege or facilities taxes (Mullen, 2003).

As discussed further below, most research on impact fees deals with their effect on housing and land prices and on their efficiency aspects. We have found no research on the effect of impact fees on the size of the urban area. For our purpose, we would like a model similar to those discussed above, that is, a static monocentric model, but apparently there is none. Instead, we present Song and Zenou's (2006) model of the property tax. Although the property tax is levied annually, whereas the impact fee is a one-time exaction, both are imposed on real property (i.e., land and improvements), and we assume that both should have the same qualitative effect.

As Song and Zenou note, Brueckner and Kim (2003) "provide the only theoretical analysis that incorporates a land market to investigate the connection between urban spatial expansion and the property tax" (Song and Zenou, 2006, p. 520). Unfortunately, however, Brueckner and Kim's finding regarding this effect is ambiguous. The ambiguity arises from two effects of the property tax and, we assume, impacts fees on the spatial size of the urban area. The first is called the "building height effect." Since the property tax, as well as the impact fee, is imposed on both land and structures, its effect is to lower developers' profits per unit of land, resulting in a lower building height per unit of land (a lower structural density). Given population, this effect would, by itself, lead to an expansion of the urban area. The other effect is called the "dwelling size" effect. Since some of the property tax or impact fee is shifted forward to households when levied on landlords or imposed directly on homeowners, then housing prices increase and households choose smaller dwelling units on smaller sites. For a given population, smaller dwellings and smaller sites imply increased population density and a spatially smaller urban area.

To get around this ambiguity, Song and Zenou use a model with specific, rather than general, functional forms. Their model yields an unambiguous decrease in the spatial size of the urban area due to the property tax, and their empirical analysis supports that finding. We should note that Su and DeSalvo (2008) have presented a model with a property tax, which is more general than that of Song and Zenou. We choose not to present that model because its main emphasis is on the effect of transportation subsidies on the spatial size of the urban area. Also, it contains two transportation modes, which would complicate the analysis needlessly. Finally, it contains no explicit housing market, which, given that impact fees are levied on housing developers, renders the model unsuitable for our use. Nevertheless, Su and DeSalvo's empirical analysis supports the negative effect of the property tax on the spatial size of an urban area.

The Model. For the household sector, Song and Zenou assume a quasi-linear utility function

$$v(c,q) = c + \ln q \tag{3.47}$$

where the variables have the same definitions as before. Maximizing this subject to the budget constraint

$$y = c + pq + tx \tag{3.48}$$

and solving the first-order condition given by Equation (3.1) above produces the closed form demand functions

$$q = \frac{1}{p} \text{ and } c = y - tx - 1 \tag{3.49}$$

Substituting these into the utility function produces the indirect utility function

$$V = y - tx - 1 - \ln p \tag{3.50}$$

where V is taken as the urban-area spatial equilibrium level of utility, analogous to Equation (3.2) above. Then the housing price function may be solved as

$$p = e^{y-ts-1-V} \tag{3.51}$$

and the housing demand function as

$$q = \frac{1}{e^{y-tx-1-V}} \tag{3.52}$$

For the housing production sector, Song and Zenou assume the housing production function

$$H = H(l, N) = 2(lN)^{0.5} \tag{3.53}$$

analogous to Equation (3.3) above. Dividing through by l gives

$$h(S) = \frac{H}{l} = 2S^{0.5} \tag{3.54}$$

analogous to Equation (3.4) above, where $S = N/l$. It is at this point that Song and Zenou introduce the property tax, θ. Hence, profit per unit of land is

$$\pi = ph(S) - (1-\theta)(r+iS) = 2pS^{0.5} - (1-\theta)(r+iS) \tag{3.55}$$

which is analogous to Equation (3.5) above and where the variables are as previously defined. Song and Zenou argue that imposing the property tax on developers produces the same effect as imposing it on households. In fact, this formulation is better for our purpose because impact fees are imposed on developers.

At this point, the methodology diverges from that of the basic model. Instead of setting π equal to zero, solving Equation (3.55) for r, and maximizing r with respect to S, getting the first-order condition analogous to Equation (3.6) above, Son and Zenou substitute the previously derived housing price function, Equation (3.51), into Equation

(3.55), then maximize the modified Equation (3.55) with respect to *S*. Given the functional forms assumed allows them to solve the first-order condition for *S*, getting

$$S = \frac{e^{2(y-tx-1-V)}}{(1+\theta)^2 i^2} \tag{3.56}$$

Substituting this into *h*(*S*) yields

$$h(S) = \frac{2e^{y-tx-1-V}}{(1+\theta)i} \tag{3.57}$$

To get the land rent function, substitute Equations (3.56) and (3.57) into Equation (3.55), set $\pi = 0$, and solve for *r*, getting

$$r = \frac{ph(S)}{(1+\theta)} - iS = \frac{e^{2(y-tx-1-V)}}{(1+\theta)^2 i} \tag{3.58}$$

which is analogous to Equation (3.7) above.

The boundary condition, analogous to Equation (3.8) above, is

$$\frac{e^{2(y-t\bar{x}-1-V)}}{(1+\theta)^2 i} = r_A \tag{3.59}$$

while the population condition, analogous to Equation (3.9) above, is

$$\int_0^{\bar{x}} \frac{h(S)}{q} dx = \int_0^{\bar{x}} \frac{2e^{2(y-tx-1-V)}}{(1+\theta)i} dx = P \tag{3.60}$$

Note that the term preceding the integrand in Equation (3.9), namely δx, is missing from Equation (3.60). This is so because Song and Zenou assume a linear, not circular, urban area. These two equations may be solved for the equilibrium values of $\bar{x}$ and V, giving

$$\bar{x} = \frac{1}{2t} \ln\left[1 + \frac{tP}{(1+\theta)r_A}\right] \tag{3.61}$$

and

$$V = y - t - 0.5\ln\left\{(1+\theta)i\left[(1+\theta)r_A + tP\right]\right\} \tag{3.62}$$

This completes the model, and from here it is easy to obtain the comparative static effects of the property tax on endogenous variables, shown in Table 3.8. An increase in the property tax raises housing price and land rent, which reduces the demand for housing and causes developers to produce smaller dwelling units per unit of land. These effects contract the urban area spatially and lower household utility.

TABLE 3.8: Property-Tax Comparative Statics, Song and Zenou (2006)

Exogenous Variable	*Endogenous Variables*					
	p	r	q	h	$\bar{x}$	V
θ	+	+	–	–	–	–

Other Research on Impact Fees. As noted above, most of the research on impact fees has been on their effect on housing and land prices (for a survey, see Fischel, 1985). The general conclusion is that impact fees raise housing and land prices (Ihlanfeldt and Shaughnessy, 2004; Skaburskis, 1992; Delaney and Smith, 1989; Baden, Coursey, and Harris, 2000; Evans-Cowley and Lawhon, 2003; Mathur, Waddell, and Blanco, 2004). Gyourko (1991) examines the relationship between impact fees and exclusionary zoning. He finds that impact fees reduce the incentive for communities to engage in exclusionary zoning, which leads to an increase in the optimal density of new development. Brueckner (1997) finds that impact fees retard urban land-use, limiting both population and spatial size of urban areas. Jeong and Feiock (2006) explored the economic consequences of impact fees on local economic development and job growth. They use time-series cross-section data for sixty-six Florida counties and find that, in contrast to other research results, impact fees enhance economic performance and lead to job growth. Finally, Skaburskis (1990) examines the incidence of development impact fees. His analysis shows that, in competitive markets, the burden of impact fees is passed forward to households. Skaburskis also finds that changing impact fees in response to changing market conditions increases housing prices by increasing uncertainty.

CONCLUSION

The purpose of this chapter is to familiarize the reader with the theory of the standard monocentric model as well as with the theoretical extensions of this model that include land-use controls. Table 3.9 summarizes the effect of land-use controls on the size of the urban area as given in the urban literature, including the behavior of density restrictions that we presented above.

TABLE 3.9: Effects of Land-Use Controls on the Spatial Size of Urban Areas

Land-Use Control	*Effect*
Minimum Lot Size, $\underline{l}$ (Pasha, 1996)	+
Maximum Lot Size, $\bar{l}$ (Pasha, 1992a)	–
Urban Growth Boundary, x^*, k (Quigley and Swoboda, 2007)	–
Maximum Density Restriction (Bertaud and Brueckner, 2005) Housing Density (FAR), $\bar{h}$ Building-Height, $\bar{S}$ Population Density, $\bar{D}$	+
Minimum Density Restriction (Bertaud and Brueckner, 2005) Housing Density (FAR), $\underline{h}$ Building-Height, $\underline{S}$ Population Density, $\underline{D}$	–
Impact Fee, θ (Song and Zenou, 2006)	–

Note: Signs represent effects from increased stringency of the control.

CHAPTER 4: A REVIEW OF EMPIRICAL ANALYSIS OF THE GENERAL EQUILIBRIUM MONOCENTRIC URBAN SPATIAL MODEL

INTRODUCTION

Empirical research on the general equilibrium monocentric urban model was initiated by Brueckner and Fansler (1983).[8] McGrath (2005) provides the most recent empirical analysis of the model. Both of these articles report tests of the basic, unextended, closed city model described in Chapter 3, pp. 27–34. Song and Zenou (2006) extend the model to include the property tax, and Su and DeSalvo (2008) extend it to include two modes of transportation, transportation subsidies, and the property tax. Both of these latter articles include empirical testing. Because we shall use similar empirical analysis, we provide a brief review of the above articles in this chapter.

All of these articles test the closed city model. To our knowledge, no one has tested the open city model. Table 3.2, p. 33, summarizes the comparative statics of the closed city model. The spatial size of the urban area, represented by its radius, $\overline{x}$, which is also the urban-rural boundary, is found to be directly related to urban area population, P; directly related to urban area income, y, assumed equal for all urban households; inversely related to marginal = average transportation cost per round-trip mile, t, also assumed to be equal for all urban households; and inversely related to rural land rent at the urban-rural boundary, r_A.

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[8] In Chapter 3, we reviewed relevant theoretical and empirical work prior to the development of the general equilibrium model.

BRUECKNER AND FANSLER

Brueckner and Fansler (1983) use 1970 census data for a sample of 40 urbanized areas, each contained within a single, relatively small county. The dependent variable is the size of the urbanized area in square miles, a proxy for $\bar{x}$. P is urbanized area population. Brueckner and Fansler (1983, n. 11, p. 481) describe their procedure for estimating income, y, as follows: "The population of the city not living in group quarters (e.g., prisons and fraternities) was multiplied by per capita income, and the resulting figure was divided by the number of households in the urban area (shown by the census as the number of occupied housing units)." Brueckner and Fansler (1983, p. 481) claim this is "a measure of average household income similar to median income." It is unclear what they mean by this because it is unclear if they use "city" to mean "central city" or as a synonym for "urbanized area." If the former, it is not clear to us that this approximates median household income for the urbanized area. If the latter, then it estimates urbanized area mean household income. We interpret their income variable as the latter. The authors use two proxy-variables for transportation cost, t. The first is called TRANSIT, which is equal to the percentage of commuters using public transit. They argue that this variable should be directly related to t because bus, which is the most widely used form of transit in their urbanized areas, is costly in terms of time. The second is AUTOS, which is equal to the percentage of households owning one or more automobiles. The authors argue that this proxy should be inversely related to t because a high value of AUTO would imply ease of auto usage due to less congestion. Finally, Brueckner and Fansler proxy rural land rent, r_A, by the 1969 median agricultural land value per acre for the county containing the urbanized area. They believe that rural land value in small counties better approximates the theoretical variable than would rural land value in larger counties, which is why they restricted their sample to small counties.

Because the theory does not dictate a particular functional form, Brueckner and Fansler use two Box-Cox specifications, a non-linear flexible form and a linear form. The authors estimate two equations for each form, one using TRANSIT and the other using AUTOS as the transportation cost proxy. The results are presented in Table 4.1, for the non-linear form, and Table 4.2, for the linear form.

TABLE 4.1: Box-Cox Non-Linear Estimation ($\lambda = 0.53$),
Brueckner and Fansler (1983)

Variable	*With TRANSIT*		*With AUTOS*	
	Coefficient	$\lvert t \rvert$	*Coefficient*	$\lvert t \rvert$
P	0.01544	9.043	0.1539	9.158
y	0.07908	3.233	0.07905	3.230
TRANSIT (t)	–0.04679	0.1979		
r_A	–0.07150	2.856	–0.07905	2.736
AUTOS (t)			0.11168	0.1573
Constant	–16.7115	3.046	–18.71665	1.309
R^2	0.7760		0.7760	
N	40		40	

TABLE 4.2: Box-Cox Linear Estimation ($\lambda = 1$),
Brueckner and Fansler (1983)

Variable	*With TRANSIT*		*With AUTOS*	
	Coefficient	$\lvert t \rvert$	*Coefficient*	$\lvert t \rvert$
P	0.00041	10.030	0.00040	9.876
y	0.00620	3.033	0.00624	3.050
t (*TRANSIT*)	–0.24440	0.406		
r_A	–0.03028	3.090	–0.02888	2.888
t (*AUTOS*)			0.24746	0.4604
Constant	–41.07232	2.277	–63.46913	1.244
R^2	0.7982		0.7985	
N	40		40	

These tables show that urban area population has a statistically significantly positive effect, agricultural land value has a significantly negative effect, and income has a significantly positive effect on the spatial size of the urbanized area, all consistent with the theoretical predictions. The authors find both proxy variables for transportation cost to have the right signs but to be statistically insignificant. Brueckner and Fansler conjecture that the proxies may fail to capture actual commuting cost differences and that, although they may be correlated with commuting cost, their small range of variation within the sample may prevent precise estimation results. The coefficients of determination, R^2, are high for all estimates, indicating that the few exogenous variables capture most of the variation in spatial size. The reason for using both a non-linear and a linear form is that they could not reject the hypothesis that the form was linear. In the non-linear version, $\lambda = 0.53$, indicating an approximately square root transformation, while in the linear version, λ was set equal to one.

MC GRATH

McGrath (2005) uses census data for 1950 through 1990 to create a sample of 153 urbanized areas contained within the thirty-three largest U.S. metropolitan areas, which would give him a potential sample size of 165, but several urbanized areas were missing data on land area and CPI, reducing the sample to 153 complete observations. Since the spatial size of a circular urban area is $A = \pi \bar{x}^2$, McGrath estimates the radius of the urban area, as $\bar{x} = (A/\pi)^{0.5}$, which he calls XBAR, where A is the area of the urbanized area in square miles. Population, P, called MSAPOP, is measured as the population in thousands for the metropolitan area. Income, y, called RPINC, is real per capita personal income for the metropolitan area in 1990 dollars. Rural land rent, r_A, called RAGVAL, is proxied by the nominal agricultural land value per acre for the state in which the metropolitan area is located. The data are from the USDA Economics and Statistics Office and were converted to 1990 dollars. As a proxy for transportation cost, *t*, McGrath creates a variable called APTCPI, which is the regionally adjusted private transportation consumer price index in 1990 dollars for the metropolitan area, where APTCPI = 100 for Atlanta. This variable was created by scaling CPI data by regionally comparative private transportation cost data for 1990, available from the American Chamber of Commerce. The author also creates a time variable, called DECADE (also called τ) , which he uses to capture the increasing polycentricity of urban areas, fiscal and social disparities, and market failures, all of which he contends contribute to the spatial expansion of urban areas over time.

We are troubled by the mixing of data for urbanized areas, metropolitan areas, and states, for these areas may differ significantly with respect to all variables in the estimated equations. We would have preferred that all variables related to urbanized areas. Despite these concerns, McGrath's results are statistically good, as we shall see.

McGrath estimates two regression models. In Model 1, the author does not use the time trend variable, DECADE. In this model, the author regresses LNXBAR (the natural logarithm of $\overline{x}$) on LNPOP (the natural logarithm of P), RPINC (y), RAGVAL (r_A), and APTCPI (t), using OLS in an equation of the form

$$\ln \overline{x}_{i\tau} = \beta_0 + \beta_1 \ln P_{i\tau} + \beta_2 y_{i\tau} + \beta_3 r_{A_{i\tau}} + \beta_4 t_{i\tau} \tag{4.1}$$

where i represents the metropolitan region and τ represents time.

McGrath argues that the functional form "is consistent with logarithmic functional forms identified for metropolitan density gradients....(McGrath, 2005, p. 4)" Although he provides no further justification, his rationale apparently follows from the fact that population density functions are usually estimated in the negative exponential functional form

$$D(x) = D_0 e^{-D_1 x} \tag{4.2}$$

which under natural log transform becomes

$$\ln D(x) = \ln D_0 - D_1 x \tag{4.3}$$

where $D(x)$ is population density at distance x from the CBD, D_0 is the level parameter, and D_1 is the density gradient (Mills, 1972). Since density is population, P, divided by area, A, at distance x from the CBD, then ln $D(x)$ is ln $P(x)$ – ln $A(x)$, and, with a little algebra, Equation (4.3) becomes

$$\ln A(x) = \ln P(x) - \ln D_0 + D_1 x \tag{4.4}$$

Since A proxies $\overline{x}$, this gives the relation between $\overline{x}$ and P that McGrath wants. This is, however, not really the same as his estimating equation, Equation (4.1). Equation (4.4) has A and P varying with x as well as including x as a regressor, while McGrath's A and P are metropolitan area totals and x is not a regressor. Nevertheless, his estimating equation produces good results.

Both OLS estimations are presented in Table 4.3. The results for Model 1 show that the coefficients on population, real personal income, and real agricultural land values are all statistically significant and have signs consistent with expectations. However, the coefficient on the transportation cost index is not statistically significant although its sign is consistent with the theory. The R^2 indicates that over 87 percent of the variation in urbanized area size is explained by the variable in the regression.

In Model 2, which includes the time trend variable, τ, all the coefficients on the independent variables are statistically significant. The coefficient on the transport cost proxy variable is statistically significantly negative, which is in accord with theory. The time variable is positive and statistically significant, which means that urbanized areas tend to grow spatially over time for reasons other than those proposed by the theory. As McGrath points out, the coefficient on the time-trend variable implies that the spatial size of urbanized areas on average grows 2.3 percent larger per year than implied by changes in the other regressors, but the explanatory power of the model improves only slightly, indicating that these variables still are the predominant forces at work explaining urban growth.

TABLE 4.3: OLS Estimation, McGrath (2005)

Variable	*Model 1*		*Model 2*	
	Coefficient	$\lvert t \rvert$	*Coefficient*	$\lvert t \rvert$
P	0.376	24.34	0.382	24.39
y	0.0000365	5.83	0.0000153	1.74
r_A	–0.0000467	2.01	–0.0000547	2.42
t	–0.000169	0.24	0.00255	2.58
τ			0.116	3.33
Constant	–0.641	6.25	–0.672	6.33
R^2	0.871		0.879	
N	153		153	

SONG AND ZENOU

The primary purpose of Song and Zenou (2006) is to estimate the effect of the property tax on the spatial size of the urban area. Their theoretical model, discussed in Ch. 3, differs from those underlying the preceding estimations in that it assumes a linear, not circular, urban area. Nevertheless, Song and Zenou use the variables of the standard model in addition to the property tax as regressors.

Their sample consists of data on 448 urbanized areas in 2000. Data on urbanized area size, population, and income are from the 2000 Census. The dependent variable is the size of the urbanized areas in acres, a proxy for $\bar{x}$. For income, y, they use median household income adjusted by the 2000 ACCRA Cost of Living Index, which permits cost-of-living comparisons among urbanized area. From the U.S. Census of Agriculture, they obtain 1997 median agricultural land value per acre for the county containing the urbanized area, a proxy for r_A. As a proxy for t, they create a variable called TRANS, which is 1997 governmental transportation expenditures per person who drives to work, obtained from the U.S. Census of Governments. Song and Zenou argue that, other things equal, a higher value of TRANS would be associated with ease of transportation system usage and a lower level of commuting cost.

An urbanized area may contain within its geographical boundaries many different taxing jurisdictions, such as, counties, cities, townships, and school districts. For consistency with their theoretical model, Song and Zenou need a property tax rate for each urbanized area in their sample. They were able to obtain an effective property tax rate (that is, the property tax rate times the ratio of assessed value to market value) for each geographical area within their sample urbanized areas from public sources as well as conversations with officials of the various taxing authorities. Next, using GIS techniques, they determine the proportion of each taxing jurisdiction's spatial size to that of the urbanized area. Their weighted-average property tax rate, called TAXRT, is the sum of each taxing jurisdiction's effective property tax rate multiplied by its proportionate size. Because of the proliferation of taxing jurisdictions in large urbanized areas, Song and Zenou exclude from their sample urbanized areas with populations larger than five million.

Song and Zenou are concerned that including their property tax variable as a regressor might give rise to simultaneity between that variable and the size of the urban area. On one hand, a higher property tax could decrease the size of the urban area. On the other hand, as an urban area expands spatially, it might increase property tax rates to pay for infrastructure required by the expansion. Of course, whether or not property tax rates rise depends on how average infrastructure costs change as population increases. They could rise, fall, or remain unchanged if the marginal infrastructure costs were greater than, less than, or equal to the average.[9]

To handle this potential problem, Song and Zenou use two-stage least squares (2SLS). As an instrumental variable (IV) for the property tax rate, they choose the magnitude of state aid to schools, obtained from the National Center for Education Statistics. This variable is negatively correlated with the property tax (richer school districts get less state aid) but uncorrelated with urbanized area size. Their IV passes the *F*-test, and the first stage of their 2SLS estimation produces a negative sign on the IV, as expected. The authors also perform a Hausman endogeneity test, which shows a significant difference between the 2SLS and OLS estimates.

TABLE 4.4: OLS and 2SLS Estimations,
Song and Zenou (2006)

Variable	*OLS*		*2SLS*	
	Coefficient	$\|t\|$	*Coefficient*	$\|t\|$
P	0.0020	17.35	0.0020	6.31
y	0.00182	6.37	0.00193	4.21
r_A	0.00009	0.41	0.00005	0.25
t	0.14417	5.57	0.14286	8.96
TAXRT	–3.48479	5.36	–4.23621	2.41
Constant	117.49260	8.63	120.0974	6.31
R^2	0.8536		0.8520	
N	448		448	

The empirical results are presented in Table 4.4. The income and population coefficients are positive and statistically significant. The coefficient on the transportation cost proxy variable is positive and statistically significant, meaning that an increase in governmental expenditures on roads and highways lowers transportation cost and in-

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[9] We thank Professor Kenneth F. Wieand for this point.

creases urban size. The coefficient on agricultural land value is positive, contrary to theory, and statistically insignificant. This poor result could be explained by the difficulty of capturing the exact value of agricultural land at the urban-rural fringe. Finally, the authors find the coefficient on the property-tax variable to be negative and statistically significant, meaning that an increase in the property tax would cause the urbanized area to contract, as their theoretical model predicts.

SU AND DE SALVO

The primary purpose of Su and DeSalvo (2008) is to investigate the effect of transportation subsidies on urban sprawl. The authors use a sample of 201 urbanized areas from the 2000 census, selected so that there is a single central city in a single county to conform better to the monocentric model (the sample size ultimately falls to 93 because of data unavailability).

The theoretical model, not presented here, indicates that the following variables are directly related to urban area spatial size: households, income, fixed and variable transit costs, and auto subsidy. Those inversely related to urban area size are: rural land rent, the property tax rate, fixed and variable auto costs, and the transit subsidy. Intergovernmental grants have no effect on urban area size.

To test these theoretical predictions, Su and DeSalvo regress the spatial size of the urbanized area on the number of households, P; mean value of agricultural land, r_A; mean household income, y; and two sets of variables representing fixed transportation cost, f_i, and marginal transportation cost, t_i, and transportation subsidy, α_i, where $i = 1$ for auto and $i = 2$ for transit. Transportation cost is represented by the following variables: the percentage of the working age population using transit; auto insurance premium, registration fee, license fee, and motor vehicle tax per household by urbanized area; bus fare cost per passenger mile traveled; and fuel tax payment per vehicle-mile traveled. Transportation subsidy is represented by the following variables: the subsidy to bus service per passenger–mile, county subsidies to auto use per vehicle-mile traveled, and intergovernmental transfers from state to local governments for transportation purposes, G. To capture taxes, Su and DeSalvo include the property tax rate, θ, estimated as the percentage of average household income paid as property taxes. A state dummy variable, S, is used to partially account for the age of the urbanized area and underlying differences in state planning laws and other factors that might influence urban spatial size. Because of some non-linearities in the data, Su and DeSalvo enter the income and transit subsidy variables in linear and squared form. The other variables enter linearly.

Data on spatial size, population, income, percentage of working age population, county subsidies to auto use, intergovernmental grants, and property tax payments are from the Census. Agricultural land value is from the National Agricultural Statistics Service. The fixed auto costs, bus fares, and variable auto costs are from the Federal Highway Administration, while the bus subsidies are from the Federal Transit Administration.

Even though, theoretically, all the independent variables in the equation are exogenous, Su and DeSalvo consider the possibility that one or more of the explanatory variables may be endogenous econometrically. In particular, they think the transportation cost and subsidy variables may be simultaneously determined with urbanized area spatial size, specifically, working age population using transit, bus marginal cost, bus subsidies, auto marginal cost, auto subsidies. In addition, they think this might be so for the property tax rate as well. To deal with these possibilities, Su and DeSalvo use three IV's for auto marginal cost: state gasoline tax per gallon, urbanized area freeway lane–miles, and the number of interstate highway rays in 1970 (a *ray* is a highway passing through downtown). The authors also use three IV's for the three potential endogenous bus-related variables: the crime rate per 1,000 bus users, adult single-trip base fare, and the federal Urban Area Formula Program funds per passenger-mile. Finally, Su and DeSalvo use state school aid per student as an IV for the property tax. An *F*-test reveals that the suspected variables do not significantly bias the OLS results. Consequently, only the OLS results are presented in Table 4.5.

TABLE 4.5: OLS Estimation, Su and DeSalvo (2008)

Variable	*Coefficient*	*p-value*
P	0.0073	0.000
y	0.1356	0.000
y^2	-0.0012	0.000
r_A	–0.0269	0.440
θ	–0.1102	0.076
G	$-1.94e^{-7}$	0.844
f_1	–0.1055	0.000
t_1	0.0093	0.020
α_1	–0.0012	0.016
f_2	–0.3957	0.008
t_2	–0.0396	0.314
α_2	0.9000	0.014
α_2^2	–0.7779	0.007
Constant	0.8992	–
R^2	0.8365	
N	93	

The authors find the spatial size of the urbanized area increases with income, as predicted, but at a decreasing rate. The coefficient on population, is positive, as predicted, and statistically significant. The coefficient on agricultural land value is negative, as predicted, but not statistically significant. The coefficient on the property tax rate is negative, as predicted, and statistically significant. The coefficient on the proxy for bus fixed cost is negative, as predicted, and statistically significant. This result indicates that as the percentage of people using transit increases, the spatial size of urbanized area decreases. The coefficient on bus marginal cost is positive, as predicted, and statistically significant. That means that an increase in the bus subsidy per passenger-mile reduces urban area size. The coefficient on auto marginal cost is negative, as predicted, but not statistically significant. The coefficient on auto subsidy is positive, as predicted, and statistically significant, while that on auto subsidy squared is negative and statistically significant. These results indicate that the spatial size of the urbanized area is increasing at decreasing rate with respect to highway subsidy.

CONCLUSIONS

The theory of urban spatial structure has been shown to be robust to specification of estimating equation, proxies for theoretical variables, sample size, and population of urbanized areas included in the database. There appears to be little or no econometric endogeneity of theoretically exogenous variables, except possible for the property tax, although Song and Zenou’s finding differ from those of Su and DeSalvo on this point. Extensions of the basic model to include property taxes and transportation subsidies have also held up well to estimation.

CHAPTER 5: DATA DESCRIPTION

INTRODUCTION

In our empirical analysis, we intend to use an approach similar to that used in studies reviewed in Chapter 4, but with the inclusion of land-use controls as regressors, in addition to population, income, transportation cost, and agricultural land value. The empirical work will test the theoretical predictions of the effects of land-use controls on an urban area's spatial size, which we presented in Chapter 3.

As discussed in Chapter 3, theoretical models predict certain effects of land-use controls on sprawl, but none distinguishes city and county controls. In the U.S. the county is a unit of government and, as such, may impose its own land-use controls. Some of the theoretical work (e.g., Pasha, 1992a, 1996) does include the geographical extent of controls within the urban area, specifically, controls in the central city and not in the suburbs and vice versa, but it is implicitly assumed that there is one entity governing the entire urban area encompassing central city and suburbs. No one, to our knowledge, has modeled an urban area with controls in both the central city and in the county while recognizing that these are different governments. Despite the theoretical predictions, therefore, it is not obvious what effect such controls have on sprawl. For example, land-use controls instituted by the city may, in fact, increase urban sprawl by inducing population to locate in the surrounding county area. On the other hand, the controls in the city and the county may reinforce each other and reduce sprawl. For these reasons, we collect land-use control information on both the central city and its surrounding county.

THE URBAN AREA

We selected a subsample of 182 urbanized areas from the complete set of 465. A subsample is used for three reasons. First, for conformity with the standard monocentric model, the subsample consists of those urbanized areas located within a single county and with a single central city. Second, the fact that the outlying portions of our urbanized areas lie within one county considerably simplifies the gathering of data on county land-use controls. Finally, the analysis should better isolate the effect of a land-use control if there is a single city and county imposing the control than if there were several cities and counties doing so.

The urbanized area as defined by the U.S. Bureau of the Census is a densely settled core of census block groups and surrounding census blocks that meet minimum population density requirements of 1,000 people per square mile for the core block and 500 people per square mile for the surrounding blocks. Together, the core block groups and surrounding blocks comprising the urbanized area must encompass a population of at least 50,000 people. The urbanized area is considered by urban economists to best approximate the theoretical urban area because the urbanized area includes interrelated urban activities without including much rural land (Mills and Hamilton, 1994, p. 6), which is why we shall use it, as have all of the empirical studies reviewed in Chapter 4.

THEORETICAL VARIABLES, THEIR PROXIES, AND DATA SOURCES

An important part of our research is to obtain the data on land-use controls for our sample of urbanized areas. In addition to data on land-use controls, we need data on the other variables included in the theoretical models, namely, the boundary of the urbanized area, $\bar{x}$; population, P; income, y; the rental value of rural land at the urban-rural boundary, r_A; and transportation cost, t. Table 5.1 presents the proxies used for these variables and their sources. The text provides more detailed discussion. In the text, we split the discussion between the non land-use control variables and the land-use control variables. Tables 5.2 and 5.3 provide descriptive statistics for these variables.

TABLE 5.1: Theoretical Variables, Proxy Variables, and Data Sources

Theoretical Variable	*Proxy Variable*	*Data Source*
$\bar{x}$	Size of the *UA*, sq. mi.	Census 2000
P	*UA* households, number	Census 2000
y	Median *UA* household income, \$	Census 2000
r_A	Farm land price, county of *UA*, \$/acre	Census of Agr. 1997, 2002
t	Highway expenditures per *UA* user, \$	Census 2000
$\underline{l}$	Minimum lot-size dummy	Planning agency website
$\bar{l}$	Maximum lot-size dummy	Planning agency website
x^*, k	Urban growth boundary (*UGB*) dummy	Planning agency website
$\bar{S}$	Maximum building-height dummy	Planning agency website
$\underline{h}$	Minimum square-footage dummy	Planning agency website
$\bar{D}$	Maximum building permits dummy	Planning agency website
$\underline{D}$	Minimum persons/room dummy	Planning agency website
θ	Impact fee dummy	Planning agency website

Note: *UA* = urbanized area.

Non Land-Use Control Variables

Spatial Size of the Urbanized Area ($\bar{x}$). In the theoretical models, the spatial size of an urban area is the radial distance from the CBD to the urban-rural boundary, symbolized by $\bar{x}$. Except for McGrath (2005), all of the studies summarized in Chapter 4 used use the area, A, of the urbanized area in square miles as a proxy for $\bar{x}$. McGrath calculated the radius, $\bar{x}$, from the area, A.

We use the area, A, of the urbanized area in square miles as a proxy for $\bar{x}$. United States Census 2000 Summary File 3 (SF3), Table P3 (http://www.census.gov), provides the spatial size of urbanized areas in square kilometers, which we have converted to square miles. In our sample, the mean size is about 80 square miles. This is approximately the size of the Athens-Clarke County, GA, urbanized area. The smallest urbanized area in our sample is Davis, CA, with an area of 13.6 square miles, while the largest is Pittsburgh, PA, with an area of 852.4 square miles.

Population (P). Brueckner and Fansler (1983), McGrath (2005), and Song and Zenou (2006) used population, while Su and DeSalvo (2008) used number of households. We think that number of households is more consistent with the theory since not all households are single-person, as assumed by the theoretical models. In any event, all of these proxies perform very well in the regressions.

We use the number of urbanized area households to measure P. This variable is found in U.S. Census 2000, SF3, Table P15. In our sample, the mean number of households is around 70,000, which is approximately the size of the Hickory, NC, urbanized area. The smallest urbanized area in our sample, with 15,286 households, is Hinesville, GA, while the largest, with 729,000 households, is Pittsburgh, PA.

Income (y). Brueckner and Fansler (1983) used a construct that they claim is similar to median income. McGrath (2005) used per-capita personal income for the metropolitan area, not the urbanized area. Song and Zenou (2006) used median household income adjusted by the 2000 ACCRA Cost of Living Index. Su and DeSalvo used mean household income. All of these alternative proxies perform very well in the regressions.

We use urbanized area median household income, which is reported by U.S. Census 2000 for 1999 in SF3, Table P54. In our sample, the median household income is about $40,750, which is approximately the median income of the Beloit, WI-IL, urbanized area. The standard deviation and range are large, however, with incomes ranging from $22,330, in the Blacksburg, VA, urbanized area, to about $74,300 in the San Luis Obispo, CA, urbanized area.

Rural Land Rent, r_A. In the theoretical models, rural land rent, r_A, is the rental value of the land per unit area immediately adjacent to the built-up part of the urban area. Since this value of land is not reported by the Census or any other published source, researchers have used alternatives. Brueckner and Fansler (1983) and Song and Zenou (2006) used median agricultural land value per acre for the county containing the urbanized area. McGrath (2005) used agricultural land value per acre for the state in which the metropolitan area was located. Su and DeSalvo (2008) used mean agricultural land value per acre of the county in which the urbanized area was located. The rural land-value variable has had mixed success in the empirical studies, being statistically significant only in Brueckner and Fansler (1983) and McGrath (2005).

We use the mean estimated market value of farm land per acre for the county in which the urbanized area is located. This variable is available from the Census of Agriculture (National Agricultural Statistics Service, 1999 and 2004). Since the Census of Agriculture is conducted every five years and in different years from the decennial census, our variable is the mean of the means reported for 1997 and 2002. We assume this mean land value approximates that for the year 2000. In our sample, the mean value of agricultural land is about $5,500 per acre, which is approximately the value for San Joaquin County in which the Stockton, CA, urbanized area is located. It ranges from nearly $150 per acre in Ector County in which the Odessa, TX, urbanized area is located, to about $45,000 in Frederick County in which the Frederick, MD, urbanized area is located.

Transportation cost, t. In the theoretical models, *t* is the round-trip cost of travel per unit distance. This variable is unavailable, so researchers have used a number of proxies for it, with mixed results. Brueckner and Fansler (1983) used two proxy variables for transportation cost, TRANSIT and AUTO, where the former is the percentage of commuters using transit and the latter is the percentage of households owning one or more autos. Neither of these was statistically significant in their regressions. McGrath (2005) created a regionally adjusted private transportation consumer price index, which was statistically significant in his Model 2 but not in his Model 1. Song and Zenou (2006) calculated the transportation expenditures per person who drives to work. This variable was statistically significant. Su and DeSalvo used proxies for both fixed and variable transportation costs for both transit and auto travel. Three of the four such variables were statistically significant.

As a proxy for transportation cost in the theoretical models, we use total annual highway expenditures for the state in which a sample urbanized area is located divided by the number of users. The term “users” includes those using cars and transit vehicles on streets and highways, those using bicycles on streets, as well as pedestrians on sidewalks. The data on expenditures and users are obtained from U.S. Census 2000 SF3, Table P58.

Song and Zenou (2006) used a similar variable and found it to be statistically significant. In our sample, highway expenditures per user average \$0.26, which is about the amount for the State of Oregon, in which the Bend, OR, urbanized area is located. It ranges from about \$0.0015 in the State of Virginia, in which the Winchester, VA, urbanized area is located, to \$1.87 in the State of California, in which the San Luis Obispo, CA, urbanized area is located.

Descriptive Statistics of Non Land-Use Control Variables. The descriptive statistics for these variables are presented in Table 5.2.

TABLE 5.2: Descriptive Statistics of Non Land-Use Control Variables, U.S. Urbanized Areas, 2000

Variable	*Unit*	*Mean*	*St. Dev*	*Minimum*	*Maximum*	*Range*
A	Sq. Mi.	79.76	90.38	13.63	852.40	838.77
P	Households	68,687	92,940	15,286	728,884	713,598
y	\$	40,748	63,975	22,330	74,335	52,002
r_A	\$/acre	5,517	24,245	147	45,100	44,953
t	\$	0.26	0.19	0.0015	1.87	1.87

Land-Use Control Variables

Introduction. Unfortunately, data on land-use controls are not available in the census or in any other published source. Consequently, we conducted an extensive search for data on land-use controls reported at the websites of local government agencies. To our regret, we could not collect values of these controls because most governmental agencies do not report this information on their websites. For example, we could rarely find the actual minimum or maximum size of a lot in those jurisdictions with minimum or maximum lot-size zoning, the maximum building height in those jurisdictions with building-height limitations, etc. Therefore, we use 0-1 dummy variables to represent the absence or presence of land-use controls. (Although we only cite cities, we found that it was always the case that the city website would lead us to the appropriate county information.)

The land-use controls for which we have central-city and county data are: (1) minimum lot-size zoning, $\underline{l}$; (2) maximum lot-size zoning, $\overline{l}$; (3) urban growth boundaries, *UGB* (Quigley and Swoboda (2007) used two variables to capture *UGB*'s, x^* and k, so we are simply naming the dummy variable *UGB*); (4) maximum building-height restrictions, $\overline{S}$; (5) minimum square-footage limitations, $\underline{h}$; (6) maximum population density controls, as proxied by building permits, $\overline{D}$; (7) minimum population density controls, as proxied by minimum number of persons per room, $\underline{D}$; and (8) impact fees, θ.

We turn now to a brief discussion of the nature of the various controls in our sample central cities and counties. Table 5.3 provides some descriptive statistics.

TABLE 5.3: Descriptive Statistics of Land-Use Control Variables, Central Cities and Counties of U.S. Urbanized Areas, 2000

Land-Use Control	*Central Cities*		*Counties*	
	Mean	*St. Dev*	*Mean*	*St. Dev.*
$\underline{l}$	0.50	0.50	0.68	0.37
$\overline{l}$	0.24	0.43	0.33	0.35
UGB	0.19	0.39	0.26	0.48
$\overline{S}$	0.77	0.42	0.83	0.44
$\underline{h}$	0.48	0.50	0.54	0.47
$\overline{D}$	0.49	0.50	0.57	0.45
$\underline{D}$	0.50	0.50	0.57	0.43
θ	0.55	0.50	0.63	0.42

None of the central cities and counties in our sample uses rent control and all of them use "traditional" zoning, so those land-use controls have been eliminated from the following discussion and from the analysis reported in Chapter 6. Chapter 2 provides a thorough discussion of the various kinds of land-use controls, so here we simply note the specific measures found in our sample.

Since the number of counties and the number of cities are both equal to our sample size, a higher proportion in Table 5.3 also means a higher number. A notable observation is that more counties than cities employ controls, which holds for every control. In addition, except for urban growth boundaries and building height limits, there is less variation in the number of controls imposed by counties than by central cities.

The table reveals that maximum building height is the most commonly used control for both counties and cities, with 151 cities and 140 counties using it. The least popular control is the urban growth boundary, with only 35 cities and 47 counties using it. Among the remaining controls, the rank order is almost the same for cities and counties, with slight variation in rank order of minimum lot-size zoning, minimum population density restrictions, and impact fees.

Although, as noted earlier, we were able to obtain values for few land-use controls, it might nevertheless be instructive to cite a few examples of the values we did obtain. These may be found in the web sites of city and county agencies. The Bellingham, WA, urbanized area imposes a minimum residential lot size of 9,500 square feet, while Canton County, OH, imposes a minimum residential lot size of 20,000 square feet. Oshkosh, WI, imposes a maximum lot size of 75,000 square feet on businesses and 30,000 square feet on residences. Although it seems contradictory, 22 percent of our sample urbanized areas impose both minimum and maximum lot-sizes. Cleveland, TN, has an urban growth boundary with a radius of about five miles from the center of the city beyond which no development may occur. Frederick, MD, imposes a maximum building height 30 feet. In Macon, GA, the minimum size of an office is 500 square feet, and the minimum size for a one-bedroom dwelling unit is 400 square feet. Some urbanized areas and counties limit new construction by requiring builders to obtain building permits. For example, Austin, TX, set the maximum number of building permits at 12,500 in 2000. Minimum density controls are usually imposed as the minimum number of people per room. For example, some residential districts in Huntsville, AL, require at least three people for three-bedroom apartments and at least two persons for two-bedroom apartments. Finally, Las Vegas, NV, imposes an impact fee of $0.36 per square foot of habitable area for residential construction to support the construction of parks in the city.

SUMMARY

Chapter 5 describes the theoretical variables of our models and their empirical proxies, which are to be used in the analysis of Chapter 6. Chapter 5 also provides descriptive statistics. To give the reader a better idea of the central cities and counties that comprise our sample of urban areas, we report ranges for values of the non land-use variables. For the land-use variables, we are forced to use dummy variables because few central cities or counties provide actual values of these variables. Proportions and standard deviations are reported for these dummy variables. We find, in general, that cities and counties use the same set of controls although more counties employ controls than do cities. We also find that the rank order of controls is almost the same for cities and counties. Again to give the reader a sense of how these controls are used, we have included some of the actual values of land-use controls for those entities that report them. Chapter 6 reports our empirical analysis of the effect of land-use controls on the spatial size of urbanized areas

CHAPTER 6: ESTIMATION

The purpose of this chapter is to estimate the effect of land-use controls on the spatial size of the urbanized area. This is an attempt to see how effective land-use controls are in restricting the spatial size of urban areas, that is, in controlling urban sprawl. As discussed in Chapter 5, we have collected data on land-use controls, coded as 0-1 dummy variables, for both central cities and counties in our sample of urbanized areas, along with other variables dictated by urban theory. We begin with a preliminary analysis of correlations among the land-use controls for central cities and for counties. We then proceed to an analysis of correlation among central city land-use controls and those of their surrounding counties. We tentatively conclude from these analyses that county land-use controls are likely to explain the spatial size of the urbanized area better than would central city controls. We also conclude that there is likely to be little strategic interaction between central cities and their surrounding counties in the choice of land-use controls. From these preliminary analyses, we proceed to regression analysis of the effect of land-use controls on the spatial size of urbanized areas. We find that, as suspected, the county regression is better than the central city regression. In the country regression, all land-use controls except building permits have the theoretically correct signs, but two, urban growth boundaries and minimum square footage limits, are not statistically significant at the 10-percent level or better.

PRELIMINARY ANALYSIS: CORRELATION MATRICES

Since we intend to use land-use control dummy variables as regressors, a natural question arises as to their correlation within the sample of central cities as well as within the sample of counties. Correlation between any two variables will cloud the effect of any one variable on the spatial size of the urbanized area. In addition, the size and statistical significance of the correlation coefficients should provide a hint as to which entity—the central city or the county—is likely to provide the better estimated regression. We adopt the criterion that a "high" correlation is one that is at least 0.5 in absolute value and in which the *p*-value is at most 0.10.

For the central cities in our sample, Table 6.1 reveals eight "high" correlations out of the twenty-eight correlation coefficients in the table. These correlations may hint of possible multicollinearity in the central-city regression.

TABLE 6.1: Correlation Matrix for Central City Land-Use Controls

	$\underline{l}$	$\overline{l}$	UGB	$\overline{S}$	$\underline{h}$	$\overline{D}$	$\underline{D}$	θ
$\underline{l}$	1.0000							
$\overline{l}$	0.5133 (0.2203)	1.0000						
UGB	–0.0034 (0.9635)	0.00586 (0.4319)	1.0000					
$\overline{S}$	–0.1043 (0.2350)	0.0961 (0.1970)	0.1287 (0.0834)	1.0000				
$\underline{h}$	0.6710* (<0.0001)	0.1019 (0.1710)	0.02101 (0.7775)	–0.0241 (0.7468)	1.0000			
$\overline{D}$	–0.5166* (< 0.0001)	0.0638 (0.3925)	–0.0177 (0.8129)	–0.0383 (0.6093)	–0.5401* (<0.0001)	1.0000		
$\underline{D}$	0.6044* (<0.0001)	0.0770 (0.3015)	0.02812 (0.7056)	0.0261 (0.7267)	0.6710* (<.0001)	–0.4946* (<0.0001)	1.0000	
θ	0.3534 (<0.0001)	0.0471 (0.5282)	–0.0193 (0.7959)	–0.0142 (0.7458)	0.2697 (0.0002)	–0.5501* (<0.0001)	0.5742* (<.0001)	1.000

*"High" correlation = greater that 0.5 in absolute value and statistically significant at the 0.10 level or better.

In contrast, for the counties in our sample, Table 6.2 shows no "high" correlation coefficients. This leads us to hypothesize that the county regression is likely better to reveal the effect of land-use controls on the size of the urbanized area. Since the urbanized area spreads beyond its central city into the county, it appears likely that the county controls have the greater effect on urbanized area size.

TABLE 6.2: Correlation Matrix for County Land-Use Controls

	$\underline{l}$	$\bar{l}$	UGB	$\bar{S}$	$\underline{h}$	$\bar{D}$	$\underline{D}$	θ
$\underline{l}$	1.0000							
$\bar{l}$	–0.0445 (0.5505)	1.0000						
UGB	–0.2158 (0.7931)	0.0350 (0.6393)	1.0000					
$\bar{S}$	0.3731 (0.0034)	0.4760 (0.5235)	–0.2519 (0.0006)	1.0000				
$\underline{h}$	–0.2809 (<.0001)	0.7643 (0.3051)	0.2485 (0.0007)	–0.2077 (0.0049)	1.0000			
$\bar{D}$	–0.4680 (<.0001)	0.1055 (0.1565)	0.2582 (0.0004)	–0.3960 (<.0001)	0.2560 (<.0005)	1.0000		
$\underline{D}$	–0.0954 (0.2003)	–0.0941 (0.2065)	0.0592 (0.4277)	–0.0272 (0.7158)	0.0140 (0.5789)	0.0600 (0.4214)	1.0000	
θ	–0.6122 (0.4116)	0.0445 (0.5505)	0.1377 (0.0639)	0.1086 (0.1447)	0.1618 (0.0292)	–0.0683 (<.3594)	–0.0052 (0.9444)	1.000

Another issue we want to address in this preliminary analysis is the possible strategic interaction between the central city and its surrounding county. Brueckner (1998) found that for a sample of California cities there existed strategic interaction in the choice of land-use controls. It is possible, therefore, that such interaction exists between the central cities and their surrounding counties in our sample of urbanized areas. Some indication of the existence of central city and county interaction may be revealed by the correlation coefficients between a central city control and its county's control. The correlation matrix is present in Table 6.3.

Of the 64 correlation coefficients, only four are "high." Nearly 50 percent of central cities and 57 percent of counties use building permits, $\bar{D}$, so it is not surprising to find the high correlation of 0.91 between central cities and counties for this variable. It probably does not represent a strategic interaction. The existence of building permits in counties is highly correlated with the existence in central cities of square footage limitations, $\underline{h}$ (–0.65) and minimum number of persons per room, $\underline{D}$ (–0.60). A country's imposition of, or reduction in, a maximum number of building permits is theoretically expected to expand the urban area. Central cities could be reacting to this by imposing, or increasing, minimum square footage limits and minimum number of persons per room limits, which are theoretically expected to contract the urban area. If this supposition is accurate, it would represent a case of strategic interaction. Otherwise, the correlation analysis seems to support the hypothesis that there is no strategic interaction between central cities and their surrounding counties.

TABLE 6.3: Correlation Matrix for County-Central City Land-Use Controls

CO\CC	$\underline{l}$	$\bar{l}$	*UGB*	$\bar{S}$	$\underline{h}$	$\bar{D}$	$\underline{D}$	θ
$\underline{l}$	0.3747 (<.0001)	–0.0436 (0.5593)	0.0196 (0.7931)	0.0684 (0.3588)	0.3785 <.0001	–0.5716* (<.0001)	0.3968 (<.0001)	0.4021 (0.0001)
$\bar{l}$	–0.1332 (0.0730)	-0.3927 (<.0001)	–0.1872 (0.0114)	0.0000 1.0000	–0.0953 (0.2008)	0.4021 (0.0001)	–0.0888 (0.2331)	0.0255 (0.7325)
UGB	–0.3194 (<.0001)	–0.0656 (0.3791)	0.2012 (0.0065)	0.1206 (0.1047)	–0.2341 (0.0014)	0.3180 (<.0001)	–01432 (0.0538)	–0.1926 (0.0092)
$\bar{S}$	0.3407 (<.0001)	–0.0656 (0.3791)	0.0177 (0.8129)	0.1164 (0.1176)	0.3200 (<0.0001)	–0.4943 (<.0001)	0.3407 (<.0001)	0.4838 (<0.0001)
$\underline{h}$	–0.1434 (0.0534)	0.0241 (0.7471)	–0.0143 (0.8480)	–0.0222 (0.7666)	–0.1033 (0.1654)	0.3621 (<.0001)	–0.0331 (0.6574)	–0.1908 (0.0099)
$\bar{D}$	–0.0193 (<.0001)	0.0429 (0.5652)	–0.0268 (0.7191)	0.0121 (0.8709)	–0.6481* <0.0001	0.9053* (<.0001)	–0.5978* (<.0001)	–0.4441 (<0.0001)
$\underline{D}$	0.1793 (0.0152)	–0.0156 (0.8347)	0.1571 (0.0341)	–0.0164 (0.8259)	–0.0131 (0.8607)	0.1398 (0.602)	0.1798 (0.0152)	0.1126 (0.0912)
θ	–0.0441 (0.5546)	0.1109 (0.1361)	0.1044 (0.1607)	–0.0362 (0.6274)	0.0255 (0.7330)	0.0237 (0.7504)	0.1383 (0.0073)	0.3578 (<.0001)

Note: CO = county; CC = central city. *"High" correlation = greater that 0.5 in absolute value and statistically significant at the 0.10 level or better.

REGRESSION RESULTS

For both the central city and county data, we estimate the following regression

$$\begin{aligned} A = \beta_0 + \beta_1 P + \beta_2 y + \beta_3 r_A + \beta_4 t + \beta_5 \underline{l} + \beta_6 \bar{l} + \beta_7 UBG \\ + \beta_8 \bar{S} + \beta_9 \underline{h} + \beta_{10} \bar{D} + \beta_{11} \underline{D} + \beta_{12} \theta \end{aligned} \tag{6.1}$$

We use a linear functional form because, as discussed in Chapter 4, various forms have been used and none is superior. The OLS regression results are given in table 6.4. Before discussing the results, we note that the regressions buttress our conjecture that the county regression would be better. For the land-use controls, the county regression has only one "wrong" sign, while the city regression reports four. Also, the country regression finds six land-use control variables to be statistically significant at the 0.10 level or better, while the city regression finds five. We turn now to a discussion of the results for the land-use control variables first, as those are our main interest.

TABLE 6.4: Regression Results

Variable	*Central City*		*County*	
	Coefficient	*p*	*Coefficient*	*p*
$\underline{l}$, *Min. Lot Size*	85.27	<0.01[b]	18.60	0.07[d]
$\overline{l}$, *Max. Lot Size*	1.45[a]	0.87	–20.37	0.02[c]
UGB, Urban Growth Boundaries	12.11[a]	0.22	–3.32	0.72
$\overline{S}$, *Max. Bldg. Ht. Limits*	4.16	0.64	19.66	0.05[c]
$\underline{h}$, *Min. Sq. Ft. Limits*	28.67[a]	0.02[c]	–8.24	0.38
$\overline{D}$, *Max. Bldg. Permits*	–57.05[a]	<0.01[b]	–21.75[a]	0.04[c]
$\underline{D}$, *Min. Persons/Room*	–47.94	0.01[b]	–22.98	0.01[b]
θ, *Impact Fees*	–77.71	<0.01[b]	–21.98	0.02[c]
P, No. of UA Households	0.41×10^{-4}	<0.01[b]	0.54×10^{-4}	<0.01[b]
y, Median Household Income	0.12×10^{-4}	0.07[d]	0.20×10^{-4}	0.01[b]
r_A,*Median Farm Land Price*	-0.96×10^{-5}	0.01[b]	0.10×10^{-4}[a]	0.02[c]
t, Hwy. Exp./User	34.22	0.08[d]	28.71	0.21
Constant	73.26	<0.01[b]	60.13	0.01[b]
R^2	0.73		0.73	
N	182			

[a] "wrong" sign. [b] $p \le 0.01$. [c] $0.01 < p \le 0.05$. [d] $0.05 < p \le 0.10$.

The Effect of Land-Use Controls on the Size of the Urbanized Area

Minimum Lot Size. The coefficient on minimum lot-size, $\underline{l}$, is positive in both the central city and county regressions, which is consistent with theory, but it is statistically significant at only the 7-percent level for the county, while it is highly statistically significant for the central city. The imposition of a minimum lot-size restriction by the county would increase the urbanized area by 19 square miles, on average, while a central city minimum lot-size restriction would increase the urbanized area by over 85 square miles. Although counties use minimum lot-size zoning to a greater degree than do central cities, the introduction of minimum lot sizes into the central city would have more impact, probably because of the greater number of households in the central city. Since lot size rises with distance from the CBD, a minimum lot-size restriction would be binding on those households near the CBD, but beyond some distance, the minimum would not be binding. This would cause those households for which the limit is binding to occupy larger lots which would expand the urban area. If central cities impose this control, it will be binding on more households than if counties impose the control and should therefore have a greater effect on the size of the urban area.

Maximum Lot Size. In the county regression, the coefficient on maximum lot size, $\overline{l}$, is negative, as expected in theory, and statistically significant at the 2-percent level. On the other hand, the coefficient is positive and not statistically significant in the central city regression. Adopting a maximum lot-size restriction by the county would cause the urbanized area to contract by slightly over 20 square miles on average.

Urban Growth Boundary. For the county regression, we find the coefficient on the urban growth boundary, *UGB*, to be negative, which is anticipated by urban theory, but not statistically significant, while for the central city regression, it is positive, contrary to theory, as well as not statistically significant. Only 19 percent of central cities and 26 percent of counties in our sample have urban growth boundaries, which may explain the poor statistical results. It may also be the case that, while these central cities and counties have urban growth boundaries, they may not yet be binding.

Maximum Building Height. The coefficient on maximum building height, $\overline{S}$, is positive, as predicted by urban theory, and statistically significant at slightly over the 5-percent level in the county regression, while being positive but not statistically significant in the central city regression. The presence of a maximum building height in the county would increase the urbanized area by nearly 20 square miles on average.

Minimum Square Footage. In the central city regression, the coefficient on minimum square footage, $\underline{h}$, is positive, contrary to theory, and statistically significant, while it is negative, consistent with theory, but not statistically significant in the county regression.

As noted in Chapter 3, we found no theoretical analysis of a minimum square footage limit. Therefore, the expected sign on its coefficient is based on the relationship between urban spatial size and a maximum floor-area ratio (*FAR*) obtained by Bertaud and Brueckner (2005). Their argument for a positive effect of a maximum *FAR* on urban spatial size is that the urban population is constrained by the *FAR* up to the distance at which it ceases to be a binding constraint (since *FAR* will fall with distance in the unconstrained model). This causes households to seek locations beyond the distance at which the constraint is binding, which raises land rents beyond that distance, which, in turn, causes the urban area to expand.

Applying this logic to a minimum *FAR* means that the constraint will be non-binding up to some distance from the CBD. Beyond that distance and up to the urban-rural boundary, however, the constrained *FAR* would be larger than preferred. This would cause the given urban population to live at higher densities than preferred, which would reduce the spatial size of the urban area.

Maximum Building Permits. The coefficient on maximum building permits, $\bar{D}$, is negative, contrary to theory, and statistically significant for both the central city and the county, but the statistical significance is better for the county, and the effect of building permits on the size of the urban area is greater in the county. Introducing maximum building permits in the county reduces the size of the urban area by 57 square mile, while introducing them in the central city reduces its size by only about 22 square mile.

As was the case for a minimum *FAR*, we found no theoretical treatment of a maximum density constraint and again used the logic of Bertaud and Brueckner (2005) to justify a negative relationship between the spatial size of the urban area and maximum building permits. The fact that for both central cities and counties the relationship is found to be negative empirically cases doubt on this explanation.

Maximum building permits do not work exactly as the theory for maximum densities argues because densities fall with distance from the CBD while a maximum number of building permits is independent of distance. Nevertheless, if the central city imposes a binding maximum number of building permits and the county does not, then those who want to live in the urban area will locate in the county, rather than the city, and will expand the urban area. On the other hand, if the county imposes a binding maximum number of building permits while the city does not, then the reverse is the case, and the urban area will contract. These results would be consistent with the theory.

In our data, however, neither of these conditions holds. As can be seen from Table 6.3, the correlation between central city and county building permits is 0.91 ($p < 0.0001$). Therefore, in the great majority of urbanized areas in our sample, both the central city and its county have building permits. Thus, if the number of building permits is binding in both the city and county, there is no place for households to locate in the urban area to avoid the cap. In this case, a negative coefficient on the variable seems reasonable. The problem is with the theory, which assumes an area in which restrictions are not binding, which is apparently not the case in reality, at least for our sample.

Minimum Number of Persons per Room. The coefficient on minimum number of persons per room, $\underline{D}$, is negative, consistent with theory, and statistically significant in both regressions, but the impact on the size of the urbanized area is much greater for the central city restriction. Using this restriction by the central city would decrease the size of the urbanized area by nearly 48 square miles, on average, while its use by the county would expand the urbanized are by nearly 23 square miles, on average. This is another example of our using the logic of Bertaud and Brueckner (2005) to justify the expected sign, for we found no theoretical treatment of this variable.

Impact Fee. The coefficient on the impact fee, θ, is negative, as predicted by urban theory, and statistically significant in both the central city and county regressions. The magnitude of the contractionary effect on the urbanized area is much greater if the central city imposes the impact fee, a contraction of almost 78 square miles, than if the county imposes the fee, a contraction of only 22 square miles.

The Effect of Other Variables on the Size of the Urbanized Area

Households. The coefficient on number of households, P, is positive, as is consistent with urban theory, and highly statistically significant in both the central city and county regressions, as is usually the case in analyses of this kind. In our case, increasing the number of households by 10,000 would increase the urbanized area by from 4.1 to 5.4 square miles.

Income. The coefficient on median household income, y, is positive, in conformity to urban theory, and statistically significant in both the central city and county regressions, as is usually the case in these kinds of regressions. In our case, a $10,000 increase in median income leads to an increase of urbanized area by from 1.2 to 2.0 square miles, on average.

Agricultural Land Value. The coefficient on the mean value of agricultural land, r_A, is negative in the central city regression, which is consistent with urban theory, but positive in the county regression, while both are statistically significant. As noted in Chapter 5, this variable has not performed well in most analyses. A possible explanation for the sign discrepancy is that rural land values rise in anticipation of conversion to urban use. In rapidly growing urban areas, the larger radius, adjusted for income and population may reflect speculation of continued growth. One way to check this conjecture is to add a variable measuring urban growth from 1990 to 2000. This variable might be change in population, change in the size of the urban area, or change in the number of households.[10] Increasing the value of agricultural land surrounding the urbanized area by $1,000 per acre would shrink the urbanized area by about 1 square mile, on average.

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[10] We thank Professor Kenneth F. Wieand for this explanation and suggestion for future research.

Highway Expenditure per User. The coefficient on highway expenditures per user, *t*, is positive, which is consistent with urban theory because higher expenditures are presumed to lower transportation costs, and statistically insignificant. The theoretical variable has proved difficult to proxy, and, as a result, few studies have found the "right" sign and statistical significance for this variable. Our choice of variable was based on a similar variable's successful use by Song and Zenou (2006).

SUMMARY OF THE EFFECT OF LAND-USE CONTROLS ON THE SIZE OF THE URBANIZED AREA

In this section, we summarize the results of the empirical analysis by comparing the theoretically predicted effects of land-use controls with the empirically estimated counterparts. As already noted, the county regression performs better than the central city regression, so we only discuss that one. Table 6.5 presents the results.

TABLE 6.5: Summary of Results

Land-Use Control	*Sign (County Only)*		*p*
	Theoretical	*Empirical*	
Minimum Lot Size, $\underline{l}$	+	+	0.07
Maximum Lot Size, $\bar{l}$	–	–	0.02
Urban Growth Boundary, *UGB*	–	–	0.72
Maximum Building Height, $\bar{S}$	+	+	0.05
Minimum Sq. Ft., $\underline{h}$	–	–	0.38
Maximum Building Permits, $\bar{D}$	+	–	0.04
Minimum Persons/ Room, $\underline{D}$	–	–	0.01
Impact Fees, θ	–	–	0.02

In all but one case, the empirically obtained sign is consistent with the theoretical prediction. The one "incorrect" sign is for maximum building permits. Five of eight estimated coefficients are statistically significant at the 5-percent level or better, while one more is statistically significant at the 10-percent level or better. Only two remain not statistically significant at these levels.

CHAPTER 7: SUMMARY, CONCLUSIONS, LIMITATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

As stated in Chapter 1, urban sprawl is a contentious issue, involving various and conflicting views on such fundamental matters as its definition, measurement, and causes. Economists' contributions to this literature emphasize the theoretical and empirical analysis of the causes of urban sprawl. This dissertation follows in that tradition with an empirical analysis of the effect of land-use controls on urban sprawl, drawing on testable hypotheses found in the theoretical literature.

As was noted earlier, many empirical studies have been performed on the effect of land-use controls on housing prices, but no study has examined their effect on urban sprawl. This dissertation therefore makes a unique contribution to the literature on urban sprawl by documenting the effect of land-use controls on the spatial size of the urban area. Such information should be useful to urban planners who are trying to curb sprawl.

In addition, this dissertation tests theoretical hypotheses on the effect of land-use controls on the spatial size of urban areas. These theoretical hypotheses have not previously been empirically tested. As such, this dissertation adds to the positive literature on urban economics.

SUMMARY

Chapter 1 provides a discussion of definitions, criticisms, and measurements of urban sprawl. From this discussion, we adopt a non-normative definition, namely, that urban sprawl is the decentralization of population and employment from the central city to the suburbs. In our empirical work, however, we have data only on population.

In the monocentric models of urban structure, this decentralization of population is characterized by increased spatial size of the urban area. In their theoretical analyses, Wheaton (1974) and Brueckner (1987) found that the spatial size of an urban area is directly related to real household income and population and inversely related to transportation costs and rural land rent.

Increasing real income, increasing population, decreasing real transportation costs, although expanding the urban area spatially, are not causes of sprawl in its normative sense, which is that sprawl is the *excessive* decentralization of population and employment. Sprawl in this normative sense has been explained by the failure to account for the social costs of road congestion, the failure to account for the social value of open space, the failure to account fully for the infrastructure costs of new development (Brueckner, 2001), transportation subsidies (Brueckner, 2005), the property tax (Brueckner and Kim, 2003), federal spending (Persky and Kurban, 2003), and land-use controls (Brueckner, 1998). Of these, this dissertation addresses the latter.

Controls on land use abound in urban areas. We find traditional zoning, which is designed to separate incompatible land uses and which has a long history that we survey in Chapter 2. More recent forms of land-use control, discussed in detail in Chapter 2, include minimum lot-size zoning; maximum lot-size zoning; maximum building heights;

various kinds of density restrictions, including maximum floor-area ratios, minimum square-footage limits, maximum building permits, and minimum persons per room; impact fees and in-kind exactions; urban growth boundaries; and rent control.

With the discussions in Chapters 1 and 2 as background, we then turn in Chapter 3 to theories of urban form, starting with the history of the development of the monocentric urban model and proceeding to a detailed exposition of that model in both its closed city and open city versions. We then turn to a discussion of extensions of the monocentric urban model that include land-use controls. Here we find analyses of minimum lot-size zoning (Pasha, 1996), maximum lot-size zoning (Pasha, 1992b), urban growth boundaries and similar land-use restrictions (Quigley and Swoboda, 2007), the maximum floor-area ratio (Bertaud and Brueckner, 2005), and the property tax (Song and Zenou, 2006).

We did not find extensions of the monocentric urban model that included analyses of impact fees and density restrictions, other than the maximum floor-area ratio. Since central cities and counties in our sample impose impact fees, we argued that the results of the property-tax model of Song and Zenou (2006) could be interpreted as applying to impact fees. Also, since central cities and counties in our sample impose maximum building heights, minimum square-footage limits, maximum building permits, and minimum persons per room, we argued that these various density restrictions could be related to the results of Bertaud and Brueckner (2005). The reasons for this is the theoretically direct relation between structural density, housing density, and population density. Maximum building-height limits are related to maximum structural density limits; minimum square-footage limits are related to minimum housing density; maximum housing permits are related to maximum population density; and minimum persons per room are related to minimum population density.

Given these theoretical results, we turned in Chapters 4 to a survey of previous empirical analysis of the monocentric model, emphasizing their results on spatial size. Specifically, we surveyed the work of Brueckner and Fansler (1983), McGrath (2005), Song and Zenou (2006), and Su and DeSalvo (2008). In all of these cases, the findings supported the theoretical predictions of the monocentric urban model.

With this as background, we turned, in Chapters 5 and 6, to our own empirical work. Chapter 5 discussed our data, and Chapter 6 presented our regression results.

CONCLUSIONS

Our findings are summarized in Table 6.5. Recall that these are the results from the county regression, as we concluded that it better represented the effect of land-use controls on urban spatial size. The interpretation of the city regression would be similar to that of the county regression. The city regression, however, appears to us to be better for reasons given earlier.

Our empirical analysis may be viewed in two ways. First, it may be seen as tests of the theoretical predictions of extensions of the monocentric urban models that encompass land-use controls. Second, it may provide guidance to urban governments in the efficacy of policies to contain urban sprawl.

Regarding our empirical findings as tests of the extended models of urban structure, it is clear that our findings support the theoretical prediction of these models. Based on the county regression, all but one of the theoretical predictions regarding the direction of the effect of land-use controls on urban spatial size are upheld. They are not, however, all statistically significant, in particular, those involving urban growth boundaries and minimum square-footage limitations. In sum, we find evidence of the importance of land-use controls on the spatial size of urban areas, a finding that heretofore had only theoretical support.

To provide a sense of the magnitude of the impacts of land-use controls on urban spatial size, Table 7.1 provides the percentage change in the size of the average urban area in our sample, approximately 80 square miles, of the presence of each control.

TABLE 7.1: Change in Mean Urbanized Area Size in the Presence of County Land-Use Controls

Land-Use Control	*% Change (sq. mi.)*
Min. Lot Size	+23.3
Max. Lot Size	–25.5
UGB[a]	-
Max. Bldg. Height	+24.6
Min. Sq. Ft.[a]	-
Max. Bldg. Permits	–27.3
Min. Persons/Room	–28.8
Impact Fees	–27.6

[a] Statistically insignificant coefficient.

Regarding our empirical findings as providing policy guidance on containing urban sprawl, it is first necessary to recognized that land-use controls are not necessarily implemented primarily to control urban sprawl. For example, Bertaud and Brueckner (2005) point out that the apartheid policies formerly used in South Africa caused black households' residences to be located far from urban centers, as did the policies of the former Soviet Union. Minimum lot-size zoning limits suburban development densities, while, Mills (2005) has charged, excluding low-income and minority households from high-income suburbs. Similarly building-height limits, found in the central areas of U.S. cities as well as in cities such as Washington, D.C., and Paris, while controlling the density of development, may be primarily for aesthetic purposes. Also, efforts to increase central density, such as through maximum floor-area ratios, may be intended to reduce population and employment densities in the hope of protecting environmental quality, reducing traffic congestion, and reducing demands on urban infrastructure.

Nevertheless, these and other land-use controls have an effect on the spatial size of urban areas and, as such, may be implemented as policies to contain urban sprawl. In any event, to contain urban sprawl, our empirical analysis supports the use of maximum lot-size zoning, maximum building permits, minimum persons per room, and impact fees. According to our results, these would have powerfully reduced the size of our mean urbanized area by 25.5, 27.3, 28.8, and 27.6 percent, respectively. Clearly, minimum lot-size and maximum building-height restrictions expand the urbanized area, by 23.3 and 24.6 percent, respectively. In the interest in controlling sprawl, these policies should be avoided. In the case of building heights, urban areas could mandate taller, rather than shorter, buildings.

LIMITATIONS OF THE STUDY AND SUGGESTIONS FOR FURTHER RESEARCH

In this section, we discuss both theoretical and empirical limitations of the present study, which lead to suggestions for future research. As already previously noted, we found no theoretical extensions of the monocentric urban model to include minimum square-footage and minimum persons-per-room restrictions. Neither did we find extensions to include maximum building-permit restrictions. We did, however, find such restrictions being used by cities and counties in our sample. To circumvent this lacuna in the theory, we drew on the theoretical relationship among population, structural, and housing density, which allowed us to interpret the work of Bertaud and Bruckner (2005) in terms restrictions on minimum square footage, minimum persons per room, and maximum building permits. Similarly, we found no theoretical work extending the urban structure model to include impact fees but, again, found evidence of urban areas' use of impact fees. As a consequence, we used the property-tax model of Song and Zenou (2006). We would have preferred to have had fully worked out extensions to the basic urban structure model, such as those discussed in Chapter 3, for all four of these land-use controls. We propose to develop such extensions in future research.

Another potentially useful area of research would be the theoretical treatment of the central city and its surrounding county as separate governmental entities, which is, of course, what they are in the U.S. None of the theoretical models reviewed in this dissertation did this. The one who came closest was Pasha (1996 and 1992b). He divided his urban area into two parts, the central city and the suburbs, but he implicitly treated them as parts of the same governmental entity. Although in some countries, such as the U.K., the city ("local authority" in the U.K.) is administered in large part by the national government, this is not the case in the U.S. Given that cities and counties do not follow a unitary policy with respect to land-use controls, as was seen by the mostly lack of correlation between city and county policies in the correlation matrix of Table 6.3, it is highly likely that results of models without this specification will generate incorrect comparative static results. We intend to pursue this line of research.

Turning to empirical limitations of our research, surely the most important is our inability to obtain actual measures of land-use controls. Unable to find such measures led us to use dummy variables representing the presence or absence of controls. Unfortunately, we do not have high expectations of finding such data in easily accessible form. Even collecting the information on the presence or absence of controls was a laborious process. While we realize dummy variables are a week measure of land-use controls, we were constrained to use them since obtaining actual values of land-use controls would an arduous and extremely time-consuming process. Nevertheless, in future research, we intend to survey planning agencies of each city and county in our sample requesting the actual value of each land-use control they employ. Obtaining the actual values of land-use controls will serve two purposes. First, it will make our empirical estimation more precise. Second, we could draw conclusions regarding the strength of each land-use control in affecting the spatial size of the urban area. The latter will give us an opportunity to provide planning agencies with valuable guidance on how to control urban sprawl.

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