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THE EFFECT OF LAND-USE CONTROLS ON THE SPATIAL SIZE OF U.S. URBANIZED AREAS*

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ABSTRACT. On a sample of U.S. urbanized areas in 2000, we test theoretical hypotheses of the effect of land-use controls on the spatial size of urban areas. We find that minimum lot-size zoning and maximum *FAR* restrictions expand the urban area, while maximum lot-size zoning, urban growth boundaries, minimum square footage limits, maximum building permit restrictions, minimum person per room controls, and impact fees contract the urban area. All of these findings are consistent with theoretical predictions although the effect of urban growth boundaries and minimum square footage limits are not statistically significant.

1. INTRODUCTION

Controls on land use abound in U.S. urban areas. Almost all urban areas employ traditional zoning, which is designed to separate incompatible land uses. More recent forms of land-use control include minimum lot-size zoning, maximum lot-size zoning, maximum building heights, maximum floor-area ratios, minimum square footage limits, maximum building permits, minimum persons per room limits, impact fees and in-kind exactions, urban growth boundaries, and rent control.

Considerable research, both theoretical and empirical, has addressed the effect of land-use controls on housing prices. In fact, there exist two reviews of this literature (Fischel, 1990; Quigley and Rosenthal, 2005). Although there is theoretical work on the effect of land-use controls on the spatial size of urban areas, to our knowledge, however, there does not exist empirical research on this subject. From a purely scientific point of view, it would seem desirable to have tests of the theoretical hypotheses. From a policy viewpoint, in light of both popular and professional concern over urban sprawl, it would seem desirable to know how land-use controls affect the spread of the urban area.[1] It is the purpose of this paper to shed light on both of these issues.

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[1]The term *sprawl* means different things to different people. We accept the normative definition, proposed by Mills (1999) and Brueckner (2001), that sprawl is *excessive* urban decentralization. We do not hold the view that urban decentralization *per se* is necessarily undesirable. We return to this issue in the conclusion.

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We recognize that land-use controls are not necessarily implemented primarily to control decentralization of population from the central city to the suburbs. Bertaud and Brueckner (2005) note that the apartheid policies of South Africa located black households' residences far from urban centers, and the policies of the former Soviet Union similarly affected households' residences. 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 decentralization.

We have surveyed the urban literature to find testable hypotheses on the effect of land-use controls on the spatial size of the urban area and report our findings in the next section. Our empirical work follows. Finally, we offer conclusions, limitations of our work, and suggestions for further research.

2. THEORY

We draw on work extending the monocentric urban model to include land-use controls and their effects on the spatial size of the urban area. Dating back at least to White (1976), urban researchers have recognized the desirability of developing multicentric urban models.[2] In light of this, the question may be raised as to whether or not our use of the monocentric model is appropriate. From a theoretical viewpoint, the monocentric model is a simultaneous equation, general equilibrium analytical model that generates empirically testable hypotheses and is capable of extension in a number of directions. Moreover, the model's major results are retained in multicentric models and in models with decentralized employment. Empirically, the model has survived testing with different estimation procedures in both cross-section and cross-section, time-series data sets. It has been extended theoretically, with empirical support. There is no multicentric model that possesses these characteristics.

Regarding the relation of the monocentric and multicentric models, Papageorgiou (1990, pp. 93–94), summarizing his earlier work, describes a model combining central place theory and urban spatial economics in which households can travel to and work in any number of centers that vary from the smallest to the largest (the central business district (CBD)). He concludes that

> . . . any such structure can be approximated by a single-centre model which coincides with the location of the highest-order centre. This happens because, in reality, the spacing of lower-order centres depends on average on their proximity to higher-order centres: their density decreases as the distance from higher-order centres, increases. One may therefore express average distances to lower-order centres in terms of distance to successively higher-order centres, until locations in the model are described by a single distance to the highest-order centre capturing an average overall centrality of locations. This is the reason why [the negative exponential population density function] has proven to be so successful (p. 94).

[2]Ladd and Wheaton (1991) provide a survey of work in this area as an introduction to an issue of *Regional Science and Urban Economics* devoted entirely to multicentricity.

Zhang and Sasaki (1997) find "that establishment of a subcenter does not change the effect of parameters in the basic monocentric model" (p. 321). Therefore, at least in the context of these models, the monocentric model captures the behavior of relevant distance-varying functions in the more general multicentric models. In addition, Zhang and Sasaki's finding ensures that the comparative static results of the monocentric model carry over to the multicentric models.

Regarding decentralized employment, Mills and Hamilton (1994) show that the introduction of a local employment sector, in which households live near where they work, does not change the nature of the housing price or land rent functions. "Many people feel that the monocentric model of household location is inappropriate, given that only a small fraction of the typical urban area's employment is located in the CBD. The description of household equilibrium, however, is unaltered by decentralized employment" (p. 119).

Brueckner and Fansler (1983) use non-parametric methods to estimate the effect of variables on spatial size for a cross-section of urbanized areas located in small counties, while McGrath (2005) uses OLS to do the same thing for a cross-section, time-series including large multicentric MSAs. Waddell, Berry, and Hoch (1993), in their study of Dallas, conclude: "The price gradient remains significant even when access to multiple employment centers and other nodes is included in the model" (p. 135). Finally, extensions of the model with empirical verification have been provided by Song and Zenou (2006) for the property tax and by Su and DeSalvo (2008) for transportation subsidies.

Brief Exposition of the Monocentric Urban Model

The theoretical studies from which we extract testable hypotheses employ the monocentric urban model extended to include land-use controls. Since the standard monocentric urban model (Brueckner, 1987) has been widely used, we provide only a very brief exposition of it.

The household sector

The monocentric model has a predetermined center, the 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 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 first-order condition

$$\frac{v_q(y - tx - pq, q)}{v_c(y - tx - pq, q)} = p, \tag{1}$$

where the price of the *numéraire* good, c, is normalized to unity, and subscripts indicate partial differentiation with respect to the subscripted variable. Equation (1) says that at the constrained maximum, the marginal rate of substitution of housing for money is equal to the price of housing. 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:

$$u = v(y - tx - pq, q), \tag{2}$$

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

The housing production sector

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

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

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

$$\frac{H}{l} = H\left(\frac{N}{l}, 1\right) = H(S, 1) = h(S),$$

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

$$\pi = ph(S) - iS - r,$$

where p is housing price, as before; i is the rental rate of the non-land input; and r is the rental rate of the land input. The spatial equilibrium condition for housing producers is that land rent absorb profit, so all housing producers are equally well off at any location:

$$r = ph(S) - iS. \tag{3}$$

Maximizing rent per unit of land produces the following first-order condition:

$$ph'(S) = i, \tag{4}$$

which says that marginal revenue product of structural density equals the rental rate of the non-land input at the profit-maximizing S.

Boundary and population conditions

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

$$r(\bar{x}) = r_A, \tag{5}$$

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

$$\int_0^{\bar{x}} \delta x \frac{h(S)}{q} dx = P, \tag{6}$$

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

Equations (1)–(6) constitute the model, but it can be solved in two ways called the "open city" and "closed city" versions. Although all of the theoretical models from which we draw empirically testable hypotheses use the closed city version, some of the articles

TABLE 1: 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."

discussed later use the open city version, so we will distinguish both versions. 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, 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.

In this context, it should also be noted that the standard model assumes that all landlords are absentee. This assumption avoids the complication of dealing with rental income that might accrue to urban area residents. Pines and Sadka (1986) provide a model in which urban land rent is redistributed to the urban area population. Most of the results of the standard model carry over to the Pines-Sadka model, except for the effect of population on urban area size. In the standard model, an increase in population expands the urban area spatially, while in the Pines-Sadka model an increase in population may shrink the spatial size of the urban area. In addition, Pines and Sadka use the terms *semi-closed city*, which is the same as *closed city* in the standard model; *fully open city*, which is the same as *open city* in the standard model; and *fully closed city*, which has no counterpart in the standard model, but which means that population is exogenous, utility is endogenous, and the income of urban area residents is endogenous. Since all of the articles whose results we use in the empirical analysis use the assumptions that population is exogenous, utility is endogenous, and all rental income accrues to absentee landlords, we will continue to use the term *closed city* for them.

Comparative static analysis: Closed city model

Comparative static analysis of this model is quite complicated and has been provided by Brueckner (1987) for both the closed city and open city versions. The results for the closed city model are summarized in Table 1. Following Brueckner, we suppress the variables for the radians of available residential land, δ, and the price of the non-land input, i. Equilibrium housing consumption, q, housing price, p, structural density, S, and land rent, r, are functions of distance from the CBD, x, and the latter three pivot at the distance x' due to changes in income and transportation cost, while the effect on q beyond x' is ambiguous.[3]

[3]As implied by Brueckner (1987, p. 835) and made explicit by Anas and Kim (1993), the distance at which the q function (and therefore the population density function, which is $1/q$) pivots (if it does) is farther out than x'.

The effect of exogenous variables on the size of the city, $\bar{x}$, may be seen from Table 1. 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.

Other variants of the monocentric urban model

We refer to the preceding model as the "standard" monocentric urban model, but articles from which we draw testable hypotheses have used 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. Finally, in some cases, the housing production sector has been omitted to simplify the model if nothing substantive is thereby lost.

Several 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

The model

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 closed city 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.[4] 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.

The utility function of suburban residents is defined as $v_2 = v(c_2, \underline{l})$, where $\underline{l}$ is the minimum lot size, which is, by assumption, exactly the amount each rich household consumes. (Pasha assumes all households, those residing in both the suburbs and the

[4] 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.

TABLE 2: Minimum Lot-Size Comparative Statics, Pasha (1996)

	Endogenous Variables					
Exogenous Variable	u_1	u_2	r_1	r_2	x^*	$\bar{x}$
$\underline{l}$	+	−	−	?	+	+

central city, have the same utility function, so we have omitted the subscript on the functional operator, v.) Residents living in the suburbs face the budget constraint, $c_2 + r_2\underline{l} = y_2 - tx$. The spatial equilibrium condition for suburban households is $u_2 = v(c_2, \underline{l})$, where u_2 is the spatial equilibrium level of utility. The urban–rural boundary, $\bar{x}$, is given by

$$r_2\left(y_2 - t\bar{x}, u_2, \underline{l}\right) = r_A. \tag{7}$$

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 to maximize $v_1 = v(c_1, l_1)$ subject to the budget constraint, $c_1 + r_1l_1 = y_1 - tx$. Solution of the first-order conditions generates the ordinary demand functions for c_1 and l_1 from which Pasha obtains the indirect utility function, $V_1 = V(y_1 - tx, r_1)$. The spatial equilibrium condition is $V = u_1$. The boundary between the central city and the suburbs, x^*, is determined endogenously from

$$r_2(y_2 - tx^*, u_2, \underline{l}) = r_1(y_1 - tx^*, u_1). \tag{8}$$

Two population conditions, one for the rich and one for the poor, similar to Equation (6) complete the model.

Comparative static analysis

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 2.

The important conclusion for us is that an increase in a minimum lot-size constraint binding on suburban households expands the size of the city. The intuition of this result is simple: Making the rich suburbanites buy more land than they otherwise would expands the urban area. In the model, this happens because, as rich households bid for more land and since land is a better buy farther out, the bid-rent function of the rich pivots counterclockwise, lowering their bid-rent at the central city boundary and raising it at the urban boundary (the question mark in the table indicates that the bid-rent function does not uniformly increase or decrease). The rich are worse off because they are forced to buy more land than they otherwise would.

In contrast, the minimum lot-size restriction on the rich suburbanites raises the welfare of the poor urbanites and expands the area they occupy. This occurs for two reasons. First, the poor can now outbid the rich at the old x^*, so the poor occupy land near the central city formerly occupied by the rich. This holds even though the bid-rent function of the poor falls everywhere, which happens because the supply of land occupied by the poor has increased and they demand less land than the rich. It is the decrease in their rent that raises their utility.

Many people, including Mills (2005), believe that minimum lot-size zoning is designed to keep the poor out of the suburbs, which presumably makes the poor worse off and the rich better off. Pasha's results are the opposite of these expectations. If this is in fact the reason for minimum lot-size zoning and if these theoretical results hold in reality, then this is an example of unintended consequences of a policy. On the other hand, the model may have omitted important reasons for the policy. Pasha (1996) suggests that the reduced utility level of the rich may be "compensated for by consumption externalities arising from lower densities or by lower property taxes or improved quality of public services (by preemption of free rider behavior by the lower income group) . . . " (p. 8). But these issues are outside the scope of his analysis.

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. Without the assumption of a fixed number of households, it is difficult to see that our conjecture would hold. If correct, this result contradicts that of Pasha. 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. Pasha's paper assumes a closed urban area, that is, one with fixed total population, and an endogenous spatial equilibrium utility level. Unlike that of Bucovetsky, Pasha's model does not contain a housing production sector. We doubt, however, that this omission would change his results. 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) show 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) analyses maximum lot-size zoning because it is prevalent in developing countries. He notes that in Pakistan, as well as presumably in other developing countries, rapid urbanization has led to growth in demand for residential land and municipal services, while governments, for a variety of reasons, have not been able to provide the requisite urban infrastructure, leading to squatter settlements, "which by now constitute

TABLE 3: Maximum Lot-Size Comparative Statics, Pasha (1992b)

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

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

a sizeable fraction of the population in most cities" (p. 1173). In Pakistan, maximum lot-size zoning has been used increasingly to limit land consumption, and most major urban areas have adopted the land-use regulation, applying it primarily to wealthier households. Developed countries presumably use maximum lot-size zoning less often than do developing countries, but we found that 33 percent of our sample of U.S. urbanized areas use that land-use control, possibly over concern for the financing of suburban infrastructure.

The model

Pasha (1992b) incorporates maximum lot-size zoning into the standard closed city monocentric model. He assumes a monocentric urban area 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 ($\delta = 2\pi$) and that there is no housing production sector.

Pasha assumes the poor do not face a maximum lot-size constraint, so the analysis proceeds exactly as for the minimum lot-size constraint in the previous subsection. Pasha assumes that the maximum lot-size constraint is operative for the rich. Hence the rich face the budget constraint, $c_2 + r_2\bar{l} = y_2 - t_2x$, where $\bar{l}$ is the maximum lot size. The spatial equilibrium condition is $u_2 = v(c_2, \bar{l})$, where u_2 is the spatial equilibrium level of utility. 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 which differ between the two cases Pasha considers. In Case I the poor live in the central city and the rich live in the suburbs, while in Case II the reverse is assumed. For each case, Pasha presents two population conditions, one for the rich and the other for the poor, and two boundary conditions, one for the central city and one for the urban area.

Comparative static analysis

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. Comparative static results show that in both Case I and Case II, reducing the maximum lot size binding on the rich leads to contraction of the urban area, as well as the boundary of the central city, x^*. We summarize the results in Table 3.

For our purposes, the main finding is that in both cases the urban area contracts spatially. Intuitively it seems obvious that making the rich occupy less land than they would in the absence of the control would shrink the urban area, but things are a bit more complicated in the models.

In Case I, decreasing a binding maximum lot-size constraint on the rich, who live in the suburbs, renders land farther out less desirable and land closer in more desirable, so the bid-rent function of the rich pivots clockwise. This is why the urban boundary contracts. Other things equal, this would cause the central city boundary to fall as the rich outbid the poor for land closer to the center. The increased demand for central city land drives up its price, raising uniformly the bid-rent function of the poor, mitigating somewhat the decrease in the central city boundary. The increased rent paid by the poor is what makes them consume less land per household and become worse off. One would think that the decrease in the maximum lot size would make the rich worse off as well, but this result is ambiguous. We conjecture that this result is due to the reduction in land rent farther out, which could result in higher utility for the rich. Whether or not it does depends on the size of the area occupied by the rich. As Pasha notes (p. 1178), the more land the rich occupy, the greater is the possibility of an inverse relationship between their utility and the maximum lot-size constraint.

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.[5] As in Case I, the decreased maximum lot size causes the rich's bid-rent function to pivot clockwise as the rich reduce their consumption of land farther our in favor or more consumption closer in. This is what causes the central city boundary to contract. The reduced demand for land by the rich in the vicinity of the old central city boundary uniformly lowers the bid-rent function of the poor, which is why they consume more land per household, why they are better off, and why the urban boundary contracts. Again, one would think that the rich must become worse off, but the result is ambiguous. We conjecture that this is again due to the lowering of land rent near the central city boundary, which could cause an increase in the utility of the rich.

It might be noted that, despite the differences of this model from the one used to analyze minimum lot-size zoning, the results of an increase in a binding minimum lot size and a decrease in a binding maximum lot size (for Case I in which the rich live in the suburbs) produce the opposite results, as might be expected, for utility of the poor, the bid-rent function of the poor, and the boundaries of the central city and urban area.

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).

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 restriction 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 United States with a UGB.

The model

Much empirical work but little theoretical work has been performed on UGBs. We think 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 closed city monocentric model, Equations (1)–(6) above, including a housing production sector, but modify it to incorporate land-use restrictions and the UGB. Quigley and Swoboda define unrestricted or urbanized land as that land

[5] In this case, in contrast to his treatment of minimum lot size, Pasha allows t to differ by income, so that t_2 could be sufficiently large to induce the rich to locate in the central city.

TABLE 4: Comparative Statics of Land-Use Restrictions, Quigley and Swoboda (2007)

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

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

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. They assume that the restrictions affect k radians 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 (6), as follows:

$$(9) \qquad \int_0^{x^{**}} 2\pi x \frac{h(S(x))}{q(x)} dx + \int_{x^{**}}^{\bar{x}} (2\pi - k) x \frac{h(S(x))}{q(x)} dx = P,$$

where $2\pi - k$ are the radians of unrestricted land. Equations (1)–(5) and (9) represent the complete model with land-use restrictions.

Comparative static analysis

We summarize the comparative static results in Table 4. Since the control can expand the annulus in which the restriction holds either circularly (by a change in k) or radially (by a change in x^{**}), we include results for both. 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, whose radius is $\bar{x}$. Finally, the spatial equilibrium utility level, u, falls because of both the increase in housing price and reduced consumption of housing. Decreasing the distance from the CBD at which the restriction takes effect, x^{**}, holding k constant, decreases the supply of urban land available for development and generates the same qualitative effects as an increase in k. Note that although the spatial size of the urban area not under the restriction expands, the area under the restriction contracts.

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 x^{**}, which is less than the unregulated radius. Decreasing x^{**} decreases the urban–rural boundary, so the UGB causes a contraction of the urban area. Under the UGB, the urban–rural boundary is determined exogenously by the local government, and the model reduces to Equations (1)–(4) and (6) above, with $x^{**} = \bar{x}$. The comparative static results of decreasing x^{**} would be identical to those of an increase in rural land rent, r_A, shown in Table 1.

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 (Kline and Alig, 1999;

Abbott, 2002; Jun, 2004; Turnbull, 2004; Cho et al., 2006; Cho et al., 2007; Cunningham, 2007); the effect of a UGB on agricultural land values (Marin, 2007); whether or not a UGB is a preferable substitute for a congestion toll (Brueckner, 2005; Anas and Rhee, 2006; Anas and Rhee, 2007; Anas and Pines, 2008); 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 (Phillips and Goodstein, 2000; Downs, 2002; Fischel, 2002; Lang, 2002; Nelson, 2002); 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 (2007) and Quigley and Swoboda (2007) deals directly with the effect of a UGB on the size of the urban area in the context of the monocentric model. It should be noted, however, that the model developed in Anas and Pines (2008) does contain such a result. In the presence of restrictions, such as a UGB, people can move to a different urban area without the restriction. In this case, the policy has two counteracting effects: (1) a contractive effect in the urban area with the UGB and (2) an expansive effect in the urban area without the UGB. We shall return to this point later in discussing our empirical findings regarding the UGB.

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 a 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

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) notes, "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,

TABLE 5: Maximum *FAR* Comparative Statics, Bertaud and Brueckner (2005)

	Endogenous Variables[a]					
Exogenous Variable	u	$\bar{x}$	h	p	q	r
$\bar{h}$	−	+	+	+	−	NC

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

as opposed to the auto, increase neighborhood interactions, and reduce infrastructure cost.

Density controls set a maximum or minimum on population, housing, or structural density. To relate density controls to the monocentric urban model, recall the intensive form of the constant-returns-to-scale housing production function, $H/l = h(S)$, 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 1, S falls with distance from the CBD. Since $h'(S) > 0$, then h also falls with distance. 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 with distance and q rises, population 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, $h(S) \leq \bar{h}$, 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 (6):

$$(10) \qquad \int_0^{x^*} \delta x \frac{\bar{h}}{q} dx + \int_{x^*}^{\bar{x}} \delta x \frac{h(S)}{q} dx = P.$$

The first integral in Equation (10) represents the urban area population where the *FAR* is binding, up to x^*, called the restricted area, and the second integral represents the urban area population where the *FAR* is not binding, beyond x^*, 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 standard closed city model.

Comparative static analysis

Bertaud and Brueckner obtain the results summarized in Table 5. If the urban area has a binding *FAR*-restricted area from the CBD out to some distance x^* 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. 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, $\bar{S}$, and population density, $\bar{D}$.

We found no theoretical analysis of minimum density restrictions, but we did find such restrictions in our data in the form of minimum number of persons per room. Consequently, we interpret the results of Bertaud and Brueckner in terms of minimum density restrictions. Applying their logic to a minimum *FAR* means that the constraint will not be binding until some distance from the CBD. Beyond that distance and up to the urban–rural boundary, however, the unconstrained *FAR* would be lower than allowed. This would cause the urban population to be located closer to the CBD than in the unconstrained case, which 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 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 that restrictions on redevelopment densities are implemented to reduce congestion. "However, higher resettlement cost and greater inefficiency in the existing land use tend to lower the restriction" (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.

Building Permits

The great majority of U.S. cities and counties require building permits, with an absolute maximum number of residential and business buildings that may exist in the urban area. If this restriction is binding, the spatial size of the urban area will be smaller than it would be with out the restriction. Despite the ubiquity of building permits, we know of no studies that have incorporated them into urban spatial models. To deal with residential building permits, we assume that the number of households and the number or residential buildings are positively correlated. They are not equal because of the existence of different household sizes and multiple dwelling units in urban areas. If this assumption holds, then, the comparative static effects of building permits is identical qualitatively to the comparative static effects of the number of households. In the standard closed city model, the spatial size of the urban area is directly related to the number of households. Consequently, reducing the binding maximum number of building permits tends to contract the urban area. We use the symbol $\bar{P}$ to stand for the maximum number of residential building permits available in the urban area.

Impact Fees

When new development occurs in an urban area, the local government must provide infrastructure 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 United States used exactions before 1960, but by the mid-1980s, 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-1980s, about 60 percent of localities were using both in-cash and in-kind exactions (Altshuler, Gómez-Ibáñez, and Howitt, 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).

The model

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. Instead, we use 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 and we assume that both should have the same qualitative effect.

As Song and Zenou (2006) 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" (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, impact 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, 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 closed city model with a housing production sector but with specific, rather than general, functional forms. Without going into the details of their model, we want to show how they introduce the property tax into the standard monocentric model. Essentially, they replace the function representing housing producers' profit per unit of land with the following equation:

$$\pi = ph(S) - (1-\theta)(r + iS), \tag{11}$$

where θ is the property tax rate. 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.

TABLE 6: Property-Tax Comparative Statics, Song and Zenou (2006)

	Endogenous Variable					
Exogenous Variable	p	r	q	h	$\bar{x}$	u
θ	+	+	−	−	−	−

At this point, the methodology diverges from that of the standard model. Instead of solving Equation (11) for r and maximizing r with respect to S, getting the first-order condition analogous to Equation (3) above, Song and Zenou substitute the previously derived housing price function into Equation (11), then maximize the modified Equation (11) with respect to S. Given the functional forms assumed allows them to solve the first-order conditions for S, from which the rest of the variables can be found.

Comparative static analysis

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. Su and DeSalvo (2008) present a closed city model with general, rather than specific, functional forms and with a property tax. We choose not to present that model, however, because 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. Table 6 summarizes Song and Zenou's results.[6]

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.

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 surveys, see Fischel, 1990, and Quigley and Rosenthal, 2005). The general conclusion is that impact fees raise housing and land prices. 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) treats a dynamic model of the urban economy with durable housing. Instead of obtaining comparative static results on the urban boundary, he obtains results on its time path. Brueckner finds that impact fees retard urban development. This implies that the impact fee causes the urban area to be smaller, at some time after the imposition of the fee, than it would have been in the absence of an impact fee. Jeong and Feiock (2006) explore the economic consequences of impact fees on local economic development and job growth. They 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.

[6]An anonymous referee suggests that the effect of an increase in the property tax and, by implication, impact fees should be a differential impact based on lower tax revenue from other sources. Neither Song and Zenou nor Su and DeSalvo perform this exercise. Since Song and Zenou use a quasi-linear utility function in which the size of the urban area is independent of income, one might, however, interpret their results as a differential effect.

TABLE 7: 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), $\overline{h}$ building height, $\overline{S}$ population density, $\overline{D}$	+
Minimum density restriction (Bertaud and Brueckner, 2005) housing density (FAR), $\underline{h}$ building height, $\underline{S}$ population density, $\underline{D}$	–
Maximum building permits, $\bar{P}$	–
Impact fee, θ (Song and Zenou, 2006)	–

Note: Signs represent effects from increased stringency of the controls; for the case of the UGB, within the affected area.

Summary

Table 7 summarizes the effect of land-use controls on the size of the urban area as given in the urban literature.

3. DATA DESCRIPTION

In our empirical analysis, we use an approach similar to that used in previous studies (Brueckner and Fansler, 1983; McGrath, 2005; Song and Zenou, 2006; Su and DeSalvo, 2008) but with the inclusion of land-use controls as regressors. The empirical work tests the theoretical predictions of the effects of land-use controls on an urban area's spatial size, presented in Section 2.

Theoretical models predict certain effects of land-use controls on urban spatial size, but none distinguishes city and county controls. In the United States the county is a unit of government and, as such, may impose its own land-use controls. Some theoretical articles (e.g., Pasha, 1992a, 1996; Bertaud and Brueckner, 2005) do include the geographical extent of controls within the urban area, 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 would have on urban spatial size. For example, land-use controls instituted by the city may, in fact, increase urban size 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 urban size. Nevertheless, we use only county controls in our empirical analysis. This renders our empirical analysis more in keeping with the theoretical analysis described earlier. In addition, the urbanized areas in our sample are larger than their central cities and smaller than their counties. Therefore the urban–rural boundary lies in the county. It seems likely, therefore, that the county controls will be the deciding factors in determining urbanized area spatial size.[7]

[7] In Geshkov and DeSalvo (2010), we distinguish between city and county controls, running separate regressions for each. The county regression has more statistically significant coefficients and more "correct" signs. In addition, simple correlations between city and county controls reveal only 4 of 64 coefficients greater than 0.5 in absolute value with $P \leq 0.1$, which indicates little likelihood of strategic interaction between the setting of city and county controls.

The Urban Area

We select a subsample of 182 urbanized areas from the complete set of 465 in the year 2000. 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 county imposing the control than if there were more than one doing so.

Non-Land-Use Control Variables

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. We begin with the 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 cited earlier use the area, A, of the urbanized area in square miles as a proxy for $\bar{x}$, as do we. McGrath calculated the radius, $\bar{x}$, from the area, A. U.S. Bureau of the Census, Census 2000, Summary File 1 (SF1), Table GCT-PH1, provides the spatial size of urbanized areas in square kilometers for the total area, water area, and land area, We use land area, which we convert to square miles.

Population (P)

Brueckner and Fansler (1983), McGrath (2005), and Song and Zenou (2006) use population, while Su and DeSalvo (2008) use number of households. The theory assumes single-person households. In reality, however, the population exceeds the number of households, which is why we use households, rather than population. In any event, both of these variables perform very well in the regressions. The number of urbanized area households is found in Census 2000, SF3, Table P15.

Income (y)

Brueckner and Fansler (1983) use a construct similar to median income. McGrath (2005) uses per-capita personal income for the metropolitan area, not the urbanized area. Song and Zenou (2006) use median household income adjusted by the 2000 ACCRA Cost of Living Index. Su and DeSalvo (2008) use mean household income. All of these alternative proxies perform very well in the regressions. We use urbanized area mean household income, which is reported by Census 2000 for 1999 in SF3, Table P54.

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 readily available published source, researchers use alternatives. Brueckner and Fansler (1983) and Song and Zenou (2006) use median agricultural land value per acre for the county containing the urbanized area. McGrath (2005) uses agricultural land value per acre for the state in which the metropolitan area is

TABLE 8: Descriptive Statistics for Non-Land-Use Control Variables, 182 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	$	54,237	63,975	1,455	897,044	895,590
r_A	$/acre	2,578	1,718	150	15,064	14,914
t	$	0.26	0.19	0.00	1.87	1.87

located. Su and DeSalvo (2008) use mean agricultural land value per acre of the county in which the urbanized area is 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 National Agricultural Statistics Service. 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.

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) use 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 is statistically significant in their regressions. McGrath (2005) creates a regionally adjusted private transportation consumer price index, which is statistically significant in his Model 2 but not in his Model 1. Song and Zenou (2006) calculate governmental transportation expenditures per person who drives to work. This variable is statistically significant. Su and DeSalvo (2008) use proxies for both fixed and variable transportation costs for both transit and auto travel, specifically, percentage of the working-age population taking bus to work, private transit cost per passenger-mile, the sum of annual average motor vehicle fees and taxes and annual insurance premiums per household, and highway fuel tax payments per vehicle-mile traveled, all but the last of these being statistically significant. Following Song and Zenou, we use total annual highway expenditures by 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 state governmental expenditures and users are obtained from Census 2000 SF3, Table P58.

Descriptive statistics for non-land-use control variables

The descriptive statistics for these variables are presented in Table 8.

Land-Use Control Variables

Unfortunately, data on land-use controls are not available in the census or in any other published source. Consequently, we collected data on land-use controls by accessing websites of city and county governments. 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

TABLE 9: Descriptive Statistics of Land-Use Controls, Counties of 182 U.S. Urbanized Areas, 2000

Land-Use Control	Mean	Std. Dev.
Minimum lot size, $\underline{l}$	0.68	0.37
Maximum lot size, $\bar{l}$	0.33	0.35
Urban growth boundary, UGB	0.26	0.48
Maximum FAR, $\bar{h}$	0.83	0.44
Minimum sq. footage, $\underline{h}$	0.54	0.47
Maximum bldg. permits, $\bar{P}$	0.57	0.45
Minimum persons/room, $\underline{D}$	0.57	0.43
Impact fee, θ	0.63	0.42

of a lot in those jurisdictions with minimum or maximum lot-size zoning, the maximum *FAR* 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. Other researchers have faced this difficulty and have resorted to using indices of urban land-use regulations. Malpezzi (1996) summarizes others' work in this area, and he develops his own index. More recent work includes Malpezzi, Chun, and Green (1998) and Quigley and Raphael (2005).

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, $\bar{l}$; (3) urban growth boundaries, *UGB* (Quigley and Swoboda (2007) use two variables to capture *UGB*s, x^{**} and k, so we are simply naming the dummy variable *UGB*); (4) maximum *FAR* restrictions, $\bar{h}$; (5) minimum square footage limitations, $\underline{h}$; (6) maximum building permits, $\bar{P}$; (7) minimum number of persons per room, $\underline{D}$; and (8) impact fees, θ. 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 later. Table 9 provides some descriptive statistics on county land-use controls.[8]

Not obvious from Table 9 is the tremendous variation among urbanized areas in their employment of land-use controls. Of the 256 possible permutations of the 0–1 values of our eight land-use controls, we find 107 in our data. The largest set of urbanized areas using the same set of controls is five, and this occurs only three times in our data.

4. EMPIRICAL ANALYSIS

Preliminary Analysis: Correlation Matrix

Since we intend to use land-use control dummy variables as regressors, a natural question arises as to their correlation 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. 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. Table 10 provides correlation coefficients for the county land-use controls. There are no "high" correlations.

[8]A data-source appendix containing the list of websites from which we obtain county land-use controls and a data appendix for all our regression variables are available at http://economics.usf.edu/research/.

TABLE 10: Correlation Matrix for County Land-Use Controls

	$\underline{l}$	$\bar{l}$	*UGB*	$\bar{h}$	$\underline{h}$	$\bar{P}$	$\underline{D}$	θ
$\underline{l}$	1.0000							
$\bar{l}$	−0.0445	1.0000						
	(0.5505)							
UGB	−0.2158	0.0350	1.0000					
	(0.7931)	(0.6393)						
$\bar{h}$	0.3731	0.4760	−0.2519	1.0000				
	(0.0034)	(0.5235)	(0.0006)					
$\underline{h}$	−0.2809	0.7643	0.2485	−0.2077	1.0000			
	(<0.0001)	(0.3051)	(0.0007)	(0.0049)				
$\bar{P}$	−0.4680	0.1055	0.2582	−0.3960	0.2560	1.0000		
	(<0.0001)	(0.1565)	(0.0004)	(<0.0001)	(<0.0005)			
$\underline{D}$	−0.0954	−0.0941	0.0592	−0.0272	0.0140	0.0600	1.0000	
	(0.2003)	(0.2065)	(0.4277)	(0.7158)	(0.5789)	(0.4214)		
θ	−0.6122	0.0445	0.1377	0.1086	0.1618	−0.0683	−0.0052	1.000
	(0.4116)	(0.5505)	(0.0639)	(0.1447)	(0.0292)	(<0.3594)	(0.9444)	

Note: *P*-values in parentheses below their respective correlation coefficients.

Regression Analysis

We estimate the following regression:

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

We use a simple linear regression because functional form seems not to matter much in previous analyses. Brueckner and Fansler (1983) use a Box-Cox transform but could not reject the hypothesis that the function was linear. McGrath (2005) uses a linear regression but with $\bar{x}$ and P in logs. Song and Zenou (2006) use a linear form, as do Su and DeSalvo (2008), but the latter include squared terms on y and on a transit-subsidy variable.

Regressions of urban area spatial size raise the question of simultaneity. For example, the property tax and transportation costs may both affect the spatial size of the urban area as well as be affected by it. This issue is not addressed by Brueckner and Fansler (1983) or by McGrath (2005). Song and Zenou find that the problem exists for the property tax, while Su and DeSalvo (2008) find that simultaneity is not a problem for the property tax, transportation costs, and transportation subsidies. In our case, the existence of land-use controls in an urban area may be affected by the spatial size of the area. If this is the case, then our OLS estimates are biased and inconsistent. Multiple land-use controls, such as we have, however, make it difficult, if not impossible, to perform simultaneous equation estimation or to find appropriate instrumental variables to correct for the potential simultaneity. Consequently, it might be best to interpret our results as partial correlations indicating empirical regularities.

The OLS regression results are given in Table 11. We discuss the results for the land-use control variables first, as those are our main interest.

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, which is consistent with theory, and statistically significant at the 7 percent level. The imposition of a minimum lot-size restriction by the county would increase the urbanized area by 18.6 square miles, on average.

TABLE 11: Regression Results

Variable	Coefficient	P	Elasticity[a]	ΔA^b
Constant	60.13	0.0004	–	–
No. of UA households, P	5.44×10^{-4}	<0.0001	0.4683	37.35
Mean household income, y	2.01×10^{-4}	0.0041	0.1027	8.20
Mean farm land price, r_A	-1.00×10^{-4}	0.0178	−0.0069	–0.55
Hwy. exp./user, t	28.71	0.2076	0.0936	7.46
Minimum lot size, $\underline{l}$	18.60	0.0691	0.2332	18.60
Maximum lot size, $\bar{l}$	−20.37	0.0233	−0.2554	−20.37
Urban growth boundary, UGB	−3.32	0.7228	−0.0417	–3.32
Maximum FAR, $\bar{h}$	19.66	0.0520	0.2465	19.66
Minimum sq. footage, $\underline{h}$	−8.24	0.3817	−0.1033	–8.24
Maximum bldg. permits, $\bar{P}$	−21.75	0.0396	−0.2727	−21.75
Minimum persons/room, $\underline{D}$	−22.98	0.0127	−0.2881	−22.98
Impact fee, θ	−21.98	0.0151	−0.2756	−21.98
R^2	0.73			
N	182			

[a]Proportionate change for dummy variables. [b]1 percent change in P, y, r_A, t.

Maximum lot size

The coefficient on maximum lot size, $\bar{l}$, is negative, as expected in theory, and statistically significant at the 2 percent level. 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

We find the coefficient on the urban growth boundary, *UGB*, to be negative, which is anticipated by urban theory, but not statistically significant. Only 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 counties have urban growth boundaries, they may not yet be binding. In addition, as the paper of Quigley and Swoboda (2007) suggests, counties may not be using a UGB that completely surrounds their jurisdictions. If this is the case, the urban area would expand in the areas not under control and contract in the areas under control. This could contribute to the regression coefficient's not being statistically significant. As previously noted, all of the articles from which we drew testable hypotheses were based on the closed city model. This rules out the possibility that households could migrate to avoid land-use controls. If they did migrate to urbanized areas in our sample without UGBs, then, according to the model of Anas and Pines (2008), those areas would expand, which could be another reason for the statistical insignificance of the variable.

Maximum FAR

The coefficient on maximum *FAR*, $\bar{h}$, is positive, as predicted by urban theory, and statistically significant at slightly over the 5 percent level. The presence of a maximum *FAR* in the county would increase the urbanized area by nearly 20 square miles, on average.

Minimum square footage

The coefficient on minimum square footage, $\underline{h}$, is negative, consistent with theory, but not statistically significant. Fifty-four percent of our sample counties use this control, and it is one of the three least-used controls, with only maximum lot size and UGB being used less. It exhibits relatively large variation among sample counties, however. It may be that the control is not binding in some of the sample counties.

Maximum building permits

The coefficient on maximum building permits, $\bar{P}$, is negative, consistent with theory, and statistically significant at the 4 percent level. Introducing maximum building permits in the county would reduce the size of the urban area by about 22 square miles, on average.

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 at the 1 percent level. Using this restriction by the county would reduce the urbanized are by nearly 23 square miles, on average.

Impact fee

The coefficient on the impact fee, θ, is negative, as predicted by urban theory, and statistically significant at the 2 percent level. The magnitude of the contractionary effect on the urbanized area is about 22 square miles, on average.

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, as is usually the case in analyses of this kind. Although inelastic, a 1 percent increase in the number of households (about 700 households) nevertheless increases the urbanized area by about 37 square miles.

Income

The coefficient on mean household income, y, is positive, in conformity to urban theory, and statistically significant, as usual in these kinds of regressions. The elasticity is small, however, so an increase by 1 percent in income (about \$400) increases the size of the urbanized area by only about 8 square miles.

Agricultural land value

The coefficient on the mean value of agricultural land, r_A, is negative and statistically significant, which is consistent with urban theory. As noted earlier, this variable has not performed well in most analyses.[9] The elasticity is very small, however. Increasing the value of agricultural land surrounding the urbanized area by 1 percent per acre (only about \$55) would shrink the urbanized area by about half a square mile, on average.

Highway expenditure per user

The coefficient on state government highway expenditures per user, t, is positive, which is consistent with urban theory because higher governmental expenditures are presumed to lower users' transportation costs, but not statistically significant. 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.

[9]An anonymous referee points out that most land at the urban–rural fringe has option value and that, therefore, the average for the whole area outside the central city may be a poor proxy for the desired variable.

TABLE 12: Summary of Results

Land-Use Control	Sign: Theoretical	Sign: Empirical	*P*
Minimum lot size, $\underline{l}$	+	+	0.07
Maximum lot size, $\bar{l}$	−	−	0.02
Urban growth boundary, UGB	−	−	0.72
Maximum FAR, $\bar{h}$	+	+	0.05
Minimum sq. ft., $\underline{h}$	−	−	0.38
Maximum building permits, $\bar{P}$	−	−	0.04
Minimum persons / room, $\underline{D}$	−	−	0.01
Impact fee, θ	−	−	0.02

Note: Signs represent effects of increased stringency of the controls.

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

In this subsection, we summarize the results of the empirical analysis by comparing the theoretically predicted effects of land-use controls with their empirically estimated counterparts. Table 12 presents the results.

In all cases, the empirically obtained sign is consistent with the theoretical prediction. 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. Strictly speaking, since these two coefficients are deemed not statistically significant from zero, then the fact that their signs are "correct" is statistically meaningless although psychologically comforting.[10]

5. CONCLUSIONS, LIMITATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Conclusions

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 model that encompass land-use controls. Second, it may provide guidance to urban governments in the efficacy of policies to contain urban decentralization, which they may regard as sprawl. Given the likely endogeneity of the land-use controls, however, we cannot claim one-way causality from land-use controls to urban spatial size. On the assumption that land-use controls are exogenous, which is consistent with the theory, then our empirical results have the following implications.

[10]In a study of urban sprawl, Burchfield et al. (2006) regressed the percentage of open space in the immediate square kilometer of each sample 30 meter cell of residential development on variables from urban theory as well as variables representing geography and climate. Their sample consisted of 8.7 billion 30-by-30 meter cells, and they got good results from their main regression. As a robustness test on our results, co-editor Marlon Boarnet suggested that we use the Burchfield et al. data with our measure of urban decentralization. We therefore replicated the main regression of Burchfield et al., with the spatial size of the urbanized area as the dependent variable. We got very poor results, including seven of eleven wrong signs, seven statistically insignificant coefficients, and a low R^2. We then added our measures of land-use controls to the previous variables. In that regression, we found three "wrong" signs and seven insignificant coefficients on our land-use control variables as well as continued poor results on the Burchfield et al. variables. These results seem to buttress those of our first regression with the Burchfield et al. data. Namely, their variables do not add much to the explanation of the spatial sizes of urbanized areas. Perhaps it is not surprising that two different measures of urban development produce such different results, but it may nevertheless be an issue worth pursuing.

All 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. Land-use controls have substantial effects on the spatial size of urban areas (coefficient estimates range from 23 to 29 percent of the spatial size of our sample mean urbanized area of 80 square miles). As such, they may be implemented as policies to contain urban decentralization. A caveat should be entered here. We agree with Mills (1999) and Brueckner (2001) that urban sprawl is *excessive* urban spatial size, a normative concept. Our empirical analysis is not, however, capable of determining if the size of an urbanized area is excessive. It can only shed some light on whether or not and to what extent land-use controls may affect the spatial size of urban areas. Brueckner (2001) has provided theoretical analyses of market and government failures that affect the spatial size of urban areas and has proposed corrective policies, including land-use controls, and Hamoudi and Risueño (2011) have studied the effect of zoning on competition, but no one has yet provided the empirical justification for governmental intervention to control the excessive spread of urban areas. Indeed, Anas and Rhee (2007) and Anas and Pines (2008) show that under certain conditions urban expansion can be efficiency enhancing and that efforts to control urban decentralization can actually increase it. Despite the lack of justification for policies to control urban spatial size, many have nevertheless concluded that the spatial size of urban areas should be controlled.

For those who believe urban area are too spread out, our empirical analysis supports eliminating or reducing the stringency of minimum lot-size zoning and maximum *FAR* or building-height restrictions, while imposing or increasing the stringency of maximum lot-size zoning, maximum building-permit restrictions, minimum persons per room limits, and impact fees. Because of statistical insignificance, our work does not support the use of the UGB and minimum square footage requirements to control the spatial size of urban areas although we think these are likely to work in practice, especially for the UGB in light of its estimated effects on housing prices. Obviously, combining these land-use controls would have a greater limiting impact on urban spatial size than employing only one of them. Unfortunately, because of our use of dummy variables for the existence of land-use controls, our findings do not provide guidance on the quantitative effects of marginal changes in land-use controls already in existence.

Limitations of the Study and Suggestions for Further Research

As already previously noted, we find no theoretical extensions of the monocentric urban model that include minimum square footage and minimum persons per room restrictions. Neither do we find extensions to include maximum building-permit restrictions. We do, however, find such restrictions being used by counties in our sample. To circumvent this lacuna in the theory, we draw on the theoretical relationship among population, structural, and housing density, which allows us to interpret the work of Bertaud and Bruckner (2005) in terms of restrictions on minimum square footage and minimum persons per room. Similarly, we find no theoretical work extending the urban structure model to include impact fees but, again, we find evidence of urban areas' use of impact fees. As a consequence, we use the property-tax model of Song and Zenou (2006). Finally, we do not find any theoretical work on the effect of maximum building permits on the spatial size of urban areas. Consequently, we draw on the effect of the number of households, which we argue is a proxy for building permits. We would have preferred to have had fully worked out extensions to the standard monocentric urban model.

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 United States. None of the theoretical models we review do this. Pasha (1992b and 1996) divides his urban area into two parts, the central city and the suburbs, but he implicitly treats them as parts of the same governmental entity. Bertaud and Brueckner (2005) recognize that a density control may not be binding throughout the urban area but, again, implicitly assume a single urban government. 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 United States. Given that cities and counties do not follow a unitary policy with respect to land-use controls (as indicated by simple correlations noted in footnote 7 above), it is possible that results of models without this specification will generate incorrect comparative static results. Along these lines, interesting research topics are why cities and their surrounding counties choose the land-use policies they do and why they do not follow a unitary policy toward land-use controls.

Turning to empirical limitations of our research, surely the most important is our inability to obtain quantitative measures of land-use controls. Inability to find such measures leads us to use dummy variables representing the presence or absence of controls. While we realize dummy variables are a weak measure of land-use controls, we are constrained to use them since obtaining actual values of land-use controls would an arduous and extremely time-consuming process. Even collecting the information on the presence or absence of controls is a laborious process. Obtaining the actual values of land-use controls would serve two purposes. First, it would make our empirical estimations 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 would provide an opportunity to provide planning agencies with valuable guidance on how to control urban decentralization.

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