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An Examination of the Link between Urban Planning Policies and the High Cost of Housing and Labor

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Abstract

Past research has established positive empirical relation between city-level land use regulations and housing costs. One interpretation of these findings is that building restrictions raise the cost of producing housing. Alternatively, these price effects could reflect greater willingness to pay for quality urban design. Disentangling and identifying cost versus amenity factors empirically is an unresolved challenge. This paper presents an alternative to empirical tests, relying instead on the predictions of neoclassical urban theory. Simulations of an open city model demonstrate that theoretical predictions differ substantially from those obtained from empirical testing in two main ways. First, restrictions on land use and housing density influence the price level but not the elasticity of housing supply. Second, the effects of land use restrictions on average house prices are ambiguous and depend on the precise location of the planning restriction. Furthermore, the model generates direct estimates of effects on wages and demonstrates that transportation impediments are more consequential for housing prices than land use restrictions. This indicates a potentially fruitful path for future empirical work, and the possibility of omitted variable bias if transportation impediments are correlated with land use regulation.

JEL Codes: R30, R31, R38

Keywords: monocentric city model, price gradient, zoning, standard urban model

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1 Introduction

Do residential building regulations significantly increase the cost of producing housing at the city level? Such cost effects, if not matched by compensating amenity gains, could become a significant concern for efficiency if labor productivity is higher in the most planned cities. As noted by Hsieh and Moretti (2015) and Glaeser and Gyourko (2018), among others, planning could induce costly failure in the national allocation of labor and capital. Many empirical studies including Segal and Srinivasan (1985), Malpezzi (1996), Mayer and Somerville (2000), Green, Malpezzi, and Mayo (2005), Glaeser, Gyourko, and Saks (2005), Quigley and Raphael (2004), Saiz (2010), and Turner, Haughwout, and van der Klaauw (2014) have estimated models of the relation between indexes of land use planning regulations and the price of housing, construction of new units, or the price elasticity of housing supply. The empirical results all indicate a significant negative (positive) relation between the strength of regulation and housing supply (housing price).

This paper uses an alternative to the empirical approach. An open-city numerical urban simulation model, that allows testing of restrictions imposed by residential building regulations, land use allocations, and transportation planning, is used to estimate the relation between exogenously imposed limits on both the pattern and density of development as well as the availability of transportation infrastructure, on the price of housing and the wage required to attract labor. The model is designed to provide upper-bound effects of planning on housing costs and wages compared to a city under laissez faire.

The advantage of the theoretical approach taken here is that it provides a sterile laboratory in which the effects of land use and transportation planning policies can be examined in a truly *ceteris paribus* fashion where possible amenity effects are eliminated. In contrast, there are many challenges to empirical studies relating house prices, or the elasticity of housing supply, to land use planning practices. Nine important issues are outlined below:

1. Land use regulation is endogenous. Regulations are produced, reconsidered, and modified in response to a political process that considers the value of land in alternative uses.[1] As is evident from observing the zoning map of any city, planners consider

[1] The politics of zoning has been the object of substantial research. In the case of Chicago, the city simulated in the model developed here, it is discussed at some length in Schwieterman and Caspall (2006). The classical statement on the endogeneity of land use restrictions is discussed in Schertzer, Twinam, and Walsh (2017) who trace the arguments from Hoyt (1933) who observed that "whenever there is any possibility of a higher use for any block or parcel of land than the one for which it is zoned, it is not very difficult to have it zoned for the higher use, as the five thousand amendments to the zoning law testify" thought Wallace (1988) and Munneke (2005). Both Ihlanfeldt et al. (2007) and Brueckner et al. (2018) discuss the endogeneity problem in detail.

the opportunity cost of land in restricting its use.[2] This produces a natural negative relation between restrictive zoning regulation and land value. For example, higher density development is allowed proximate to mass transit or other sites with accessibility advantages.

2. Planners argue that regulations have an aesthetic component that raises the demand for housing by making planned cities more attractive to workers.[3] Davidoff (2016) has demonstrated that regulations are often prompted by environmental or topographic features that make areas more attractive and raise the demand for housing.

3. Planning decisions not only influence the design, location, and density of residential structures; they also govern the fraction of land available for residential real estate and the transportation system both of which have a major effect on the supply of buildable land. Indeed, land use and accessibility planning in most cities are intentionally integrated. This makes differentiating the effects of land use and transportation planning challenging.

4. There are empirical challenges in measuring intercity differences in the quantity and price of housing. The cost of supplying housing should be based on a physical measure like interior space rather than a sociological measure like number of households. Housing cost is usually based on asset prices rather than rents, although the proportion of rental units in some MSAs exceeds 50% and location within the city tends to vary by tenure status.[4]

5. There is confusion over the implications of land use restrictions for the price of housing in levels versus the elasticity of housing supply. Some empirical studies measure effects on price level and others on elasticity.

6. In the typical large city, the regulations of many localities must be aggregated to some overall index number reflecting city-wide restrictions. Thus empirical studies are based

[2] Provisions for open space and density restrictions increase with distance from the CBD along with land values.

[3] See Ihlanfeldt (2004) for a discussion of a special issue considers whether another consequence of zoning may be to separate households by income and/or race. If this is the case, the question considered here is whether the limitations on land use also raise housing prices throughout the city rather than in selected exclusive neighborhoods.

[4] The fraction of rental units rises with both city size and the degree of regulation, Malpezzi (1996). This introduces another relation among housing price, tenure ratio, and regulation. Furthermore, the proportion of rental units falls dramatically with distance from the CBD. This makes the use of median value as a measure of housing price problematic because the location and representativeness of owner occupied units varies with city characteristics.

on the average level of regulation, rather than its variance or specific application within the city.

7. There is no index of transportation regulations or restrictions to use in empirical work which means that transportation planning effects are an omitted variable in empirical estimates of the effects of land use regulations.

8. The effect of height or density limits on median housing price in a city depends on where the regulations are implemented because regulation has a locational as well as a pure level effect on prices. The model developed here demonstrates that implementing height limits near the city center can actually lower median housing price by forcing development out to the suburbs.

9. The housing stock and transportation infrastructure of cities is a function of both current and past planning regulations. The vast majority of housing units build in large cities were constructed before current land use maps were ever drawn. Current land use is not necessarily a product of recent zoning practice.[5]

Taken together, these factors provide significant challenges to any empirical tests of the effects of housing regulations, land use restrictions, and transportation infrastructure on the cost of supplying housing.

An open city numerical urban simulation model calibrated to a large city avoids these problems by imposing regulations exogenously and selectively in different portions of the city. Furthermore the regulations can take the form of limitations on density, on the fraction of land available for housing, and/or on transportation systems of a large city. This allows housing price effects to be related to either specific types of regulation or to the interaction of regulations. Additionally the location(s) within the city in which the regulations are imposed can be varied.

The model is first calibrated to Chicago, and used to generate the characteristics of an urbanized area under laissez faire. Among other variables, house prices, earnings of homogenous households, and the aggregate supply and price of housing are generated by the

[5]Shertzer, Twinam, and Walsh (2016) demonstrate that current land use patterns in Chicago have been substantially influenced by the comprehensive zoning ordinance of 1923. In addition to zoning, there are many aspects of land development in Chicago that give it its unique urban form, including its cultural history, geographic features, government corruption, racial and economic sorting, and high levels of violent crime in some areas. These features keep the actual city of Chicago from representing a city in an efficient long-run equilibrium in a neoclassical, laissez faire framework. The model is not designed to replicate Chicago precisely as it current exists, but rather as it would exist with a deregulated land market, the absence of local geographic features limiting development, the absence of crime, parks, or any other positive or negative local externalities, and under a homogeneous population.

model. Problems in measuring the price and quality of housing supplied in actual cities are avoided. In addition to normal calibration and validation procedures associated with the model, the elasticity of housing prices with respect to population is generated and compared to empirical estimates. Then a succession of simulation experiments is performed. Land use regulations, restricting both the fraction of land available for housing and the floor area ratio (FAR) of existing structures are lowered selectively in different parts of the city. The extent of regulation is based on departures from the laissez faire city. For example, the FAR can be lowered to half the value under laissez faire in different portions of the city and the effects on city characteristics, including housing prices at specific locations, labor earnings, and the elasticity of housing supply holding location constant generated. This is important because median housing price change is a misleading indicator of the effects of FAR regulation because changes in the spatial distribution of housing alter the median housing price in a manner that may not reflect changes in price at any given location.[6] The fraction of land available for housing in various parts of the city can be limited. Planning limits on transportation facilities are also imposed and their implications for the same variables compared to land use restrictions. The results suggest that the location within the city where the regulations are imposed is important with areas near the central business district (CBD) being most consequential.

The numerical simulation resolves the list of challenges confronting empirical estimation of the housing supply effects noted above. First, the regulations are imposed exogenously. Second, the regulations have no esthetic effects on the attractiveness of the city. Accordingly, the results represent the largest (smallest) possible effects on earnings (house prices) because regulations that enhance city amenity would produce smaller (larger) earnings and house price effects through application of the Rosen (1974)-Roback (1982) model.[7] Third, transportation planning decisions are considered explicitly and separately from housing regulation. Fourth competition and strategic behavior among localities is eliminated. Fifth, regulations are not averaged over the entire city but imposed specifically on locations within

[6]Geographic regulation changes both the housing price function and the spatial distribution of units in the city so that it is possible for housing prices to fall everywhere at the same time that the median or mean price of housing rises. Consider the following thought experiment in deregulation. Imagine that Central Park in New York City was rezoned for housing. A substantial number of very high priced new housing units would be built on the site. However the average price of housing in New York would likely rise as a result because high priced center city construction would be substituted from low priced suburban units. Conversely, opening suburban park land to residential construction would raise supply and lower price due to the natural supply effect and because housing suburban prices are lower. The location of deregulation changes the effect on average housing price because of this location composition effect.

[7]See Albouy (2016) for an empirical demonstration of this concept.

the city. Finally, the model is putty-clay and constructs the city in response to a specific set of current regulations and is designed to generate long run effects assuming modern building and transportation technology as well as efficient provision of local public services and the absence of crime and other local externalities.

The next section of this paper discusses the challenges of measuring the relation between land use and transportation restrictions and housing supply. Then the form of the simulation model is presented. Next model calibration is discussed. The fifth section presents and discusses a variety of simulation results in which the laissez faire city is contrasted with various regulated cities. Conclusions and implications are then discussed.

2 Problems in measuring effects of regulations on housing supply elasticity

Before considering the effects of regulation on housing prices and housing supply elasticity, a prior question concerns the empirical literature on housing supply elasticity itself. Extensive discussions of this subject have already appeared in the literature. The general consensus is that the correct answer is somewhere on the interval between unity and thirty. Put another way, as noted by reviews by DiPasquale (1999) and Harter-Dreiman (2004), there is little consensus in estimates of either aggregate or cross sectional variation in the supply elasticity of housing. Estimates of the variation in supply elasticity vary substantially across areas. For example, Green, Malpezzi, and Mayo (2005) report statistically significant elasticities ranging from 1.43 (Pittsburgh) and 1.77 (Boston) to 17.0 (Charlotte) and 21.6 (Atlanta). In contrast, using more recent data, including the boom and bust of 2000 through 2010, Wheaton, Chervachidze, and Nechayev (2014) produce estimates ranging from 0.5 through 3 associated with this period of extreme price volatility.

There are substantial data problems in estimating supply elasticities for cities. First, housing supply is based on units rather than square feet of housing or some other measure of housing services. Given that the average size of a new single-family housing unit has increased at a rate of 1% per year, measuring supply as a count of units systematically understates the actual elasticity of supply of living space. Furthermore, because of their larger size, new units sell, on average for 35% more than existing units, measuring price changes by median unit value systematically overstates price increases in areas where supply is growing. The net effect of understating the increase in supply of interior space and overstating price increase in areas where there is substantial new production tends to understate the elasticity of housing supply. In view of this it is not uncommon to find some cities where estimates of the elasticity of housing supply are equal to or even less than zero.

A further difficulty in estimating the elasticity of supply is the presumption, noted in Green, Malpezzi, and Mayo (2005) and Glaeser and Gyourko (2005), that the housing supply function should be kinked. Because of the durability of housing, prices can fall well below replacement cost with little effect on supply except in the very long run when units are abandoned. To determine the role of regulation in constraining supply, research should concentrate on the long run market response to prices that are above replacement cost. Panel or cross section estimates tend to involve a mixture of cities where prices are above and below replacement cost.

Against this backdrop of difficulty in obtaining agreement on the elasticity of housing supply in cities, recent literature has attempted to relate differences in these estimates of supply elasticity to variation in city characteristics, including regulation and topography. The hope in this literature is, although there may be little agreement on the elasticity of housing supply in cities generally, perhaps estimates of the differences in estimates can be related to variation in topography and regulation.

Three main potential determinants of the elasticity of housing are explored in the literature. All three will be investigated in the simulation models in this paper. First, land use regulations limit the fraction, θ, of land in the city that can be used for residential development in what can be called the land use effect. There may be exogenous topographic factors that prompt low levels of θ with land use reflecting these constraints on development. Second, housing regulations limit the density of structures on land available for housing by lowering the structure/land ratio below its laissez faire level. This will be termed floor area ratio (FAR) regulation. Third, transportation infrastructure, interpreted here as land allocated for congestible highways, changes the total cost of the housing-commuting bundle faced by urban households. Planning has an important effect on the level and effectiveness of transportation infrastructure as does topography. Each of these three factors can have separate effects on the cost of providing housing in cities and there may be significant interactions among them.

The land use effect of topography or zoning restrictions

In the extensive literature on the standard urban model (SUM), calibration of the θ parameter, reflecting the fraction of land in each annulus available for housing, is a standard exercise. It is common to regard θ as independent of distance from the CBD although there have been some exceptions to this rule. For reasons that will be apparent, there has been little interest in the effects of θ on housing supply elasticity in the SUM literature.

Segal and Srinivasan (1985) conducted their own survey of land use regulations and formulated a measure of effects on the fraction of land unavailable for residential uses. They found a positive relation between this regulation and the level of housing prices rather than with the elasticity of supply. More recently evidence of the land use effect on the supply of housing has been based on Saiz (2010) who demonstrated that, in a classical land market model with one housing unit per unit land and constant commuting cost per unit distance, the elasticity of housing supply is increasing in θ.[8]

This expectation was then tested and confirmed by relating the average value of θ in cities to the relation between the change in housing units and the percentage change in average house price. Price elasticity was found to increase with empirical measures of θ. The result was statistically and economically significant.

An alternative view of the land use effect on the elasticity of supply is provided by the neoclassical SUM in which there is substitution between housing and the composite commodity in consumption and between structure and land inputs in production. In this case, even with constant commuting cost per mile, there is no relation between θ and the elasticity of housing supply. For given population, housing price and θ vary inversely but this is an effect in levels. Elasticity is not a function of θ. The simulation model used in this research, adds endogenous congestion in commuting but this has little effect and there is no significant relation between θ and the elasticity of housing supply. Overall, the neoclassical SUM suggests that the Segal and Srinivasan (1985) approach relating land availability to housing prices is the appropriate test for the effects of lowering θ on housing cost. Recently, Williams, Cosman, and Davidoff (2018) have argued that the marginal rather than the average supply of land of housing is most important.

[8] In the classical land market model which originated with von Thunen, there is one housing unit per unit land area, the housing and land price gradients are linear, and the city radius expands by a constant amount with increases in housing price, $dR/dP = k$. It follows that if total land area for hosing is $A = \theta\pi R^2$, where θ is the fraction of land in each annulus available for housing, the $(dA/d\theta)/A = 1/\theta$ and the rate of expansion of land area for housing is inversely proportional with θ. This contrasts with the neoclassical SUM where Zhao (2017) has demonstrated the Unitary Elasticity Property (UEP) of the SUM which holds that the sum of the elasticity of central density plus land area equals unity independent of the value of θ. Empirical tests demonstrate that the UEP fits US cities reasonably well in contrast to the classical model where the elasticity of population would necessarily equal the elasticity of land area.

The effect of regulations affecting density or floor-area ratios

There is ample evidence that FAR and height regulations can restrict the height of individual housing projects. Less obvious is the fact discussed in Bertaud (2018) that binding regulations are set on new construction to make developers accept additional design costs to have them eased. Glaeser, Gyourko, and Saks (2005) note the substantial difference between the marginal revenue associated with additional building height and the marginal cost of new construction in New York City as a measure of the distortion introduced by FAR zoning. Ihlanfeldt et al. (2007) finds effects on housing and land prices that vary with the availability of substitute locations and changes the size of the units that are constructed. These outcomes are consistent with the results of the simulation model used here. An alternative approach using the elasticity of land value with respect to FAR regulation by Brueckner et al. (2018) shows that, particularly for New York and Washington, D.C, but not for Chicago—which is the object of this modeling effort—current regulations have a substantial effect on the value of land used for individual projects. The results obtained here are consistent with this literature in that FAR regulation which is significantly below laissez faire structure density depresses land values, and drives a wedge between marginal revenue and marginal cost of construction.

Testing for the effect of limits on FAR on the supply of housing required that some measure of the strength of regulation be assembled for a cross section of cities. This was accomplished in waves of research as data quality improved. Linneman, Summers, Brooks, and Buist (1990) surveyed local governments regarding the types and performance of land use regulations. Malpezzi (1996) combined these with measures—such as the incidence of rent control—into a regulatory index, and estimated both reduced form and structural models finding that house price and rents vary directly and homeownership rates inversely with his regulation index. Subsequently Harter-Dreiman (2004) used a two equation vector error correction model and found supply elasticities ranging from 1.8 to 3.2 but found no effect of the Malpezzi index on her estimated elasticities. Finally Green, Malpezzi, and Mayo, (2005) add the Malpezzi (1996) index to their estimates of housing supply elasticity and find that areas that are heavily regulated have lower supply elasticities. Thus estimates of effects of regulation on supply elasticity appear consistent with the effects of regulation on housing price levels.

Gyourko, Saiz, and Summers (2008) produced, in a landmark study, the Wharton Residential Land Use Regulatory Index (WRLURI) based on survey responses from over 2,000 local governments supplemented by legal and voting analysis. Eleven individual indexes were aggregated to produce an overall measure of development restrictions. Saiz (2010) used both the WRLURI and a topographic interruptions index to estimate the effects of land use and development restrictions on the elasticity of supply based on the relation between the percentage changes in median house price and the number of housing units in cities over the 1970 to 2000 period. The long time period was chosen to ensure full supply adjustment and the endogeneity of both number of units and the WRLURI index itself were dealt with by using instruments for both variables. Results show that while regulation is important, topographic features have a major role in lowering supply elasticity. All 20 of the MSAs with supply elasticities of unity or less have significant water features that interrupt development. Chicago, the city simulated in this research, has an estimated supply elasticity of 0.81 while the elasticity estimate for Washington, D.C. with its very intrusive height limits is 1.61. The highest supply elasticity is Wichita at 5.45, a figure at the median of the Green, Malpezzi, and Mayo, (2005) supply elasticity estimates.[9]

In sum, the empirical literature on the effects of regulation on housing costs has been based on models of effects on both price levels and supply elasticity. The empirical evidence suggests that effects on prices are positive and elasticities are negative. The addition of geographic limits on supply due to topography has produced complementary empirical results. However the presumption that geographic barriers, whether topographic or regulatory, should influence the elasticity of housing supply is based on the implications of a classical model of a city with no CBD rather than on a neoclassical SUM with a CBD which is the theoretical basis for the results presented here. Implications of regulation for wages has been inferred based on the weight of housing in the urban consumption bundle.

The effect of transportation infrastructure and regulations

There is no counterpart to the WRLURI for transportation. This means that, in empirical studies of the effects of geographic restrictions on housing supply, the quality and quantity of transportation infrastructure has resided in the error term. It is possible to measure differences in accessibility among locations within a given city. A vast literature has documented the positive effect of changes in accessibility on housing prices, but, of course, within cities, improving accessibility raises surrounding housing prices. Similarly, the literature on urban wage gradients indicates that there is a negatively sloped wage gradient within the city, while

[9] Recently Albouy et al. (2017) have used the WRLURI index to measure both housing price and wage effects of land use regulation. They conclude that regulation raises prices 15% with little effect on wages. Such empirical house price effects contrast sharply with the results of the simulation model presented here.

intercity analysis produces a positive association between commuting time and wages.

There is a literature on the effects of oil price shocks on urban housing markets. This also concerns differential effects within a given city and often involves tests of the SUM to determine if commuting cost increases make the bid rent curve for housing steeper. The initial contribution to this research was by Coulson and Engle (1987). More recently Molloy and Shan (2013) have identified a housing supply effect of gasoline price shocks and Larson and Zhao (2016) have affirmed the housing price effect using similar methods with a larger sample of cities and multiple oil and house price cycles.

All this empirical evidence is consistent with the prediction of the SUM that higher transportation costs throughout a city should, in equilibrium, increase the wage via a compensating differential, and constrain growth. The endogenous relation between congestion and other city characteristics has thus far thwarted efforts to estimate the causal relation between transportation infrastructure and other city characteristics such as housing prices and earnings. A final complication in such testing is Braesss paradox which states that, in complex systems with no congestion pricing, like urban transportation, it is possible to add infrastructure and have system performance deteriorate.

In view of all these challenges to empirical attempts to measure the causal relation between any of these three geographic determinants of limits on laissez faire housing supply, the alternative of using theory, in the form of an open city numerical urban simulation model, seems attractive. A further advantage of the simulation is that it generates estimates of the compensating variation needed to attract labor. This is particularly important because land use and transportation planning influence both housing and commuting costs, which together determine the size of the compensating variation in earnings.

3 Model Structure

The model framework in this paper is based on the standard urban model (SUM) of Alonso (1964), Mills (1967), and Muth (1969). The model has been extended to study the effects of different policies on urban spatial structure, including height limits (Bertaud and Brueckner, 2005, and Borck, 2016) and greenbelts (Larson, Liu, and Yezer, 2012). This research incorporates zoning regulation and transportation planning into the standard urban model to study the effects of these policies on urban density, the wage rate, and interactions and elasticities with respect to city size.

The Standard Urban Model

The city initially lies on a featureless plane, with no geological or regulatory features that would inhibit development. Firms occupy the central business district (CBD), and they exogenously demand E identical workers, which provides the impetus for households to locate and remain in the city. Along with ignoring amenity effects of planning, forcing all employment into the CBD provides and upper bound estimate of the costs of regulation. It also means that labor supply effects are captured by changes in a single number, CBD earnings.

An agricultural hinterland determines the reservation land rent at the edge of the city. Between the CBD and the hinterland reside the workers who commute to the CBD. Housing producers and households receive a reservation profit and level of utility, respectively, at every location inside the city. The city is uniform at every radius, allowing characteristics to be expressed in radial terms as a function of the distance from the CBD, k. The city is open and people are free to costlessly migrate within or across cities.

Housing Production

Housing H at distance k from the CBD, is produced by profit-maximizing firms, combining structure S and land inputs L under a constant returns to scale technology according to a CES production function with an elasticity of substitution of $1/(1-\rho)$.

$$H(k) = A\left[\alpha_1 S(k)^\rho + \alpha_2 L(k)^\rho\right]^{1/\rho} \tag{1}$$

Structure inputs are perfectly elastically supplied, but aggregate land input is fixed at each radius as the fraction of land available for residential development, θ.[10]

Households

All households are identical and consume two goods, rental housing h and a numeraire consumption good y, under a CES utility function.

$$U = \left[\beta_1 y^\eta + \beta_2 h^\eta\right]^{1/\eta} \tag{2}$$

[10]This model ignores the role of maintenance, rehabilitation and durability of structures in housing production.

β_1 and β_2 are related to consumption shares between the two arguments, and $1/(1-\eta)$ represents the constant elasticity of substitution between housing and the numeraire good. Household expenditure is divided among the numeraire good, $y(k)$, housing purchases, $r(k)h(k)$, and total transportation costs given by the product of workers per household, ϵ, and transportation costs per worker, $T(k)$.

$$w = y(k) + r(k)h(k) + \epsilon T(k) \tag{3}$$

Households maximize utility by choosing how much transportation cost they are willing to bear and how much numeraire and housing to consume, all of which vary by location.

The number of households in the city is N, which is equal to the integral of the density of households from the CBD to the edge of the city at radius $\bar{k}$.

$$N = \int_{k_{CBD}}^{\bar{k}} 2\pi\theta k D(k) dk \tag{4}$$

Cost of Commuting

Annual commuting costs for a household living at radius k include fixed costs of owning an operating an automobile m_0 (e.g. insurance, licensing), variable costs related to distance traveled (e.g. vehicle depreciation), nonlinear gasoline costs with price per gallon of p_g, and non-linear time-cost of commuting which is τ fraction of the wage rate. All workers commute to the CBD via automobile.

$$T(k) = m_0 + \left[m_1 k + p_g \int_0^k \frac{1}{G(V(M(\kappa)))} d\kappa + \tau W \int_0^k \frac{1}{V(M(\kappa))} d\kappa \right] \tag{5}$$

Both fuel and time cost is related to the velocity of the automobile at various locations in the city, which is in turn related to the ratio of traffic volume to roads. Following the common "Bureau of Public Roads" specification of the congestion function, velocity is expressed as

$$V(k) = \frac{1}{a + bM(k)^c} \tag{6}$$

where $M(k) = \overrightarrow{N}(k)/R(k)$, and a, b, and c are congestion parameters and $\overrightarrow{N}(k)/R(k)$ is the ratio of traffic passing through annulus k to roads. It is assumed that fraction of land area allocated to roads is uniform, therefore $R(k)$ is a constant fraction ψ of land area in each annulus. The traffic volume at radius k, $\overrightarrow{N}(k)$, is calculated as the sum of the commuting workers living at or beyond radius k.

$$\overrightarrow{N}(k) = \int_{k}^{\bar{k}} \epsilon 2\pi\theta k D(\kappa) d\kappa \tag{7}$$

Model Solution

The solution method follows Muth (1975), Arnott and MacKinnon (1977), Altmann and DeSalvo (1981), and McDonald (2009). The system of equations described above can be solved and reduced to one with two simultaneous differential equations with initial values. After a solution is obtained, the remaining gradients can be found recursively. The two-equation system of nonlinear differential equations includes marginal commuting costs and the household density at radius k.

$$\begin{bmatrix} \frac{dT(k)}{dk} \\ \frac{dN(k)}{dk} \end{bmatrix} = \begin{bmatrix} \left[(m_1 + p_g \frac{1}{G(V(M(k)))} + \tau w \frac{1}{V(M(k))})\right] \\ 2\pi\theta k D(T(k)) \end{bmatrix} \tag{8}$$

with initial values

$$\begin{bmatrix} T(k_{CBD}) \\ N(k_{CBD}) \end{bmatrix} = \begin{bmatrix} m_0 + k_{CBD} \left[m_1 + p_g \frac{1}{G(v_{low})} + \tau w \frac{1}{v_{low}}\right] \\ 0 \end{bmatrix}$$

After solving this system, it is possible to derive house prices, housing demand, land prices and structure/land ratios as a function of commuting costs and housing unit density, following Altmann and DeSalvo (1981).

There are two necessary conditions that then must be met. First, the land price at the edge of the city must be equal to the agricultural land rent $p_L(\bar{k}) = p_L^a$, and second, the number of workers in the city must be equal to the number of jobs available $\epsilon N = E$. If either of these equilibrium conditions is not met, the simulation is re-initialized and simulated again until subsequent iterations achieve an equilibrium solution.

Once these two necessary conditions are met, there is a third necessary condition required to close the model. The city is “open” as is typical in the familiar regional iso-utility framework. Yet, in order to determine the effects of imposing regulations on housing cost, it is necessary to hold population constant in the city. The solution is for firms to pay workers a compensating wage differential so the reservation utility is achieved and the population remains constant. Households are free to relocate across cities, but choose not to because w adjusts endogenously to achieve the reservation utility.

4 Calibration

The calibration of numerical urban simulation models is evaluated by comparing simulation outputs to characteristics of Chicago. The Chicago urbanized area is selected as calibration target due to its city size and low regulatory barriers. Gyourko, Saiz, and Summers (2008) report a low value for Chicago in the Wharton Residential Land Use Regulatory Index. In addition, Chicago urbanized area's population ranked No. 3 among all urbanized areas in the US. A large city was selected because of the concern that land use planning artificially raises housing costs in large cities. It should also be noted Chicago is not at long-run equilibrium. For instance, Helms (2003) reports on a steady pattern of gentrification in older areas with good transportation access. According to Saiz (2010), 60% of city area is available for development in Chicago due to the geographical constraint imposed by Lake Michigan and other features. This gives rise to a simulated city with the geometry shown in Figure 1, which shows the actual city of Chicago alongside a stylized monocentric city. The simulated city has a CBD, a residential district, and an agricultural hinterland with an arc angle of 216 degrees (60% of 360 degrees) to reflect the fraction of the circular area occupied by water. Finally, government forces play a significant role in causing the current form of Chicago to depart from that expected under laissez faire.

Parameter calibration is performed following the literature on numerical urban simulations. These parameter values are shown in Table 1. The housing and utility parameters are close to those found in Altmann and DeSalvo (1981), which gives elasticities of substitution between structure and land inputs in the housing production function, and housing and the numeraire consumption good, of 0.75 in both equations. Land shares to housing and roads are similar to Muth (1975), as well as the speed parameters in the congestion function. Fixed and marginal commuting costs are from the American Automobile Association. The time cost of commuting is set to 30% of the wage. The reservation agricultural rental price per acre per year is $300.

Results of the simulation calibration are shown in the final column of Table 3. The baseline city consists of 3,169,562 households, with an assumed CBD radius of 2.5 miles, and a total developed radius, including the CBD, of 27.36 miles– lower than the Chicago city average of 36 miles (assuming a circular city, given the land area). Median income is set at $65,649 per year in the simulation based on the data. Commutes are slightly longer in the simulation, at 32.91 minutes per trip compared to city average of 32 minutes. Average unit size is about 1,499 sq. ft. compared to 1,500 in Chicago, with an average single-family lot size of 0.21 acres in the simulation. Generally, the simulation fits the composite city quite well, with the exception of the city radius. This difference is the product of two effects. First, simulations with only one income group tend to produce cities with a smaller land area than those in the real-world (Altmann and DeSalvo, 1981). Second, the laissez faire simulation abstracts from problems of violent crime and poor public services that reduce central densities in some inner-city areas.

Figure 2 shows visually the within-city simulation outputs. Price gradients tend to fall with proximity pursuant to Muth's equation relating transportation costs to house prices. Traffic congestion causes vehicle velocity to fall as the journey to the CBD becomes closer to the CBD. Accordingly, traffic times increase with distance in a non-linear fashion. Density also falls with distance to the CBD.

It is also possible to calibrate the city with respect to city size elasticities. When the city population changes, several variables can be evaluated to determine whether the simulation is producing reasonable outputs. Using each decennial census between 1970 and 2000, a simple reduced form (i.e. long-run) model is estimated for three city-level variables—household income, home values, and housing rents— alongside population, where each is measured in natural logs:

$$y_{it} = a_t + \beta population_{it} + \epsilon_{it} \tag{9}$$

As discussed previously, and outlined in detail in Glaeser and Mare (2001), this specification has a host of issues. In particular, aggregation bias, omitted variable bias, and endogenous sorting of household types due to city-level amenity and productivity differences confound this specification. Nonetheless, this model produces estimates which should give a rough indication of empirical elasticities with respect to population.

Table 2 presents estimates from Equation 9. With respect to city size, the elasticity of income is about 0.09, home value is about 0.13, and rent is about 0.08. In the simulation model, the elasticities produced are 0.12, 0.07, and 0.04, respectively (see Table 3). Given that the estimated elasticities are developed using data from a cross-section of cities and the model is calibrated specifically to Chicago, this level of agreement is remarkably close.

5 Results

Three main classes of counterfactual scenarios are considered in this section. Each alters one aspect of the baseline city introduced previously in order to determine the general equilibrium effects, *ceteris paribus*. The three types of restrictions considered include a reduction in the supply of land for housing, a restriction of the floor-area ratio (FAR), and reduced land use for commuting roads. These changes are discussed in turn.

Geographic land use restrictions, whether due to topography or zoning, are most straightforward. Indeed, the baseline simulation includes an adjustment for the fact that Lake Michigan cuts off almost half of the land area that would be available if Chicago were located on a featureless plane. The fraction of land available for housing in each annulus, θ, is adjusted for the presence of the lake by lowering θ from the normal level of 0.33 on a featureless plane to 0.2 (-40%). This is a common procedure in simulation models. The effect of further restrictions due to zoning regulations, is generated by lowering θ below 0.2.

Building restrictions on FAR are imposed consistent with the prevailing view that planners, or at least the political system within which they operate, consider market forces. The FAR at each location associated with the laissez faire model solution sets the standard for unregulated development. Then, at locations selected within the city, that FAR is reduced by a given percentage. Thus the FAR regulation is expressed as an area-specific fraction of the laissez faire density.

Transportation system restrictions are based on departures from the infrastructure that generates the laissez faire city. Over selected exogenous segments of the journey to work, restrictions on transportation infrastructure are imposed by reducing the fraction of land available for roads used for commuting transport. The consequent increase in congestion slows vehicle speeds through those regions. The effects of transportation regulation are accordingly very non-linear because they are based increases in congestion. Restrictions imposed some distance from the CBD have less effect because, although substantial land is diverted away from transportation, the initial levels of congestion are low and hence the increase in congestion is modest.

The individual effects of the three types of geographic effects are discussed below. Because there is a concern with the effects of regulations on labor supply, special attention is given to the effects on the compensating variation, compared to laissez faire, in earnings of workers required to hold population of the open city constant. For those interested in consequences for the housing market, the change in the price and quantity of housing consumed at the edge of the CBD are noted. In addition, effects on median and mean housing price are presented in order to demonstrate the effects of differences in location of regulation on these price changes. The implication of these results is that the effects of regulations on median or mean housing prices give a misleading representation of the actual effect on prices which should be measured holding location constant. The primary issue is that land use regulation alters the location of the mean and median housing unit in a fashion that has been ignored in the empirical literature.

Because much of the empirical literature has attempted to estimate the effects of geographic restrictions on the elasticity of housing supply, a series of exercises are simulated in which earnings are increased sufficiently to raise city population by 10%. The elasticity of city size, and the price and quantity of housing consumed at the CBD are then noted under laissez fair. The effect of regulation on these elasticities is then computed as the difference in the elasticity under regulation and laissez faire. As noted above, these differences are often very small because, in the SUM, geographic restrictions create differences in levels rather than differences in elasticities. It is very much like dropping a marble and a cannon ball, both land at the same time but the cannon ball has much more energy and momentum because its mass is larger.

Effects of restrictions on the fraction of land used for housing

Topography and zoning already limit the availability of land for housing in Chicago so that the initial value of θ in the laissez faire simulations of the city is 0.2. The top portion of Table 6 shows the departure from laissez faire when θ is successively reduced to 0.18 and 0.16, with earnings rising sufficiently to maintain population constant. Land available for transportation at each radius is not changed in this exercise and the city predictably sprawls. Restricting land for housing raises density, with the city experiencing approximately equal proportions of size and density increases as land used for housing falls while households per unit land rises. Note that the increase in earnings required to compensate workers for living in the city is quite modest, less than 1% even in the case of the reduction to 0.16. While the city radius rises by 5.7% in this case, average commuting time to work only rises 1.67% because of the increase in density. The fall in the average size of housing units is also less than 1% in response to the 2% rise in housing price at the CBD. Overall these results indicate that changes in θ, whether due to topography or zoning restrictions, have a relatively small effect on the ability of the city to attract workers while effects on city form are significant. This is consistent with the observation that the largest U.S. cities have grown in spite of having substantial topographic barriers imposed by water features.

The bottom portion of Table 6 shows the effect of restrictions on residential land for the elasticity of wages and house prices with respect to the number of housing units. A wage shock sufficient to achieve a 10% increase in households is imposed on the simulation under with θ set respectively at 0.2, 0.18, and 0.16. The elasticity of the earnings with respect to households under laissez faire is 0.12, and the elasticity of housing space supply is 0.97

because housing space per household falls slightly.[11] In the table, housing price elasticity is reported at the edge of the CBD (0.14) and for the median housing unit (0.07). The implied elasticity of housing supply with respect to the price of housing at the CBD is 0.97/0.14 = 6.8, and for the average housing unit it is 0.97/0.07 = 14.6. The next two columns of Table 6 demonstrate that differences in θ have little effect on any of these elasticities. This suggests that empirical testing for the effects of variation in θ due to either topography or regulation should be based on differences in the level of housing prices or earnings rather than on differences in the elasticity of earnings or house prices with respect to these variables. The land use regulation changes the level of earnings required to compensate workers but not the elasticity of that compensation with respect to city size.

Effects of restrictions on FAR

Only restrictions on FAR that are binding on the housing market have real effects and more binding regulations should have larger effects. Location should also matter. In order to standardize the degree to which FAR regulation is binding where it is imposed, in the simulations, FAR is scaled to be 50% of the laissez faire density. In any location where FAR regulation is not imposed, the housing market is allowed to respond fully to the housing price that prevails in that location. This allows housing density to rise in areas which are not regulated producing a potentially irregular pattern in both housing density and land rents. Of course, the compensating variation in earnings is well-defined because earnings are measured in the CBD but the effects on wages vary with the location of the FAR regulation.

Figure 2 shows the relation between the laissez faire city and three alternative patterns of FAR restrictions in an open city where earnings are adjusted to maintain population constant. In each case FAR is cut to half the laissez fair level over a restricted part of the city. The three cases involve FAR restrictions on the intervals [0,5], [0,10] and [5,15] miles from the edge of the CBD which itself has a radius of 2.5 miles.[12] Note in the first panel of the figure that FAR restriction shifts the housing price profile vertically because it has

[11] These results are all standard properties of the neoclassical SUM. See Liu, 2018) for both a general proof that, in an open city SUM, average housing consumption falls with rising CBD wages and an empirical test that demonstrates this result holds in the data.

[12] A city with an inner-region FAR restriction resembles present-day Washington, DC, which has a height limit and restrictive historical designations throughout the District, which occupies the CBD and several radial miles of housing. Outside the district, but still within the metropolitan area, regulations are much more relaxed, and correspondingly, maximum density is much higher (see Rosslyn, VA, Silver Spring, MD, and Rockville, MD). Other cities in this class include major European cities such as Dublin, Amsterdam, Paris, and London (to name several) with large historic center cities.

no effect on Muths equation. This contrasts with the land price and housing density effects where FAR lowers land values and density where is it imposed and raises them elsewhere. In contrast to these massive effects on the physical form of the city, FAR leaves commuting times little changed although the successive regulation of increasing amounts of land causes the city to sprawl further and commuting distances to increase.

Table 4 compares the land use, commuting, and house price effects of the three FAR restrictions. Some effects are proportional to the increasing amount of land affected by the policy. For example, the compensating variation in earnings is 0.59%, 1.51%, and 2.39% as the restriction moves from the [0, 5] through the [5, 15] interval, while the housing price at the CBD rises by 1.5%, 3.8%, and 6.1%, and city area increases by 7%, 21%, and 29%. Average density falls uniformly as the quantity of land regulated rises.

Other effects are far from uniform. Median rent falls when FAR near the CBD is restricted and rises when the FAR restriction is moved toward the suburbs. This illustrates that FAR restrictions can either raise or lower the median price of housing units depending on where the restriction is enforced. The presumption that FAR restrictions have a positive effect on measured median house price appears to rest on the assumption that these restrictions are imposed in the suburbs and do not restrict densities significantly near the CBD. Strict imposition of limits on FARs near the city center raises densities in the outer portions of the city where housing prices are lower. This can result in lower median housing price even if prices near the CBD rise. FAR regulation has a location and housing composition effect as well as a pure price effect. This appears to have been neglected in the literature on the effects of FAR regulation where testing has been based on the relation between changes in mean or median housing value or rent rather than rent at the CBD.

The results in Table 4 illustrate that, while FAR regulation has a positive effect on wages, ranging from 0.59% to 2.39% as the area influenced moves from [0, 5] to [5,15],and on CBD housing price, again ranging from 1.49% to 6.10%, the effect on average housing prices is only positive when the regulation is imposed on the [5,15] interval, while it is negative when FAR begins at the edge of the CBD in the other two alternatives. Similarly the effect of zoning on total square footage supplied is positive when FAR is imposed near the city center and only negative when the regulation is concentrated in the [5, 15] ring. Put another way, these results indicate that discussion of a general relation between FAR regulation and either the average price or quantity of housing supplied is a vexed question because the answer depends entirely on the location of regulation. The important question for effects on labor market efficiency, is the effect of the regulation on the required wage to attract labor and those effects range from 0.59% to 2.39% for the examples considered here.

The bottom portion of Table 4 shows the elasticity of various city characteristics with respect to changes in city size. As was the case with Table 6 where θ was changing, these elasticities do not vary significantly with the nature of FAR restrictions except in the case of mean house price effects where elasticities vary substantially because of the measurement problems when the spatial composition of housing units varies. Specifically the earnings elasticity of size is approximately 0.12 and elasticity of interior space supply 0.97 regardless of FAR regulation. As was the case with variation in the fraction of land used for residences, the effect of FAR regulation is on the level of housing prices rather than the elasticity of price change in response to city growth.[13]

The final right side column of Table 4 contains the results of a simulation exercise designed to reveal the possible effects of FAR regulation implemented throughout the city. The FAR regulation is set at 50% of laissez faire until it falls to a value of 0.05, which is approximately one acre minimum lot zoning. At that point, the FAR regulation is stabilized. Based on the discussion of the WRLURI index in Gyourko, Saiz, and Summers (2008), this level of density restriction exceeds that found in any U.S. city. The simulation is designed to produce the maximum effect possible effect on earnings that could be associated with FAR regulation assuming that it produces no external benefits associated with better urban design. The compensating variation in earnings associated with this universal application of FAR to the city is 15.2%. Because the regulation is binding throughout virtually all of the city, both the average price of housing (+23%) and the price per square foot at the CBD (+41%) rise. The city area and more than doubles as the city sprawls in this extreme example. In order to achieve such an extreme result, the FAR regulation must be applied throughout the city in spite of the financial incentive for individual jurisdictions to defect and raise their land values as happens in the areas that are not regulated in Figure 2.

Effects of restricting transportation infrastructure

Because the simulation model allows the highways to become congested, slowing traffic velocity, commuting costs are sensitive to the fraction of land allocated to roads, which

[13]Two different experiments were performed to supplement the exercise in Table 4. In the first exercise, the effects of regulations reducing laissez faire FAR by 50% was examined over the intervals [0, 5], [0, 10], and [5, 10] in order to illustrate the difference in effects on CBD housing price and unit size versus the effects on average price and unit size. However, in this exercise, the amount of land regulated increases. The intervals [0, 5], [5, 7.8], and [7.8, 10] produce a pure locational effect holding the quantity of land regulated constant. The same patterns of sign reversal are found in this exercise but the sizes of the differences are attenuated because land area regulated is held constant.

is 15% in the baseline simulation. The shock to transportation infrastructure implemented here is accomplished by reducing the fraction of land to 10%, or a 33% decrease. Table 5 compares the city under the 15% allocation and various restrictions on infrastructure to 10%, which can be implemented at different distances from the CBD. The most extreme scenario reduces land for transportation throughout the city while other alternatives reduce land to 10% on the [0, 1] and [1, 2] mile intervals from the edge of the CBD. The most obvious result of the exercise is that the reductions in the first mile from the CBD are most consequential. For example the earnings effect of infrastructure restriction over the entire city is 4.74% and for the first mile only it is 4.32%. Restricting transportation infrastructure makes the city denser and smaller as housing supply contracts and prices rise.

This creates the false impression of a negative supply elasticity as, in the case of a uniform fall in land for transportation, total supply falls 0.17%, while the price at the CBD rises 3.24%. In this case, average house prices rise only 0.41% although the average unit moves close to the CBD. This result is due to the increase in the transportation cost per mile, which causes the house price gradient to become much steeper. In the case of transportation restrictions, the effects on labor supply are captured in a straightforward way through earnings increases. The housing cost effects are complicated by the shift in the slope of the price gradient along with the change in location of the average and median housing units.

The bottom part of Table 5 shows that restrictions on transportation infrastructure have a dramatic effect on the elasticities of earnings and other city characteristics with respect to city population. In the baseline case, the elasticity of earnings with respect to city population is 0.12. Transportation restrictions dramatically increase the elasticity of earnings with respect to labor supply. There is also a significant change in the elasticity of central population density as transportation restrictions increase the slope of the housing price gradient, resulting in a more compact city.

6 Conclusion

The general theoretical results obtained from a neoclassical open city model differ substantially from those obtained from empirical testing. First, restrictions on land use and housing density are shown to influence the level but not the elasticity of housing cost or compensating variation in earnings with respect to city households. Second, the empirical relation between the median or mean price of housing in a city and land use regulation is confounded by composition effects: regulation—both land use and density— alters the spatial distribution of housing in a city, affecting the mean and median locations. Regulations that lower central density and force households to live further from the CBD can lower median house price but raise the compensating variation in earnings needed to maintain housing supply. Third, transportation infrastructure restrictions, which are an omitted variable in empirical studies of housing cost and land use and zoning regulation, can have a substantial effect on housing cost and on the compensating variation in earnings required to attract labor. Finally, unlike land use and density restrictions, limits on transportation infrastructure raise the elasticity of earnings with respect to city size in a fashion that has implications for continued growth of urban giants.

Specific results from the simulation model have additional implications for the hypothesis that planning decisions are restricting the growth of high-productivity cities. First, removing a fraction of land from housing and using it for open space or other public purposes has only a small, positive effect on the compensating variation in earnings even under the strong assumption that this type of planning has no amenity effect.[14] Second, introduction of binding density restrictions, set at 50% of laissez faire FAR, results in a relatively small (less than 3%) increase on the compensating variation because regulation in one part of the city simply raises density in other locations. Only when restrictive regulations are implemented throughout the entire city is the effect on labor supply substantial. Finally, limits on transportation infrastructure can have a dramatic effect both in levels on the compensating variation and on the elasticity of labor supply to the city.[15] In sum, concern over the relation between planning and the cost of raising labor supply in large cities should focus on transportation rather than land use planning except in cities where planning restrictions are both binding and implemented everywhere.

[14] A positive amenity would reduce the compensating variation.

[15] A further point is that while land use planning may have aesthetic benefits that lower the required compensating variation, restrictions on transportation infrastructure likely have smaller amenity effects.

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Figure 1: Chicago, Actual and Simulated

(a) Satellite Map

(b) Simulated

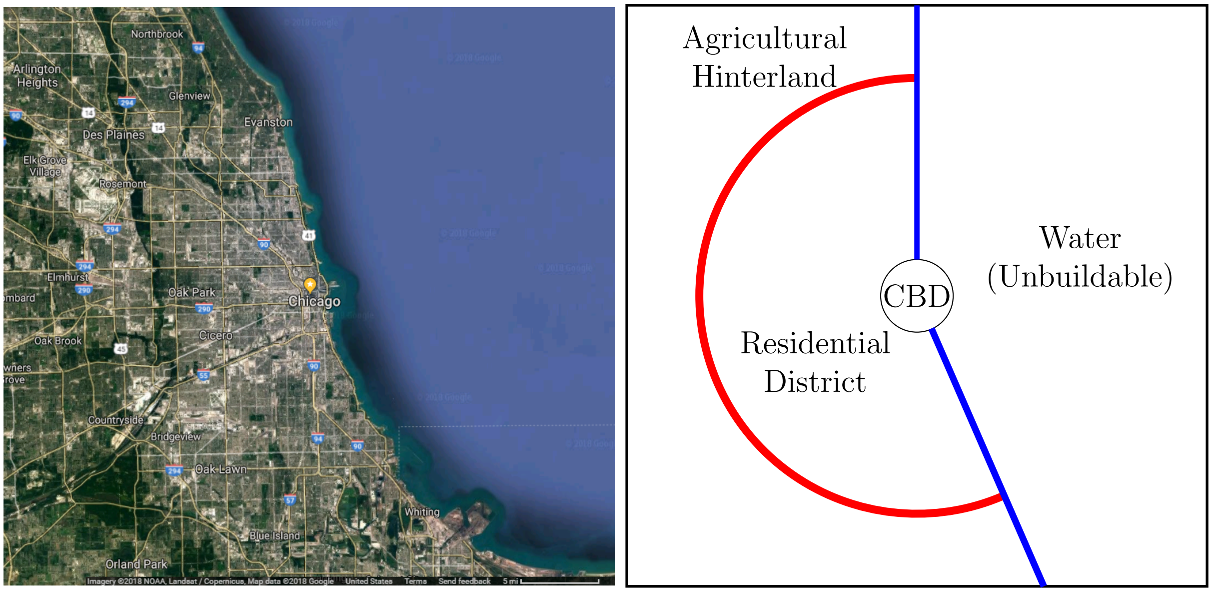

Figure 2: Baseline and FAR Restriction Simulations

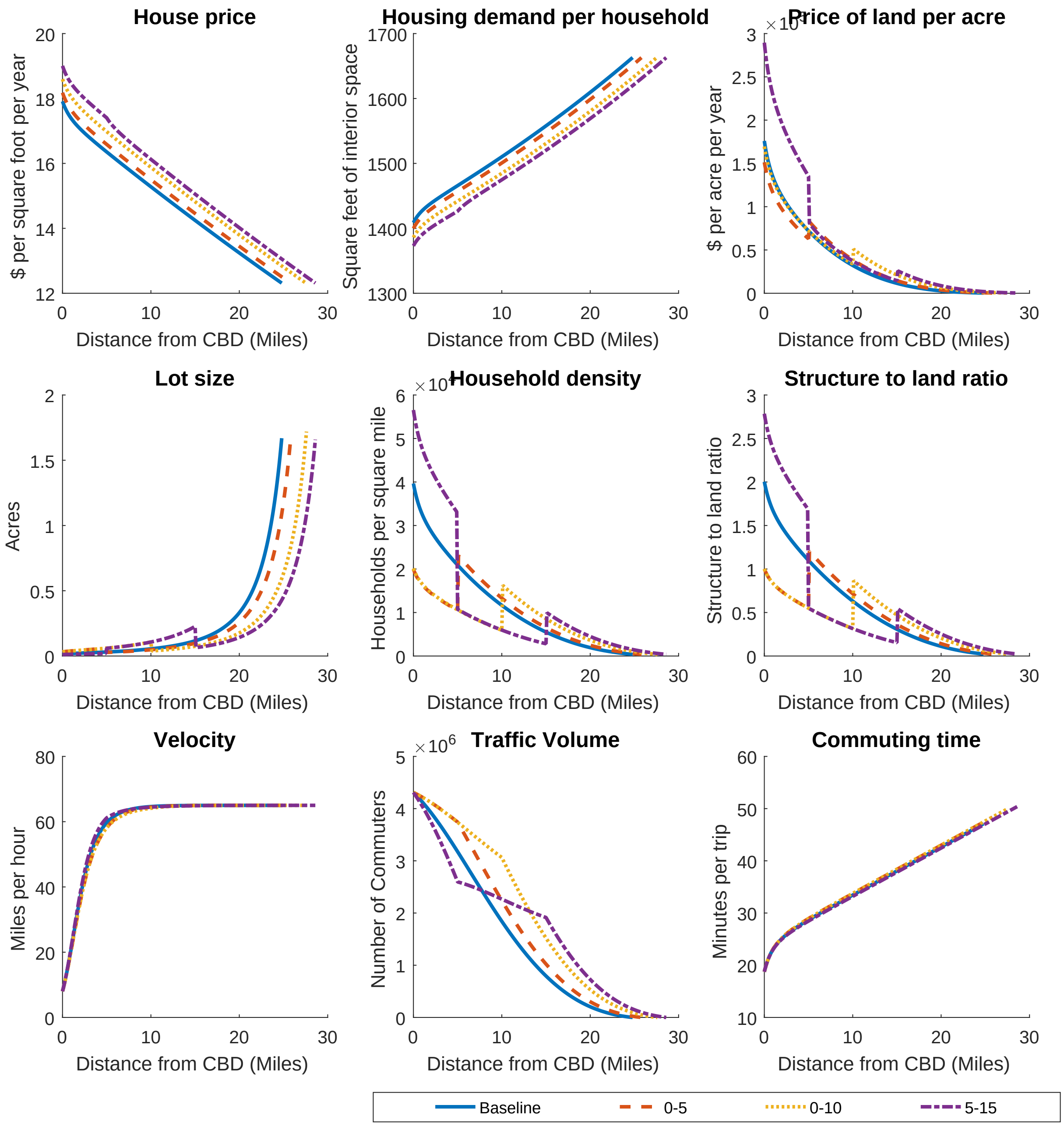

Table 1: Simulation Parameters

Parameter	Baseline Value	Description	Source
City Income and Size			
W	65,649	Annual earnings	American Community Survey
N	3,169,562	Households	American Community Survey
Housing Production			
$1/(1-\rho)$	0.75	Elasticity of substitution	Altmann and DeSalvo (1981)
α_1	1	Structure share	Muth (1975); Altmann and DeSalvo (1981)
α_2	0.04	Land share	calibrated; Muth (1975); Altmann and DeSalvo (1981)
A	0.09	Technology parameter	Calibrated
Household Utility			
$1/(1-\eta)$	0.75	Elasticity of substitution	
β_1	1	Numeraire share	Numeraire
β_2	0.25	Housing share	American Community Survey, Calibrated
Land Use			
θ	0.2	Fraction of land used for housing	Muth (1975)
k_{CBD}	2.5	Radius of the CBD	Muth (1975)
p_L^a	300	Reservation agricultural land rent per acre	Bertaud and Brueckner (2005)
Transportation			
v_{low}	8	Minimum commuting speed	calibrated
v_{high}	65	Maximum commuting speed	calibrated
c	1.75	Parameter in speed function	Muth (1975)
τ	0.3	Commuting time cost fraction of income	Bertaud and Brueckner (2005)
p_g	2.5	Gasoline price (USD) per gallon	Energy Information Administration
m_0	2,654	Fixed cost of commuting	American Automobile Association
m_1	0.222	USD per mile of depreciation	American Automobile Association
V_c	0.822	Miles per gallon constant term in polynomial	American Automobile Association

Note: This table presents the parameters used in the calibration of the model. Values are approximate to those from the cited source where available and calibrated with respect to model output.

Table 2: Estimates of City Size Elasticities

	Dependent variable: log(*Column Variable*)		
Model:	[1] Median HH Income (log)	[2] Median Home Value (log)	[3] Median Housing Rent (log)
Population (log)	0.0867*** [0.00434]	0.126*** [0.00851]	0.0792*** [0.00433]
Decade Fixed Effects	Yes	Yes	Yes
Observations	1,324	1,324	1,324
R-squared	0.937	0.843	0.935

Notes: Robust standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The sample includes a balanced decadal panel of 331 MSAs (1998 definitions) between 1970 and 2000 from the Decennial Census. Decade fixed effects are included in all specifications.

Table 3: Calibration

City Characteristics	Chicago Urbanized area	Simulation
Occupied Units	3,169,562	3,169,562
Population	8,660,237	8,660,237
Lot Size (acres, detached mean)	0.21	0.21
Housing Unit Size (sqft, median)	1500	1499
City Radius (miles)	36	27.359
Time to work (minutes, mean)	32.0	32.9
Median Income	$ 65,649	$ 65,649
City Size Elasticities	Decade Panel	Simulation
Median Income	0.09	0.12
Median Home Value	0.13	0.07
Housing Rent	0.08	0.04

Notes: This table presents values from the Chicago urbanized area from the American Community Survey/Decennial Census and the American Housing Survey, alongside simulation output from the calibrated model. The empirical city size elasticities are from Table 2.

Table 4: Density Restriction

	————*Baseline City Size*————				
	Baseline	Floor-Area Ratio -50%			
		0-5 miles	0-10 miles	5-15 miles	Everywhere
Simulation Model	[1]	[2]	[3]	[4]	[5]
Unit Size (Average)	1,506	0.31%	0.37%	-1.21%	-8.17%
Housing Stock (Sq. Ft., Millions, Sum)	4,774	0.28%	0.40%	-1.24%	-8.26%
Land Price (Acre, CBD)	$ 175,945	-13.99%	-3.62%	64.54%	163.96%
Land Price (Acre, Average)	$ 19,450	1.21%	3.93%	11.18%	15.32%
Land Price (Acre, Median)	$ 39,828	-7.90%	-17.65%	-27.47%	3.33%
House Price (Sq. Ft, CBD)	$ 17.91	1.49%	3.82%	6.10%	41.54%
House Price (Sq. Ft, Average)	$ 15.40	-0.70%	-0.82%	3.05%	23.11%
House Price (Sq. Ft, Median)	$ 15.54	-0.65%	-1.52%	1.68%	31.60%
FAR (CBD)	2.00	-50.00%	-50.00%	38.97%	-50.00%
Residential Density (HH/Sq. Mi.)	2,246	-7.20%	-17.93%	-23.11%	-74.61%
City Area (Sq. Mi.)	1,411	7.01%	21.05%	29.23%	292.49%
Time to work (Average)	32.91	4.62%	9.87%	3.68%	34.62%
Wage Rate	$ 65,649	0.59%	1.51%	2.39%	15.26%
	Baseline	Floor-Area Ratio -50%			
		0-5 miles	0-10 miles	5-15 miles	Everywhere
Simulation Model	[1]	[2]	[3]	[4]	[5]
Unit Size (Average)	-0.71	-0.80	-0.90	-0.84	-1.41
Housing Stock (Sq. Ft., Millions, Sum)	0.97	0.98	0.97	0.97	0.92
Land Price (Acre, CBD)	1.33	0.81	0.78	1.43	1.33
Land Price (Acre, Average)	0.77	0.60	0.64	0.61	0.22
Land Price (Acre, Median)	0.85	0.74	0.70	-0.97	-3.07
House Price (Sq. Ft, CBD)	0.14	0.15	0.16	0.17	0.56
House Price (Sq. Ft, Average)	0.07	0.06	0.05	0.07	0.24
House Price (Sq. Ft, Median)	0.07	0.06	0.05	-0.02	0.25
FAR (CBD)	0.86	0.00	0.00	0.91	0.00
Residential Density (HH/Sq. Mi.)	0.53	0.41	0.51	0.46	-0.49
City Area (Sq. Mi.)	0.45	0.57	0.47	0.52	1.57
Time to work (Average)	1.27	1.25	1.23	1.22	1.40
Wage Rate	0.12	0.12	0.12	0.13	0.29

Notes: This table presents simulation output from five different models. Column 1 represents the baseline model which is calibrated with respect to Chicago. Columns 2 through 5 represent model output under counterfactual simulation parameters.

Table 5: Reduced Roads

	Baseline City Size			
	Baseline	-33% Roads		
		Everywhere	0-1 Miles from CBD	1-2 Miles from CBD
Simulation Model	[1]	[5]	[6]	[7]
Unit Size (Average)	1,506	-0.17%	-0.09%	-0.02%
Housing Stock (Sq. Ft., Millions, Sum)	4,774	-0.17%	-0.09%	-0.02%
Land Price (Acre, CBD)	$ 175,945	31.62%	20.71%	3.49%
Land Price (Acre, Average)	$ 19,450	3.59%	2.30%	0.33%
Land Price (Acre, Median)	$ 39,828	3.11%	2.30%	0.18%
House Price (Sq. Ft, CBD)	$ 17.91	3.24%	2.19%	0.39%
House Price (Sq. Ft, Average)	$ 15.40	0.41%	0.22%	0.04%
House Price (Sq. Ft, Median)	$ 15.54	0.25%	0.18%	0.01%
FAR (CBD)	2.00	19.98%	13.31%	2.31%
Residential Density (HH/Sq. Mi.)	2,246	2.02%	1.45%	0.12%
City Area (Sq. Mi.)	1,411	-1.98%	-1.43%	-0.12%
Time to work (Average)	32.91	67.77%	62.36%	3.38%
Wage Rate	$ 65,649	4.74%	4.32%	0.15%

	Elasticity WRT City Size			
	Baseline	-33% Roads		
		Everywhere	0-1 Miles from CBD	1-2 Miles from CBD
Simulation Model	[1]	[5]	[6]	[7]
Unit Size (Average)	-0.71	-0.84	-0.80	-0.73
Housing Stock (Sq. Ft., Millions, Sum)	0.97	0.96	0.97	0.97
Land Price (Acre, CBD)	1.33	1.86	1.60	1.65
Land Price (Acre, Average)	0.77	0.85	0.82	0.80
Land Price (Acre, Median)	0.85	0.91	0.89	0.87
House Price (Sq. Ft, CBD)	0.14	0.21	0.18	0.18
House Price (Sq. Ft, Average)	0.07	0.08	0.07	0.07
House Price (Sq. Ft, Median)	0.07	0.07	0.07	0.07
FAR (CBD)	0.86	1.19	1.03	1.06
Residential Density (HH/Sq. Mi.)	0.53	0.57	0.56	0.54
City Area (Sq. Mi.)	0.45	0.41	0.42	0.44
Time to work (Average)	1.27	1.49	1.48	1.28
Wage Rate	0.12	0.21	0.19	0.13

Notes: This table presents simulation output from five different models. Column 1 represents the baseline model which is calibrated with respect to Chicago. Columns 2 through 5 represent model output under counterfactual simulation parameters.

Table 6: Reduced Land for Housing

	————*Baseline City Size*————		
	Baseline	Land for Housing	
		−10%	−20%
Simulation Model	[1]	[8]	[9]
Unit Size (Average)	1,506	-0.26%	-0.61%
Housing Stock (Sq. Ft., Millions, Sum)	4,774	-0.28%	-0.61%
Land Price (Acre, CBD)	$ 175,945	0.97%	2.09%
Land Price (Acre, Average)	$ 19,450	0.60%	1.41%
Land Price (Acre, Median)	$ 39,828	0.71%	1.47%
House Price (Sq. Ft, CBD)	$ 17.91	0.40%	0.82%
House Price (Sq. Ft, Average)	$ 15.40	5.84%	12.73%
House Price (Sq. Ft, Median)	$ 15.54	5.31%	12.84%
FAR (CBD)	2.00	5.84%	12.73%
Residential Density (HH/Sq. Mi.)	2,246	-5.20%	-10.50%
City Area (Sq. Mi.)	1,411	4.75%	11.67%
Time to work (Average)	32.91	0.04%	1.67%
Wage Rate	$ 65,649	0.39%	0.83%

	———*Elasticity WRT City Size*———-		
	Baseline	Land for Housing	
	Everywhere	−10%	−20%
Simulation Model	[1]	[8]	[9]
Unit Size (Average)	-0.71	-0.72	-0.73
Housing Stock (Sq. Ft., Millions, Sum)	0.97	0.97	0.97
Land Price (Acre, CBD)	1.33	1.32	1.31
Land Price (Acre, Average)	0.77	0.71	0.78
Land Price (Acre, Median)	0.85	0.82	0.86
House Price (Sq. Ft, CBD)	0.14	0.15	0.15
House Price (Sq. Ft, Average)	0.07	0.07	0.07
House Price (Sq. Ft, Median)	0.07	0.07	0.07
FAR (CBD)	0.86	0.86	0.85
Residential Density (HH/Sq. Mi.)	0.53	0.47	0.54
City Area (Sq. Mi.)	0.45	0.51	0.44
Time to work (Average)	1.27	1.26	1.25
Wage Rate	0.12	0.12	0.12

Notes: This table presents simulation output from five different models. Column 1 represents the baseline model which is calibrated with respect to Chicago. Columns 2 through 5 represent model output under counterfactual simulation parameters.