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General Equilibrium Impacts of an Urban Growth Boundary: Application of RELU-TRAN2 to the Chicago MSA

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ABSTRACT

Urban growth boundaries (UGBs) are aimed at limiting the outward expansion of urban areas and are often proposed by planners as a means of containing urban sprawl, inducing urban compactness and intensifying the use of public transit. Economists have been critical of the impacts of UGBs, reasoning from basic principles that they raise rents and make housing within the boundary less affordable, that they increase congestion within the boundary and might well cause economic activity to leave the urban area for other places. There exist some theoretical analyses of the effects of UGBs, but this paper is the first attempt to apply an empirical computable general equilibrium model, RELU-TRAN2, to a systematic analysis of the effects of UGBs. We use the model to evaluate the impacts of hypothetical UGBs imposed on the Chicago MSA's outer suburban ring. Varying the tightness of the UGB, that is increasing the amount of land excluded by the UGB from development, we can see how the UGB impacts the values of residential and non-residential buildings and their rents within the UGB. We can also see how wages, public transit use, road congestion, construction and demolition flows and commuting and other travel behavior within the MSA are affected. The tighter the UGB, the more negative the effect of the UGB on consumer welfare: the utility of each income quartile decreases monotonically with UGB tightness. The main reason for this is that the UGB increases rents significantly in the outer suburban ring, causing consumers to relocate inward in less attractive residence locations and in smaller housing units. The UGB has negligible effects on transit use, congestion trip making and travel behavior, fuel consumption and CO2.

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1. Introduction

Urban growth boundaries (UGBs) have been proposed and implemented in many parts of the world as tools for containing sprawl and urban expansion. On the one hand, planners believe that UGBs are an effective tool for creating compact cities with higher density in land use, that UGBs increase the use of public transit, and reduce some infrastructure provision costs such as the supply of suburban roads to serve ever expanding urban areas. Economists, on the other hand, are naturally skeptical. Even the most rudimentary economic reasoning suggests that in a city closed in population, UGBs would result in higher rents within the UGB, by restricting the supply of land available to meet the demand for floor space. In an open city, population and businesses may move out and relocate to other cities.

Indeed, for a UGB to create benefits, it is necessary that there be an existing inefficiency that arises from a market failure or from a tax-induced distortion that causes an urban area to be more sprawled than is optimal. Then, a UGB could work as an imperfect (lower best) policy instrument that by restricting expansion offsets in part the existing inefficiency or distortion. Starting from such a premise, economists in the late 1970s and early 1980s (Kanemoto (1977), Arnott (1979) and Pines and Sadka (1985)), extended an insight originally due to Solow (1972) and showed that an optimally designed UGB that restricts urban expansion reduces the excess sprawl that is present in a monocentric city with un-priced road congestion. In the absence of the Pigouvian tolling of congestion, therefore, a UGB can be a second best policy to alleviate congestion. This result, while elegant, it relies on the urban area being monocentric that is having all of its jobs situated in a high density downtown CBD (central business district). Such a situation was far from being true for the most and latter part of the twentieth century. Most urban areas, especially larger ones but not only, are far from being monocentric. Jobs are largely

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dispersed throughout or concentrated in a number of employment centers of which the downtown CBD is only one. However, since the tools needed to rigorously model urban areas with dispersed and polycentric employment were not available at the time interest on the issue appeared to have waned until recently.

The issue became of interest again when Anas and Rhee (2006) applied a model of dispersed employment to an urban area with road congestion. In this model, based on a theory that recognizes realistic dispersion of trips, jobs and mixed productive and residential land use, it was possible to observe that higher congestion in the urban core causes jobs to spread to the suburbs. Congestion, therefore, can be reduced with Pigouvian tolls without necessarily making the city more compact but instead by making it more spread out. The authors obtained the result by numerical simulations, that on such an urban area installing a UGB is absolutely harmful. There are additional aspects of their model that reinforce this result. In their model the urban area is composed of discrete geographic places with unique features and character. Consumers have idiosyncratic tastes for the different places and, at equilibrium they are matched to their most-preferred residential locations. Consider then those located in an edge town that comes under the restriction of the UGB. Some residents are forced out and find it necessary to relocate to less desired places and paying higher rents in the process. Their welfare losses influence the outcome that the UGB is absolutely harmful. If the attachment of such consumers to the edge town is very strong, then they are unwilling to move out but instead they endure the very high rents. This again militates against the UGB carving out a welfare gain. It may indeed slightly reduce overall traffic congestion by pushing people together and shortening the travel distance between jobs and residences, though it will increase congestion per mile unless sufficient trips switch to transit if it is available. But the other costs of the UGB work against any welfare gain. In a simplified version of their model (Anas and Rhee, 2007), the authors did show that pricing traffic congestion can cause either a more compact or a more dispersed city, the latter occurring when jobs decentralize enough in response to congestion pricing. In such cases a restrictive UGB is harmful and an expansive UGB (that is, a sprawl-inducing one) that carves out land from farming and puts it into the urban use can provide a benefit.

2. The RELU-TRAN CGE Model

RELU-TRAN is a computable general equilibrium (CGE) model, calibrated and tested for the Chicago, MSA. The model's structure and equation system are described in Anas and Liu (2007). RELU-TRAN2, developed by the authors, is an extension of RELU-TRAN in which the travel behavior of the consumer has been enriched by treating the choice of automobile type by fuel economy level and by adding equations that calculate gasoline consumption and CO2 emissions from automobile travel (Hiramatsu, 2010). In the model, the Chicago area is represented by a system of 15 zones covering the entire area and by an aggregated abstract representation of the major road network and of local roads. In the next subsection, the representation of the Chicago, MSA is described in detail. In section 2.2 the model equations are reviewed briefly with emphasis on the RELU-TRAN2 enrichments and in section 2.3 the calibration of the model's key elasticities are described.

2.1 Representing the Chicago MSA

Figure 1 shows the 15 zone system representation of the Chicago MSA for modeling purposes. The zones can be grouped into 5 concentric rings. Ring 1 consists of zone 3 which is the major employment center in the region commonly referred as the CBD or Central Business District. Ring 2 includes zones 2-5 which together with the CBD (that is Ring 1) complete the rest of the City of Chicago. Ring 3 consists of zones 6-10 which include all of the inner ring suburbs encircling the City of Chicago. Ring 4 consists of zones 11-14, the outer ring suburbs and finally zone 15, a single peripheral zone represents all other exurban areas which are primarily rural in character and which in addition to areas in Illinois, include areas of Northwest Indiana and Southeastern Wisconsin. The model can be computed in two modes. In both modes the total number of consumers in the model is given exogenously and so in both cases the model is closed in population. In the first mode, the partially open MSA, all 15 zones are included as possible locations for consumers but those consumers who choose residence or job location in the peripheral zone 15 are treated as having partially exited the region. Such consumers can still choose job or residence location in one of the 14 zones, but the wages they earn or the rents they pay in zone 15 are taken as exogenous and are not adjusted in the general equilibrium the model calculates for the 14 non-peripheral zones. The second computational mode is that of a closed MSA. In this case, the model consists of only the 14 zones and allocates the given aggregate population of consumers among those zones only. In this paper, all of the simulations we report are based on the second mode. Residents located in the peripheral zone 5 are only 5% of the total and so the two versions of the model would yield fairly similar results. Which of the two versions would be more realistic to use is a judgment call that depends on the purpose of a particular application.

All intra-zonal trips, that is trips that originate and terminate within the same zone, utilize a *local road* that is an abstract aggregation of the underlying street and minor road system. Inter-zonal trips, that is trips originating in one zone and terminating in another, choose and utilize a path over the inter-zonal road-links of Figure 2 which are a crude aggregation of *major roads and highways*, but they also use the intra-zonal links to access and egress from the inter-zonal road network. Figure 2 shows the aggregated inter-zonal road network consisting of 34 two-way road-links connecting the zone system. In the model, each local road and each one-way inter-zonal link is represented by a capacity which is crucial in calculating congestion. The model calculates an equilibrium congested travel time for each local road and each one-way inter-zonal link, to be discussed in section 2.2

2.2 Model structure: consumers, firms, developers

The model is microeconomic in structure and consists of consumers, firms, real estate developers and the government. The last sector does not represent a particular level of government such as local, State or Federal, but is an abstract representation of the public sector. It can do a variety of functions setting tax rates, congestion tolls or other tax levies and performing a redistribution of the revenues generated by various policies. In the present paper, the role of the government will be to just impose a UGB policy limiting land development in the suburbs.

We now briefly describe the behavior of the key economic agents that is consumers, firms and developers. Consumers, firms and developers are treated in the RELU model which consists of several sub-models. These sub-models correspond to different markets: the housing market, the labor market, and the markets for the outputs of industries. In all these markets, consumers are competitive with each other, taking all prices as given and firms are perfectly competitive and price-takers. All consumer decisions involving travel mode and the choice of a travel route on the road network are treated in TRAN, the transportation sub-model. RELU and TRAN are linked sequentially, but are iterated to a fully simultaneous equilibrium (see Anas and Liu, 2007).

Consumers in RELU

Consumers in RELU are adults that can be potentially active in the labor market. Each such consumer is, in reality, either a whole household or a fractional household. The model, however, treats consumers not households and any conclusions about households can be drawn only by pasting together the independently calculated consumption or other decisions of consumers. Consumers are divided into four groups representing skill levels in the labor market that correspond to quartiles of the income distribution in the calibration of the model. Each consumer makes a set of simultaneously determined utility maximizing decisions consisting of discrete and continuous choices. Consumers are myopic and spend the income of each period during that period. They neither save nor borrow. It is attractive to discuss these choices in hierarchical fashion even though they are simultaneous in the model. The highest-level decision of a consumer is whether to enter the labor market or remain outside the labor market. Thus "unemployment" in the model is voluntary. If a consumer chooses to remain outside the labor market, she has an exogenous unearned income that is constant and increases by skill level. If a consumer chooses to enter the labor market the consumer will be employed in equilibrium and will earn an income from wages plus have an exogenous constant unearned income that increases with skill level. Apart from this labor force participation decision all consumers face the same choices on all other variables. The only difference is that consumers that choose not to be employed remain outside the labor market and thus do not have to choose a job location. Hence, they also do not have a commute and, of course, supply zero labor. At a technical level, such consumers are assumed to choose a fictitious job location called "zone 0" and have a commute that entails zero travel time and cost. Should wages increase (decrease), then consumers are more (less) likely to choose work, rather than non-work.

The other discrete decisions that are common to working and non-working consumers are the following:

(i) *Job-residence location pair*: Choice of one of the MSA's zones as a place of work and another zone as a place of residence. Consumers regard each zone as a distinct and imperfect substitute in the labor and housing markets. Thus each consumer has an idiosyncratic preference for each one of the 196 (14 by 14) job-residence location pairs. Wages in each zone are determined by the skill level of the consumer and not by industry of employment. It is assumed that consumers are indifferent to industry of employment. The choice of a residence-job location pair (*i*,*j*) by an employed consumer also determines the consumer's commute as will be discussed in more detail below.

(ii) *Housing type*: Choice of a housing type at the chosen residence location. In the model there are two housing types representing floor space in single family housing or in a multiple family housing structure. All housing choices are treated as renting, thus the model does not currently treat tenure choice.

(iii) *Car-type*: Choice of an automobile type. In the model there are five discrete car types representing cars of decreasing fuel economy. It is assumed that more fuel inefficient vehicles are also larger, more comfortable and safer and have higher acquisition and maintenance cost. The consumer's utility function has a systematic preference that increases with the comfort, safety and size of the vehicle and an idiosyncratic component for each car-type. Thus the choice of a car-type involves a trade-off between the marginal utility of owning a larger and less fuel efficient vehicle and the higher acquisition, maintenance and operating costs such as gasoline for such a vehicle. As a result, in the model less fuel efficient vehicles are owned by higher-skill-and-income consumers with idiosyncratic variation within such a group.

The consumer's choice of the continuous variables depends on the above discrete choices. A particular bundle of discrete choices will be denoted as (i, j, k, c), where i =1,…,14 are zones of residence, j =1,…,14 are zones of job location where, k = 1,2 are the two housing types and c =1,…,5 are the five car types. Thus, a working consumer faces 1960 discrete bundles to choose from, whereas a non-working consumer faces 140 discrete bundles. In all, each consumer faces 2100 discrete bundles. Given a particular such bundle, the conditional choices of the continuous variables depend on the discrete choices as follows:

(i) *Housing quantity*: For each residence zone i, and housing type k, the consumer chooses the amount of housing floor space to rent.

(ii) *Labor hours*: For each residence-job location pair (i, j), the consumer chooses the hours of labor to supply at the workplace in j.

(iii) *Shopping trips*: For each residence location, i, the consumer chooses how many shopping trips to make from i to all other zones z= 1,…14, in order to buy goods that are retailed in those zones. The consumer decides the quantity of retailed goods to buy at z, and the number of trips required to make those purchases are determined according to calibrated fixed rates of trips required per unit of the retailed good that is purchased. Consumers regard the goods they purchase at a particular zone as distinctly different from the goods they purchase at other zones that is the alternative retail locations are imperfect substitutes and all retail locations are patronized because the consumer's utility exhibits a taste for location variety in shopping.

An important aspect of the consumer is the trade-off in the utility function between work, leisure and travel. it is implicitly assumed that the time a consumer allocates to leisure is fixed and that the remaining time is allocated between working hours (labor supply) and travel which includes both commuting (assumed to occur once per work day) and discretionary non-work trips to buy the retailed goods which are endogenously determined. The consumer allocates time in this way by maximizing utility. Travel time of any purpose is valued at the wage rate since an extra hour of travel means that one hour less in wages will be earned. It is also assumed that commuting time creates some disutility. Thus, the marginal rate of substitution between disposable income and commuting time is more than the wage rate. The disposable income determined in this way is composed of wage income which is labor hours multiplied by the wage rate and unearned income which is treated as exogenous. Naturally, all chosen quantities such as floor space, retailed goods and trips to purchase them as well as cars are determined in part by the disposable income and in part by the relevant prices.

Consumers in TRAN

(i) *Mode choice*: For each residence-job-car bundle (i, j, c), the consumer chooses a travel mode for each of her trips (whether for commuting or for shopping) that are determined in RELU. There are three modes of travel. m =1 is car, m =2 public transit and m = 3 other (mostly non-motorized) modes. The last mode is overwhelmingly unused for most inter-zonal trips, especially in the suburbs where the zones are larger) so it applies largely to intra-zonal trips. When the consumer chooses auto, it is assumed that she uses her chosen car-type, c. When the consumer chooses the non-car modes, the car of the consumer is assumed to be unutilized. Both systematic and idiosyncratic generalized costs are considered in the choice of mode.

(ii) *Route choice*: For trips that choose the car mode, the consumer making the trip chooses the route over the road network that gives the minimum generalized cost for traveling from trip-origin zone i to trip-destination zone j, and by considering the entire round trip's generalized cost. As in mode choice, the systematic and idiosyncratic generalized costs of the available routes are considered. In choosing a route the consumer takes as given the speed of travel on each road-link on that route since speed is determined by traffic congestion which is the ratio of the trip volume using the link and the link's capacity. As the ratio increases traffic slows down. Thus, the travel time on each link is endogenously determined at equilibrium. All car-types are assumed to cause the same congestion on each other. The generalized cost of travel on a link is a weighted sum of travel time and the monetary cost of travel, where the consumer's value of time is used to convert time to monetary units. This value of time is exogenous and increases by the income quartile. The monetary cost of travel depends on the vehicle type (which as discussed earlier determines the fuel economy) and on the cost of gasoline. Figure 3 plots the U-shaped speed versus fuel consumption curves for the model's five car types. CO2 emissions are strictly proportional to the fuel consumption. Consumers can determine their monetary expenditure on operating a car by choosing their car-type and by choosing routes that are faster or slower. Consumers with lower (higher) values of time are more likely to prefer monetarily cheaper (faster) routes and this together with their preference for car-size and the level of car acquisition costs relative to their income will indirectly determine the type of car they drive as well.

Firms

RELU includes four industries producing different abstract goods. They are: (a) agriculture, (b) manufacturing, (c) business services, and (d) retail. Goods in the same industry produced in different zones are treated as variants of the same good. Consumers buy only the retail good by shopping it in every zone as explained earlier. All variants of a good are used as intermediate inputs in the production of the other goods except for the retail good which is produced by the input of the other goods, but is not itself an input in the production of those goods. In addition each industry uses primary inputs which are business capital, space in commercial and industrial buildings and labor from each of the skills groups (income quartiles) of the working consumers. All outputs can be exported to other regions from any of the MSA's zones.

Production functions are constant returns to scale and all firms are assumed to be myopic in profit maximization and perfectly competitive with other firms producing in the same industry and zone in the same time period, thus paying the same wages and rents. Since the number of firms is indeterminate, the model determines firms as aggregates specific to zone and industry. Firms in the first three industries supply their outputs to meet demand from other firms that use it in their production and from exports, while retail trade supplies its output to the consumers shopping it and to exports. The price of each good is endogenous in the model and from the zero profit condition of long run competition and free entry it can be determined as a function of the wages, rents and intermediate product prices.

Developers

Our treatment of developer behavior is based on Anas-Arnott (1991) which has been adapted to the RELU model. The model's developers are special firms active in the real estate sector. We use developers as agents that incorporate the activities of landlords (who rent out floor space), investors who buy and sell real estate and contractors who either construct or demolish buildings. Unlike firms and consumers who are myopic, developers operate with perfect foresight about the future and are risk neutral profit maximizers. In this article, the model is implemented as a stationary state or long run equilibrium model, and developers therefore, operate with perfect foresight of this stationary state. Time is view in discrete periods consisting of five years in duration. There are no transactions costs in buying and selling real estate. In the beginning of each period, a developer is the owner either of vacant land in some zone or of either residential or commercial or industrial buildings. Developers in the same zone who own vacant land face the same construction cost for constructing one of the building types, but they are horizontally differentiated by idiosyncratic variations around the common cost. It is assumed that the idiosyncratic cost draw of each developer for each type of building or for just keeping the vacant land vacant is determined towards the end of the period. Therefore, when these costs are determined the developer decides whether to continue to hold the vacant land or whether to construct a particular building type, given the per-square-foot construction cost of floor space in such a building. At the beginning of the period when the uncertainty about the idiosyncratic costs has not been resolved, the developer values the vacant land asset at the expected maximum profit the land would fetch from the most profitable construction or doing nothing at the end of the period. Similarly, developers who start the period owning a particular type of building have common systematic costs of demolition and idiosyncratic costs around the common systematic cost that are revealed near the end of the period. Again, they decide whether to demolish or not at the end of the period, while in the beginning of the period they value the building asset knowing only the expected value of the profit maximizing action (whether to demolish or not). Developers being perfectly competitive, asset prices for vacant land and for each type of built up land are determined in the beginning of each period so that the expected profit that can be realized during that period, including net rental income from leasing out the property is zero.

In the case of a UGB, the behavior of developers is affected significantly. Note that the above paragraph makes clear that asset values for different types of buildings or vacant land have two components. These are the discounted present value of the rental income during the period, and the expected maximum profit from its development. At the beginning of a period, the latter is an option value, since it will only be realized if the developer chooses to exercise the option to develop the property. Now, if a developer's land falls inside the UGB, then it can still be developed into all of the available building types although the prices per square foot will be altered (higher) because of the UGB. If the developer's land falls outside the UGB then it must remain forever vacant and cannot be developed. Hence, all of the option value associated with that land parcel vanishes. This reflects the fact that the UGB in a dynamic setting even under stationary dynamics) indirectly confiscates without compensation the option value of undeveloped land. Such land continues to fetch a rental in its alternative use (e.g. agriculture) but there is no longer any uncertainty about its future status. We also assume that developers who own vacant land incur common and idiosyncratic financial and non-financial costs every period that reflect the costs of research to evaluate development prospects. When the land can no longer be developed, these costs also cease being incurred. Therefore, in our model, the land that remains outside the UGB is valued at the present value of future net rents from a non-urban use.

2.3 Model structure: general equilibrium

Piecing together the demands of the consumers, the output supply and input demand functions of the firms, the travel decisions of the consumers and the floor space supply decisions of the developers, the model's equilibrium conditions are derived. The relevant markets are the labor market for each labor skill level in each zone (56 equations consisting of 14 zones by 4 skill levels), the residential rental market for each residential building type (single-family and multiple-family) in each zone (28 equations, that is 14 by 2), the business rental market for commercial and industrial buildings (28 equations, that is 14 by 2), and the good markets for each industry and zone (that is 56 equations, 4 industries by 14 zones). Solving these equations determines the rental price (per square foot) of each type of floor space in each zone, the hourly wage for each skill level in each zone and the output price for each industry in each zone.

Additional equilibrium processes are the determination of congestion on every link of the major road network as well as the local congested travel time in each zone on the local roads. This allows the calculation of speeds and then of congested travel times and of travel monetary costs from zone to zone in TRAN, that are then entered into RELU to calculate the demands of the consumers (since travel time reduces the time available for work and thus determines the disposable income of the consumers), and the demand for intermediate inputs by firms. Meanwhile the developers' behavior is assumed to be stationary in the aggregate in each zone and for each type of building and vacant land. At such an equilibrium the asset prices for building and land make all expected economic profits zero so that developers earn only normal profits, while stocks, rents and values are stationary by the construction flow of the floor space of each building type equaling the demolition flow of the floor space of the same building type. An exogenous change such as the installation of a UGB would change the long run equilibrium stocks that prevailed prior to the UGB, but would also change the rates of demolition and construction necessary to maintain the stocks at a stationary level.

2.4 Calibration of the Model

The model's calibration is evaluated by certain key elasticity measures and the marginal rate of substitution between commuting time and disposable income. The values of these relationships are for the year 2000 Chicago MSA data and are shown in Table 1.It is important to put these numbers in the context of the literature where the same relationships have been estimated by others.

As mentioned earlier that MRS between disposable income and commuting time is higher than the consumer's wage because while the consumer gives up the hourly wage for every additional hour of commuting, there is also a disutility from the commuting time itself and so the opportunity cost of an extra hour of commuting exceeds the wage rate and increases with income.

The elasticity of location demand with respect to commuting time has been estimated repeatedly in the 1970s by Charles River Associates (1972), Lerman (1977), Atherton (1975), Train (1976). A survey of the literature which includes their own estimates is given by Anas and Chu (1984). Their estimates were higher than those of others and range from -1.462 to -2.190. they reported that:

"*The in-vehicle time elasticity ranges from -0.36 to -1.40 for transit and from -0.55 to -1.77 for the drive-alone mode. Out-of-vehicle time elasticities range* from -0.23 to -2.7 for transit and are -0.42 in the CSI model. *Train and CRA do not report out-of-vehicle time elasticities for the auto mode*."

As shown in Table 1, our workers' travel time elasticity of location demand in RELU-TRAN2 ranges from -0.544 to -0.619 and is in the range of the above estimates.

It is reported in Anas and Arnott (1993) that the average rent elasticity of housing demand, the rent elasticity of white households and the rent elasticity of non-white households in the Chicago MSA for 1970 to 1980, are - 0.554, -0.516 and -0.683 respectively. In our model, the rent elasticity of housing demand cannot be larger than -1, because of the functional form of the utility function, and ranges from -1.38 to -1.95. Our elasticity combines two aspects of the demand for housing, one aspect is the demand for housing size as floor space and the other is the number of consumers who demand housing. Housing demand is the product of these two quantities. Thus our elasticity is higher than that in Anas and Arnott (1993), who estimate a model in which the size effect is fixed.

Kimmel and Kniesner (1998) studied US household data for the period from 1983 to 1986. Their wage elasticity of labor supply (hours worked) is +0.51. In the context of our model, their wage elasticity of labor supply would be compared with the second term in our equation of the wage elasticity of labor supply, and those are negative, ranging from -0.16 to -0.19. In our model, the consumer makes more non-work trips when the wage increases (because of the income effect for shopping normal goods), and this reduces the labor supply.

In Anas and Arnott (1993), the elasticity of housing floor space supply with respect to rent is +0.1016 and 0.1136 for single-family and multiple–family housing respectively. In our model the corresponding values are +0.0991 and +0.23. Thus our single-family housing is similarly elastic with theirs, but our multiple-family housing supply is more elastic than theirs. This elasticity measures the percent of existing housing stock that will be put on the market to be rented (than being kept vacant) by the landlords. Our +0.23 estimate for multiple family housing is almost the same as that reported for by Anas (1982) for the Chicago MSA using 1970 data.

DiPasquale and Wheaton (1994) report that the long run price elasticity of the aggregate housing stock is in the +1.2 to +1.4 range. Blackley (1999) reports that the construction elasticity ranges from +1.0 to +1.2, and that the long-run price elasticity of new housing supply (supply measured in value terms) in United States for 1950 to 1994 ranges from +1.6 to +3.7. Green et al. (2005) report a price elasticity of housing supply in the Chicago MSA for the period from 1979 to 1996 as +2.48. But their estimate is not significantly different from zero. Their housing supply is defined as the number of housing units for which building permits were issued, multiplied by 2.5 (the average household size), divided by the population. Our elasticity of housing construction measures what percent of the land available for construction will be developed into type k building (housing) if the asset price of type k building rises by 1%. This elasticity ranges from +0.03 (for single-family housing in city) to +0.68 (for multiple-family housing in the suburbs). One of the reasons why our elasticity of construction is so small is that many of our modeled zones are urbanized and there is not much land left to be developed. The area covered by the Chicago MSA in Green et al. (2005) covers a broader than our modeled zones. It is also the case that by the year 2000, our modeled zones had become more developed than they were during their period, and the available land would have decreased significantly. Also, the definition of our elasticity of construction is different than theirs, because they measure the percentage by which a 1% increase in asset price would increase building permits multiplied by the population that would use the newly constructed housing, whereas our elasticity measures the percent by which the developed land would increase. In addition, there are two assumptions that could be affecting our elasticity in real estate variables. First, is the assumption is that our building structural density (in floor space per unit of land), is constant by building type and zone. Average structural density in our model zones is not constant and can change over time, for example, by demolishing low structural density buildings and constructing higher structural density buildings. But, if the building's floor space amount could be directly chosen by the developer, the stock could be more elastic when the building value increases. This would be especially true in the zones where the vacant land is scarce. Smith (1976) reports that the price elasticity of density is +5.27, where their density is the number of dwelling units built on a unit land area, from Chicago MSA cross-section data between 1971 and 1972. The second assumption, that could be affecting our low elasticity of stock, is the equilibrium condition that the construction and demolition flow of each building stock in each zone is equalized by the real estate market being in stationary equilibrium. In reality, the construction flow would be larger than demolition and stock in a growing economy. In any case, the methodology used in the literature to estimate the supply elasticity of housing is not robust. There are important data-driven or definitional differences between any two studies. This suggests that it might be better to evaluate the reasonableness of our housing supply elasticity by actually simulating the model in a comparative static exercise, and observing how the housing stock responds in quantity. In such a comparative statics exercise (Hiramatsu, 2010), we simulated a simple urban growth scenario, in which we increased the total population and the net exports by 10%. The vacant land stock decreases in both the city and the suburbs. The single family housing stock decreases in the city and increases in the suburbs. The multiple family housing stock increases in both the city and the suburbs, and increases more in the suburbs than in the city. Both the single and multiple family housing stock increases less than the 10% population growth and the average floor space per person decreases. The industrial and commercial buildings also increase in the city and in the suburbs. The rate of increase is more in the city than in the suburbs, but not as high as the rate of increase of the housing stock. In the city, where the available land is limited, some single family housing is demolished and multi-family housing, industrial and commercial buildings are constructed. In the suburbs where there is plenty of land, both single and multiple family housing is constructed. Industrial and commercial buildings are also constructed in the suburbs. Thus the building stocks respond reasonably with respect to the increase of the population and net exports. Accordingly, the rents and values of each building type change in a normal way. In the city the rent of single family housing increases by more than 10%, because the supply decreases. The other building rents also increase since demand increases by more than supply does. Both rent and value increase more for those building types and locations where the demand increases more and the supply increases less. In this way we conclude that the building markets, including stocks, rents and values, respond reasonably under the calibrated elasticities of the model.

Another important elasticity present in our model is the elasticity of the aggregate demand for car fuel with respect to the fuel price. As is well known this is quite inelastic. RELU-TRAN2 provides a complete framework for estimating how this elasticity increases as consumers in the model are allowed more choices. As explained in Hiramatsu (2010), consumers in the model make hierarchically related choices on route of travel, model of travel (car versus public transit), non-work trips and job-residence location choices. The elasticity is -0.000066 when consumers can adjust only routes. When mode choices can also be adjusted the elasticity is -0.0158. When non-work trips patterns can be adjusted as well the elasticity rises to -0.0173 and when locations can be adjusted to -0.0191. Finally, when all of the abovementioned adjustments occur but rents and wages also adjust to clear markets, then the elasticity rises to -0.0899 and when consumers are also allowed to choose the fuel economy of their vehicle, its rises to -0.253. These results can be compared to econometric estimates obtained in the studies of Small and Van Dender (2007a, 2007b). Their short-run and long-run price elasticities of gasoline are, -0.0892 and -0.4268 for the period from 1966 to 2001; -0.074 and -0.0363 for the period from 1966 to 2004; -0.0667 and -0.334 for the period from 1997 to 2001; and -0.041 and -0.237 for the period from 2000 to 2004. Thus our estimates obtained with a totally different methodology are consistent with theirs.

3 The Impacts of the Urban Growth Boundary

Table 2 shows the distribution of important variables by ring at the base situation circa 2000.

On the base and install hypothetical urban growth boundaries of varying restrictiveness. The UGBs we install exclude from development a part or all of the land in the outer suburbs that is undeveloped in the base situation. Undeveloped land in the CBD, the rest of the city or the inner suburbs is not excluded as one of our purposes is to see how much infill development will occur as a UGB of increasing tightness is installed. The least tight UGB we install excludes from development 10% of the base's undeveloped land in the outer suburbs. We then increase the tightness by adding 10% increments to the excluded land, until at the other extreme all of the base's undeveloped land is excluded by the tightest UGB.

The effects of these alternative UGBs on the most important variables of interest are shown in a series of Figures: 4 through 10. The two panels of Figure 4, panels a and b, show that as the UGB is made tighter the jobs and residences located in the outer suburbs become relocated inward. Under the tightest UGB, jobs in the outer suburbs decrease by 12% and residential locations by 15%, while in the CBD, rest of city and the inner suburbs jobs increase by about 3% and residential locations by about 5%.

Looking next at Figures 7a-7d, we see that the stocks of each kind of building in the outer suburbs decreases. The reason for this is that in the base more land is available to build on than under any UGB. Each landowning developer has a certain probability of constructing on his land depending on profits that can be obtained by converting land to buildings. But since developers whose land remains outside the UGB are no longer able to build, there are fewer developers who can do so. The amount of construction of any type of building is calculated by the model as the product of the total undeveloped land in a zone and the probability that any one piece of such land will be converted to a particular type of building. Whether this probability rises or falls because of the UGB, depends on whether the UGB raises building values more than it raises undeveloped land values. The figures show that the stock of each type of building in the outer suburbs decreases, while the stock of almost all building types in the inner rings (CBD, rest of city, inner suburbs) increases. The only exception to this is that the single family stock in the CBD decreases to make room for higher density apartments and commercial buildings. Infill development therefore, is a direct consequence of installing a UGB. Undeveloped land in the CBD, the rest of the city and the inner suburbs decreases by 3.5%, 2.5% and 8% respectively, whereas in the outer suburbs the percentage decrease is approximately equal to the percent of the ring's land excluded by the UGB policy. The changes in stock are in the direction of higher structural density since the stock of low density structures such as single family and industrial are reduced while the higher density apartment and commercial stocks are increased. Figures 8a-8d show that all construction flows decrease at the post-UGB equilibriums. Again since construction flow is the product of land available for development and the construction probability, this is the result of primarily having less available land at the post-UGB equilibrium because of the infill development that has occurred and the effect of the change in the construction probability which depends on the building value and land value differential.

The stock and construction flow adjustments described above are driven by the changes in values of buildings and land that are in turn driven by the changes in rents that are caused by the UGB's rationing the outer suburban land. Figures 5a-5d shows sharp increased in floor rents in the outer suburban ring. We mention here the increases for the tightest UGB. Industrial and commercial rents increase the most by 70%, while single family and multi-family housing rents rise by 25% and 40% respectively. This is consistent with the earlier result that residential locations are centralized more than job locations are. In the inner suburbs, increases in all floor rents are minor and about 3% to 5.5%. In the CBD and the rest of the city, single family housing rents increase by 7-8% and commercial industrial floor rents by 3-4%. From Figures 6a-6d, value increases are similar in relative magnitudes to rent increases but higher in absolute percentage terms. Industrial and commercial floor values increase by 250% in the outer suburbs, but single family and multiple family residential rents rise by 100% and 50% respectively. In the inner suburbs, the percentage increases are milder about 14% to 18% for industrial and commercial and about 8% to 12% for housing. CBD housing values increase by 15% to 23% while non-housing floor values increase by less around 7% or so. And in the second ring (rest of the city), housing values increase by 12% to16%, and non-housing floor values by about 10%.

As shown in Figure 9 the expected utility of a consumer in each income quartile and employment status decreases the tighter is the UGB, the unemployed faring worse. The utility decreases are obviously because of the rent increases. Wages also increase but these increases are very mild.

Finally, Figure 10 shows the effect of the UGB on variables related to driving. While the average car speed and the fuel economy of cars owned remains essentially flat with UGB tightness, VMT (vehicle miles traveled) falls by 2.5%, miles per gallon by 1% and fuel consumption and CO_2 emissions by 1.5%. The number of auto trips (not shown in Figure 10) decrease by only 1%, thus trips by public transit are increased little as well. These numbers indicate that the expectations of planners that UGBs can increase transit ridership or reduce carbon emissions are unwarranted.

4 Conclusions

Additional work remains to complete the picture that emerges from this paper. First, the real estate asset value increases inside the UGB provide a basis for a better policy than a UGB without surplus redistribution. Since the UGB causes aggregate rents inside the UGB to increase, it would be optimal to tax the aggregate asset value increase, annualize it and distribute it among the consumers as a dividend (though not necessarily equally since our consumers differ in their incomes). With such redistribution we would be able to see whether a UGB of some tightness can increase utility at least initially which was a claim of some urban economists in the late 1970s and 1980s as discussed in the Introduction. However, the dynamic behavior of the developers in our model means that we can also calculate the loss of option values in undeveloped land that remains outside the UGB (as discussed in section 2). The taxed asset value surplus inside the UGB should be redistributed after compensating the option value losses.

As well, the results obtained here should be tested for robustness by performing systematic perturbations of the key elasticities listed in Table 1. For example, increasing the importance of other goods relative to housing in the utility function would cause consumers to centralize their residence locations even more, while increasing the importance of land in the production functions relative to that of labor would cause firms to centralize less when a UGB is installed.

Perturbing the values of time is also important because it relates to the UGBs ability to induce changes in travel patterns away from auto and in favor of transit. Such changes would be driven primarily by two broad effects: (i) the more residents centralize, the more likely they become to use transit rather than car, because the central areas are better served by transit; (ii) the lower their values of time, they are more likely to switch to transit because transit is slower than car for most commuting arrangements.

Our model allows consumers to change the sizes of their dwelling units without any cost. At another extreme, consumers may have fixed dwelling sizes. Then, dwelling sizes could only be changed by demolishing buildings with large dwelling sizes and replacing them with dwellings with smaller sizes, that is replacing single-family houses with multi-family buildings. This would make it more costly to adjust to a UGB’s effects on rents by reducing dwelling size.

A shortcoming of our model is that structural density (floor to land area ratio) is fixed by building type and zone. An extension could make endogenous structural density so that new buildings built after the UGB is installed can be constructed at higher structural densities. It would be interesting to see how much such an extension could change the results we have observed here.

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