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Results from a New Approach to Modeling Land and Housing Markets

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RESOURCES FOR THE FUTURE

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Abstract

This paper uses an economic agent-based model of land use in a hypothetical urban fringe community to examine the effects of large-lot zoning on land conversion, land prices, and the spatial configuration and density of new development. The model incorporates the actions of heterogeneous housing consumers, developers, and farmer/landowners who make economic decisions in land and housing markets. The model allows for population growth and simulates the evolution of land use patterns and prices over a 20-year time period. Zoning regulations in the form of minimum lot size restrictions imposed in an outlying area are shown to have effects that vary with the stringency of the regulations: 2-acre minimum lot sizes have little effect on the spatial patterns of development, but they do increase land and housing prices and result in higher incomes in the region; 5-acre minimum lot sizes push development toward the city center, leaving agricultural land in the zoned region undeveloped until quite late in the simulation period. While house prices are higher with 5-acre zoning, land prices in the zoned region fall, highlighting the countervailing influences of lot size restrictions on land prices. The new modeling approach allows for the tracking of the transitional dynamics of development, both over space and time as the urban area grows.

Key Words: land use, agent-based model, zoning, urban sprawl

JEL Classification Numbers: R11, R12, R14, R38

Contents

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I. Introduction

Zoning codes that regulate land uses, establish minimum lot sizes, and set a variety of other building restrictions are common in cities and towns across the U.S. In suburban and ex-urban settings, minimum lot size regulations are an important part of the local planner's toolkit for either limiting high density uses, or for controlling growth, and preserving open space and farmland. Actual land use outcomes with these regulations are highly uncertain, however. In this paper, we use a new approach to examine the effects of zoning—an economic agent-based model that incorporates significant landscape and agent heterogeneity and tracks the spatial transitions of land use over time. This model allows us to explore fundamental questions about zoning more fully than many traditional spatial equilibrium models: how are the spatial patterns of land use altered by minimum lot size requirements and what are the impacts of such rules on land and housing prices over time and space?

There is a large literature on the motivations for communities to use minimum lot zoning and whether endogenous zoning is welfare enhancing for the provision of public goods, including recent papers by Calabrese, Epple, and Romano (2007), and Coate (2010). The focus in this paper is on the effect of zoning on land and housing prices, and on urban spatial development patterns. Past theoretical studies have reached different conclusions about the effects of zoning on urban form depending on model structure and assumptions. In one of the first papers to look at the effects of zoning, White (1975) found that large lot zoning in a suburb can cause either expansion of the metropolitan area or contraction. Moss (1977), in a non-spatial model of a single jurisdiction with a suburban housing sector and an agricultural sector, shows that under reasonable assumptions for key parameters, minimum lot size constraints imposed in the suburban housing sector increase land values and accelerate rural land

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conversion. Sullivan (1984), on the other hand, finds that minimum lot size regulations reduce sprawl. In his monocentric city model, the zoning is imposed in an outer area; displaced residents in the zoned area move to the unzoned area, thus increasing density there, and because the radius of the city is fixed, the zoning policy does not cause an increase in the size of the urban area. Pasha (1996), like Moss (1977), finds that minimum lot size zoning increases sprawl. In a model with a center city and a suburban area, Pasha's comparative statics analysis shows that large lot zoning in the suburban area forces suburban residents to increase land consumption and this flattens the rent gradient in the suburbs, resulting in an expansion of both the central city and the whole metropolitan area. Finally, in a monocentric setup, Mills (2005) shows that zoning density limits imposed city-wide expand the size of the city.

Empirical evidence on the effects of zoning could lend credibility to one or more of these models. However, empirical work has been stymied by the difficulty involved in isolating the effects of zoning from other influences on urban structure over time. Quigley and Rosenthal (2005) highlight some of these empirical difficulties, and review the evidence on the effects of zoning on housing and land prices. Zoning restrictions are found to increase land and housing prices in most studies, but how and why those prices change, and how they are part of a larger dynamic economic system are not well understood. One empirical analysis that is able to isolate the effect of minimum lot size zoning on developer choices over lot size is a study by McConnell et al. (2006). That study found that in an exurban county in the Washington, DC, area, the stringency of the zoning constraint relative to underlying economic conditions matters for how zoning affects development outcomes. Gottlieb and Adelaja (2009), in a study of the effect of downzoning on agricultural land values, also find that the impacts of minimum lot size restrictions are context specific—whether land prices rise or fall depends on the underlying market conditions and the restrictiveness of the zoning regulation.

In this paper, we add to this literature on zoning restrictions and sprawl by simulating two different minimum lot size restrictions in an economic agent-based model (ABM) of housing and land markets in a growing ex-urban area. The model, described in full in Magliocca et al. (2011a; 2011b), includes as agents farmer/landowners who choose each period between continuing to farm and selling their land for development, developers who purchase land from farmers and build and sell houses, and consumers who choose housing. Housing is characterized by lot size, house size, and location. Similar to all ABMs, macro-scale development patterns emerge from many micro-scale interactions between individual agents, which are modeled computationally.[1] While the model is not a traditional spatial equilibrium model, it shares many of the features of such models. Agents optimize and interact with each other in the land and housing markets, and important feedbacks occur as in any general equilibrium setting.

The model's advantage over traditional spatial equilibrium models is its ability to incorporate far more heterogeneity in agents and the landscape and its ability to characterize out-of-equilibrium market dynamics (Arthur, 2006; Filatova et al. 2007, 2009; Irwin 2010). Many spatial equilibrium models, including those we referenced above, divide the landscape into city and suburb, with an arbitrary boundary between the two, or consider location only as distance from a central business district. Our landscape is modeled at a 1-acre "cellular" level; we trace out the patterns of land use over the full landscape. Moreover, both consumers and owners of agricultural land are heterogeneous in our model, in contrast to the representative agent framework in many economic models. Characterizing the transitional dynamics, another feature of our approach, allows us to follow land and housing sales and prices over time and on the landscape as population grows.

There are many arguments about why communities use minimum lot size zoning rules, including to prevent externalities that might arise from overcrowding or congestion; to affect the distribution of the cost of public services (fiscal zoning); to exclude certain groups or types of housing (exclusionary zoning); and to prevent development and preserve undeveloped land uses such as farming, typically by setting very large minimum lot size restrictions (Fischel, 2000; Ihlanfeldt, 2004; Calabrese et al.. 2006). In this paper, we do not set out with a particular view of the reason for zoning, nor do we model zoning endogenously. Rather, we use the ABM model to compare temporal and spatial land use outcomes in a baseline, no-zoning scenario to two different zoning scenarios that are typical of those we see in exurban developing regions in the U.S. We then assess the degree to which these alternative rationales for large lot zoning seem to fit the results. We impose zoning in one sub-region and leave the other areas unzoned, so comparisons can also be made between zoned and unzoned areas. The first zoning scenario is one that requires 2-acre minimum lot sizes, which may represent a type of exclusionary zoning.

[1] For a comprehensive review of ABM techniques for modeling emergent spatial patterns, see Parker et al. (2003). Chen et al. (2011) and Heckbert et al. (2010). See O'Sullivan (2009) for an application to residential sorting; the model in that study only incorporates consumer agents and does not address rural land conversion and sprawl issues, but it is a good example of the ABM technique applied in an urban economics framework.

Such restrictions seem consistent with a community's intent to keep out high density, and possibly low-income, development. In the second zoning scenario, we analyze a more restrictive rule: 5-acre minimum lot sizes. We often observe these large minimum lot sizes used in practice as an attempt to prevent residential development altogether thereby preserving the land in its undeveloped uses.

We analyze the impacts of these two zoning approaches on land conversion, the number of lots developed, and the density of development, all by geographic location and time period. We also compare land prices, house prices, and the incomes of residents in the two zoning scenarios to the baseline. We find that while there are some similarities in the results across the two zoning scenarios, there are some fundamental differences. Our simulations show that the 5-acre minimum lot size restriction essentially prevents development in the zoned area. For many years, almost all building occurs closer to the "city," or what we refer to as the Suburban Development District (SDD), and land in the zoned outlying area remains in agriculture. Only at the end of the 20-period simulation do we start to see some farmland converted to development in the zoned region. The 2-acre limit, on the other hand, has no such effect. Farmland continues to be converted in the zoned region in patterns that are similar to the baseline case, but most houses are built on 2-acre lots. The percentage of farmland converted to development in the zoned region is almost exactly the same in the 2-acre case as in the baseline, but it is sharply lower in the 5-acre zoning case. Average lot sizes are largest in the 2-acre case and smallest in the 5-acre case, where much more small-lot development occurs in the unzoned region.

Land prices rise substantially in the unzoned region in both zoning cases due to demand pressures that result from the supply restriction in the adjacent area; this spillover effect of zoning has been emphasized in the literature (Pollakowski and Wachter, 1990; Dalton and Zabel, 2009). However, land prices in the zoned area remain about the same in the 2-acre case as in the baseline, and are *lower* in the 5-acre case. These results highlight the countervailing effects of minimum lot size restrictions. On the one hand, zoning restrictions make undeveloped land less valuable per acre since fewer houses can be built on each acre; this is the argument made most often by owners of undeveloped land protesting potential downzoning (Liu and Lynch, 2010). On the other hand, the land supply restriction tends to drive up the bid-price for land. Our results suggest that these two effects approximately offset each other in the zoned region in the 2-acre case, and the constraint on development potential seems to dominate in the 5-acre zoning case.

We find that the minimum lot size restrictions in both of the zoning scenarios increase housing rents in the zoned region. But interestingly, because our model includes house and lot sizes, it is able to capture some dampening of this price rise. We find that developers build on smaller lots in the unzoned region when there is zoning in the outlying area. This keeps housing rents and land prices from rising as much as they otherwise would. In fact, housing rents rise much more in the zoned region as consumers are forced to buy houses on larger lots.

The ABM approach frees us from some of the tractability constraints in traditional economic models—constraints that are usually necessary to obtain analytical solutions—but it comes with a different set of issues. One is that market clearing conditions for markets with many agents cannot be solved for simple equilibria, so the process by which prices are determined must be clearly specified for each market. In addition, because these models are bottom-up, with multifaceted interactions, the causal links between agent behavior and aggregate city-wide outcomes can be difficult to determine. The model we have developed is for a relatively small, stylized geographic area yet it is still rather complex; adding more geographic detail and additional agents—a government sector, for example—would exacerbate this problem.

Despite these shortcomings, the approach shows promise for better understanding land use patterns and the dynamics of land markets. The landscape and agent heterogeneity that is a defining feature of ABMs is missing in virtually all spatial equilibrium models in economics. This feature allows for new insights into the potential impacts of zoning and other land use policies. For example, our model is able to distinguish policies with different levels of stringency as well as policies that vary geographically, a virtue of the approach compared with most traditional economic models. Further policy analysis using the ABM technique could provide useful information for local land use planners and other government policymakers.

We briefly describe the model in the next section, though many of the details are left to Magliocca et al. (2011a; 2011b). In Section III, we parameterize the model and Section IV shows the baseline results with no zoning. Section V shows the zoning results and the final section provides some concluding remarks and directions for future research.

II. The Model

In our model, we consider a single jurisdiction in a rural setting just beyond the most distant suburb in an urbanized area. The jurisdiction contains a Suburban Development District (SDD) that has some initial residential development and beyond that developed area there is a large undeveloped agricultural region. Our objective is to characterize the additional residential (single family) development that takes place over time as the population grows and land is converted to development from farming uses. The region we are modeling can be considered an ex-urban area outside of any major U.S. city where farmland is under pressure from development. The landscape is highly stylized, but we parameterize the model using data from exurban areas of the Mid-Atlantic region (see section III). The jurisdiction is not strictly "open" or "closed" in the traditional economic sense. The population size is endogenous, consistent with an open city model. On the other hand, the utilities and incomes of residents are also endogenous, which is typical of a closed city.[2] We elaborate further on this point below.

The model incorporates the decisions of three types of optimizing agents: consumers, a single developer,[3] and farmer/landowners. Consumers are motivated to choose housing and other goods to maximize utility subject to a budget constraint, where housing is characterized by house size, lot size, and location relative to the SDD. Consumers are differentiated by income and preferences over different types of housing. Farmers compare the returns from farming each period to the expected profit from selling to developers. Farmers differ in both farm size and productivity and in how they form expectations about future land prices. The developer forecasts future housing sales, and purchases land from farmers to build housing to maximize profits. We abstract from any consideration of externalities, and we do not explicitly model the government sector so the model does not incorporate property or other taxes or provision of public services. When we analyze zoning, we assume that minimum lot size regulations are imposed on the market and study the development outcomes that result.[4] Figure 1 provides a schematic that shows how the model works and the interactions among agents.

We model two different approaches to zoning that communities at the urban fringe have used to influence land development patterns. The first is 2-acre minimum lot size zoning that may be considered a type of exclusionary zoning used to ensure that lower income, higher density does not occur over time. We chose the 2-acre minimum lot size because it is a very

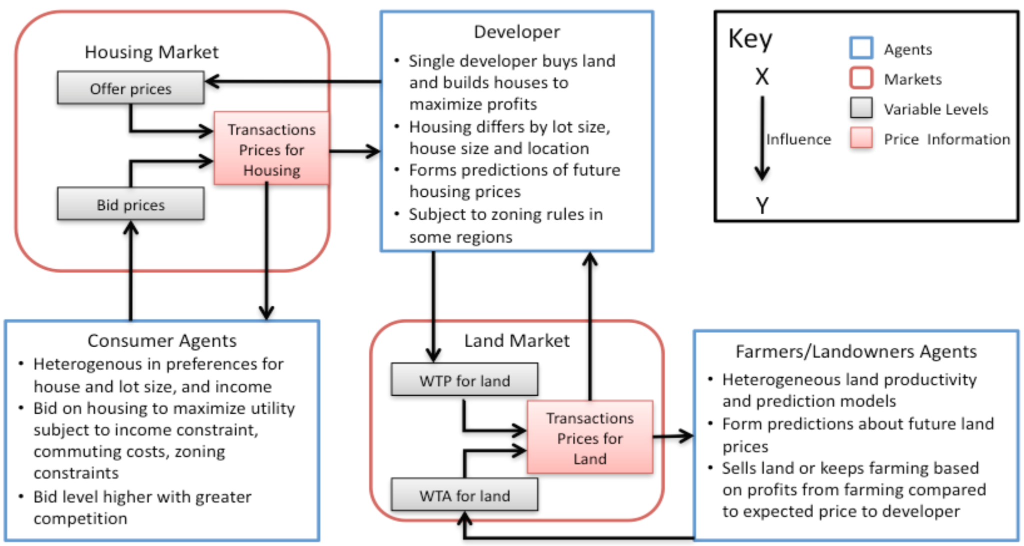
[2] See Pines and Sadka (1986) for more on the distinction between open and closed city models. Our model is also not an equilibrium sorting model in the sense of Epple and Sieg (1999), Bayer and Timmins (2007), and others (see Kuminoff et al.(2010) for a recent review) but it includes some elements of this approach in that households sort across the landscape. The difference is that we are not modeling multiple jurisdictions.

[3] The assumption of a single developer makes the model easier to analyze. Having multiple developers would add a layer of complexity and provide little additional insight for the purpose of modeling spatial patterns of development. We assume the developer does not exert any monopoly power over the farmers or households.

[4] A large literature exists that is focused on the endogeneity of zoning (see for example McMillen and McDonald 1991, 2002, and Calabrese et al., 2007). However, since we are focused only on one jurisdiction and our objective is to assess how minimum lot size rules can affect development patterns in that jurisdiction, we feel that endogenizing the zoning rule would unnecessarily complicate the model. This is a potential topic for future research.

common minimum lot size in many ex-urban regions around the country.[5] As a point of comparison, we also model a more restrictive zoning: 5-acre minimum lot sizes. We see this type of zoning in many jurisdictions trying to protect rural areas and farmland on the periphery of urban areas.[6]

Figure 1. Agents and Markets



In the next sections we describe the model briefly, starting with explanations of the behavior and decisions of each of the agents, consumers, the developer, and farmers. Then we discuss how the agents come together and make transactions over time in the land and housing

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5 The 2-acre minimum lot size is a large lot zoning designation that can be observed in a number of ex-urban areas of the eastern U.S., for example in the Washington, D.C. (Kopits et al. forthcoming) and Boston ex-urbans (Glaeser et al, 2006, and Dalton and Zabel, 2009). These communities may be using such restrictions to try to maintain consistency with the initial type of development that has occurred in those newly developing rural areas.

6 We see some ex-urban communities use such zoning to make development of agricultural land less profitable and thus less likely and also in an attempt to preserve "rural character." Both Calvert County and Montgomery County, Maryland, for example, have 5-acre rural zoning in many areas.

markets. In the application of the model developed for this paper, the landscape is modeled at a 1x1-acre level and the full landscape covers 6,400 acres (80 acres square), or 10 square miles. Each period, land use decisions are made for each 1-acre cell (see figure 2).

II.A. Consumer Utility and Formation of Bid Prices for Housing

Each consumer, c, has income I_c, and receives utility from housing and a numeraire good. Consumers choose from available houses, with each house n characterized by house size, h_n, lot size, l_n, and location relative to the SDD. Houses in each period may be either part of the existing stock from a previous period, or they may be newly constructed. Consumers determine the house with the highest utility from a Cobb-Douglas utility function as shown in equation (1):

$$U_c(n) = \left(I_c - R_n - \psi_n\right)^{\alpha_c} h_n^{\beta_c} l_n^{\gamma_c} \tag{1}$$

where the budget constraint has been substituted for the numeraire good; ψ_n is the travel cost from the location of house n to the SDD[7], and β_c and γ_c are the consumer's idiosyncratic preferences for house and lot sizes, respectively. R_n represents either the rent of an existing house or the asking price (both annualized) of a new house on the market.[8]

The consumer will bid on all houses for which his maximum willingness to pay is greater than the developer's asking price. The consumer's willingness to pay for any given house n is equal to the constant share of income as given by the Cobb-Douglas structure:

$$\mathrm{WTP}_c(n) = (I_c - \psi_n)(\beta_c + \gamma_c). \tag{2}$$

Although this functional form for the utility function implies that consumers would pay the same amount for all housing net of transportation costs, consumers identify the housing option with the greatest utility and adjust their bids on other houses relative to this most preferred option. We first determine which house provides the highest utility among the affordable houses. The consumer then determines a rental payment $R^*(c,n)$ for each other affordable house such that it provides the equivalent utility level (U^*) as the most preferred house:

[7] We assume that transportation costs do not vary by consumer type. This is a simplification; relaxing this assumption would significantly complicate computations of spatially discounted housing rents.

[8] We do not explicitly model housing financing and thus refer to the annualized house price as a housing rent.

$$R^*(c,n) = I_c - \psi_n - \left(\frac{U^*}{h_n^{\beta_c} l_n^{\gamma_c}} \right)^{\frac{1}{\alpha_c}}. \tag{3}$$

In Section II.D below, we describe how we use these maximum rents to form bid prices for individual houses, how the interaction between consumers and the developer takes place in the housing market, and ultimately how individual consumers get allocated to particular houses.

II.B. Developer Purchase of Land and House Construction

There is a single developer in the model who buys land from farmers and builds the number and type of houses that will maximize expected profits. To calculate expected profits, the developer needs to form predictions about housing rents for houses of different types. The developer starts each period with information about the sales of housing of different types and locations from past periods. He obtains information on past rents, lot sizes, house sizes, number of bidders before sale, percent that sale price was above/below the original asking price, and the number of houses of each type in any given neighborhood.

The developer uses this information to form expectations of future rents for each undeveloped cell. The rent projections for each housing type account for the distance of the given cell from the SDD and associated travel costs. Projected rents are a combination of weighting between local (when it is available) and regional (the entire developing area) rent information. [9] More detail on the approach used to form these price expectations can be found in Magliocca at al. (2011b).

Based on projected rents, the developer's potential (annualized) returns can be calculated for every housing type in every undeveloped cell by subtracting the costs of construction and the price of land for the given cell.

The developer determines the maximum return for each cell as the maximum return over all possible housing types for the given cell. Those returns will vary across any given farm because of distance from the SDD. The housing type that produces the maximum return in each cell *i* of a given farm *F* is determined, $\boldsymbol{R_{i_F}^{max}}$, and the developer's willingness to pay for that

[9] There are situations when there is no past information about the price of a particular house type in one region because it has never been built there. In these cases, expected rent must be inferred from houses built elsewhere in the region.

farm, on a per acre basis, WTP_F, is the average of these maximum returns over the extent of the farm:[10]

$$WTP_F = \frac{\sum_{i_F} R_{i_F}^{\max}}{A_F} \tag{4}$$

where A_F is the acreage of farm F.

II.C. Farmer/Landowners' Land Conversion Decisions

Farmers in the model provide a supply of land for future residential development. In each model period, farmers decides whether to sell their land to a developer or continue farming until the next period when they take in new information and go through the same decision process again. When a farmer decides to sell, the entire farm is sold.[11]

Farmers are endowed with heterogeneous plots of land that differ from each other by their size, agricultural productivity, and operating costs. Each farmer calculates the amount they are willing to accept to sell in each period. The willingness to accept for each farm (WTA_F) can never go below the value of the farm's agricultural return per acre in perpetuity—i.e., this amount is the lowest that the farmer would ever accept for his land. However, the farmer also bases his WTA_F on past land prices and price prediction models. Using an approach adapted from price expectation formation in the agent-based financial literature (e.g. Arthur, 1994, 2006; Axtell, 2005), each farmer is randomly assigned a set of models that vary in, for example, the length of time over which past prices matter, the functional form of the effect of past prices, or the amount of remaining land in the suburban area. Farmers adapt their prediction models over time according to the success of past predictions.[12] Based on the accuracy of their predictions of the price of land in period *t-1*, each farmer uses his most successful prediction model to set his

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[10] This methodology assumes that the developer earns zero economic profit.

[11] Selling portions of farms would greatly complicate the model. In addition, selling an entire farm is typical practice in many land markets; for example, our review of land sales data and discussions with developers and farmers in exurban counties in Maryland suggests this is the norm there.

[12] The specifics of the price prediction models are described in the Appendix to Magliocca et al. (2011b) and are based on techniques in Arthur (1994). Farmer expectations of land prices are formed using a randomly allocated set of twenty prediction models. Each prediction model uses one of six different methods for forming predictions. This allows for a great deal of heterogeneity in how farmers predict future prices, but we find that prediction models converge over time to the most accurate prediction methods.

WTA_F in the current period. This represents a price floor for the farmer in negotiations with the developer.

II.D. Market Interactions

In our ABM framework and with modeling at the individual cellular level, it is necessary to define how individual transactions take place and markets clear. While each farmer forms a WTA_F for his land and the developer has a WTP_F, we need to specify when and how transactions will be made and at what price. Likewise, consumers form bid prices for houses and the developer has offer prices; consumers must be allocated to houses through a market clearing process.

The Land Market

In each period, farms for which the farmer's WTA_F is less than the developer's WTP_F have the potential for a sale. For each of these farms, the developer and the farmer are assumed to enter into negotiation over the final transaction price. The transaction price for each farm will be influenced by the amount of excess demand or supply in the land market during that period. If farmers are willing to offer more land than is demanded by the developer in that period, the developer will reduce his bid price for each farm *F*, P^F_{bid}, below the initial WTP_F . Conversely, if the developer demands more land than farmers are willing to supply, the farmers will increase their asking prices, P^F_{ask}, above their initial WTA_F. The adjustments to the WTA_F and WTP_F to form P^F_{ask} and P^F_{bid} are:

$$P^F_{ask} = WTA_F \cdot (1+\varepsilon); \quad P^F_{bid} = WTP_F(1+\varepsilon) \tag{5}$$

where ε is a measure of the relative size of the excess demand for land. Below, in the application, we specify ε as (Land Demand -Land Supply)/(Land Demand +Land Supply).[13]

If P^F_{bid} falls below P^F_{ask}, then the farmer withdraws and is returned to the farmers' pool to await the next time step where there is the same decision-making process. However, if P^F_{bid} remains above P^F_{ask}, then a mutually beneficial transaction is made. We assume that the final transaction price for each farm *F* is the average of P^F_{bid} and P^F_{ask}.

[13] This approach to establishing the transactions price for land was adapted from Parker and Filatova (2008).

This method for endogenously generating land prices has several important consequences. First, the land market is responding to the behavior of farmers who are responding to uncertain future prices, each with idiosyncratic approaches to predicting those prices. Predictions are made based on past and present trends in land prices and substantial uncertainty about future trends. In general, farmers with the highest agricultural productivity will have the lowest probability of selling and the highest asking prices all else equal, but the process of land sale is less orderly than in traditional economic models. The timing of farm sales is not based purely on relative values in agriculture and development because of the uncertainty in future prices and farmer heterogeneity in predicting those future prices.

The Housing Market

As we explained above, consumers will bid on each house for which their maximum willingness to pay (from equation (2) above) exceeds the developer's asking price. Consumers will then determine a rental payment for each of these houses that maximizes their utility and is within their budget as described in section II.B above. The developer's projected rent for each new house described in section II.C above forms the basis of the developer's asking price for each house.

To allocate houses to consumers, the model goes through a careful matching process. The first step in the process is to adjust the price that each consumer is willing to bid on each house based on the level of competition that consumer faces in the marketplace. A competition factor faced by consumer c, HMC_c, is calculated by comparing the number of houses consumer c will bid on, N_c, to the number of other consumers bidding on the same houses, M_{N_c}.

$$HMC_c = \frac{(N_c - M_{N_c})}{N_c + M_{N_c}} \tag{6}$$

This ratio is positive if there are more consumers bidding than there are houses the consumer is bidding on; it is negative if there are fewer consumers bidding than houses the consumer is bidding on. We use HMC_c to adjust the bid price from equation (3) above for each house in the affordable set of houses. The extent of the change in the bid price for a house depends on the difference between the asking price for the house and the maximum the consumer will pay for a house out of income ($WTP_c(n)$ from equation (2)). Consumers with higher income or with a higher preference for housing out of income, for example, would adjust their bid prices more for any house given the level of competition. The determination of the bid price by consumer c for house n is defined as:

$$P_{bid}(c,n) = R^{*}(c,n) + HMC_c[WTP_c(n) – P_{ask}(n)] \quad (7)$$

where $P_{ask}(n)$ is the developer's asking price for house *n* and all other variables are as previously defined.

The adjustment of consumers' bid prices in response to market conditions allows consumers to try to maximize utility in the housing choice but also improve the likelihood that they will be the highest bidder.[14] After the bidding process is completed, the highest bidder on each house is identified. For each consumer who has at least one "winning bid", the house or set of houses for which the consumer owns the highest bid is identified. The consumer's utility is recalculated (using eq. 1) for each of these houses using the winning bid instead of the initial asking price. Given these new levels of utility, the consumer is matched with the house for which that consumer is the highest bidder and derives the highest utility. Once a consumer is matched with a house, both the consumer and house are removed from the market. The matching process continues with the remaining consumers until all consumers are matched with houses or until all houses are occupied or all positive bids are exhausted. This process is carried out at each time step.[15]

III. Parameterization of the Model

The Suburban Development District (SDD) represents the outer edge of suburban development in a larger metropolitan area. It is shown as the dark blue half-moon shaped region at the top of Figure 2. The rest of the land in the region we model is made up only of farms in the initial period but development begins to occur as farmers decide to sell to developers to build housing. Households who locate in the newly built housing are assumed to commute to the suburban area or beyond for work, so being closer to the SDD is more desirable. The SDD has housing of different sizes and types, and prices, which the developer uses to inform his forecasts for the value of new development as it begins to occur in the rural area.

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[14] See Magliocca et al (2011a, 2011b) for more detail on the specifics of the housing competition.

[15] Although the consumer and house are removed from the market in a particular period, in subsequent periods, the consumer may move out of the area and the house be put back on the market. At the time of purchase, the consumer is given a 'residence' time that is randomly drawn from a normal distribution of mean and standard deviation of 6.2 and 5.5 years, respectively. When a consumer's residence time has been reached, the consumer moves out, rejoins the consumer pool in search of a new house, and the old house is put back on the market. Thus in each period, there are some newly constructed houses and some existing houses on the market.

There are initially 334 households located in the SSD before the development period begins, and housing there includes four lot sizes—¼ acre, ½ acre, 1 acre and 2 acre. This range of lot sizes for single family houses is typical of suburban jurisdictions adjacent to large cities in the Mid-Atlantic region of the U.S.[16] There are three housing structure sizes, small (1,500 square feet), medium (2,000 square feet) and large (2,500 square feet).

The SDD is surrounded by 50 farms, as shown by the different colored areas in Figure 2. Farmers are endowed with heterogeneous plots of land that differ from each other by their size, agricultural productivity, and operating costs. Farms are randomly assigned to the landscape; no particular region is more naturally productive than any other.[17] Total region size is 6,400 acres (80 acres square), or 10 square miles.

The number of households wanting to move into the region is assumed to grow at 10 percent per year. Developers buy land and build specific housing types to maximize profits. Farmland is gradually converted to developed uses over time; once developed, land cannot return to agricultural uses and there is no redevelopment to a different housing type. There can be resale of houses, however, as we described above. The model tracks growth over a 20-year period. No zoning or other regulations exist in the baseline case.

Table 1 shows the parameters used for the baseline model. The first several rows show baseline assumptions for the farm sector, including the distribution of farm size and agricultural returns, or productivity. Both the size and productivity distributions are based on data from farms in the Mid-Atlantic region from the 2007 Census of Agriculture. The standard deviation on farm productivity is relatively small, so there is not a great deal of variation in land productivity in this model. In addition, we assume no scale economies in farming, so that farm size does not affect average return per acre.

In addition to the four lot sizes that exist in the SDD, we allow for 5-acre and 10-acre lot sizes in the developing rural area. This means that there are potentially 18 house and lot size combinations (6 lot sizes and 3 house sizes).

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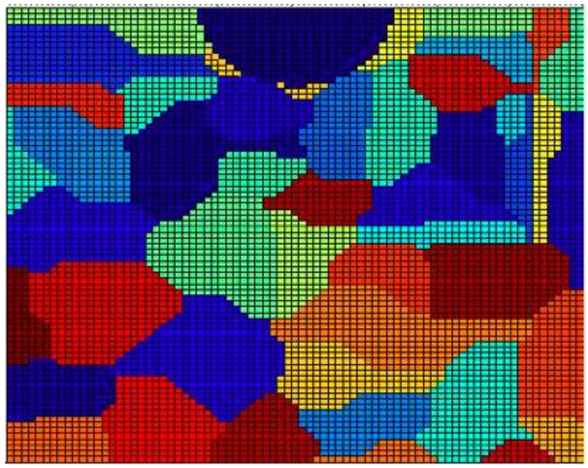
[16] For example, lot sizes for detached single family homes in the suburbs of Montgomery County, Maryland, that are adjacent to Washington D.C. range from 0.2 acres to 2 acres (Kopits et al., forthcoming).

[17] In Magliocca et al. (2011a), we conduct sensitivity analyses to key model parameters, including the agricultural productivity. In one of these, we assume equivalent agricultural productivity across all farms and in a second, we assume a particular region is more productive than other regions. In Figure 2, the colors have no significance other than to delineate the farms.

Figure 2. Initial Landscape Configuration and Location of 50 Farms



The costs of housing construction include building construction costs and infrastructure costs such as streets and sewers or septic systems. We use an average of construction costs in urban areas of the Mid-Atlantic region, using a range of $85 to $165 per square foot (US Census Bureau)). Infrastructure costs include estimates of local road costs and sewer and septic costs, with estimates taken from Frank (1989), Fodor (1997), and more recent evidence from Juntunen and Knaap (forthcoming).[18] Incomes of the incoming households are assumed to vary with a log-normal distribution from $40,000 for the lowest quintile to $200,000 for the highest quintile. These data are based on median household incomes for suburban counties in the Mid-Atlantic region (Delaware, Maryland, Pennsylvania, and Virginia) from the 2000 Census.

Parameters of the consumer utility functions were developed based on an examination of available evidence in the literature and from Census data.[19] The share of income spent on housing is assumed to vary within income groups (Safirova et al. 2006). Within each income group, parameter values are randomly drawn from the range of values shown in Table 1. Travel costs for households are assumed to depend both on time and monetary costs, and both are specified based on available evidence. Time costs are assumed to be $1.30/mile[20], and monetary

[18] In the case of 5- and 10-acre lots, we assume there are septic systems instead of sewers.

[19] See Magliocca et al. (2011a) for sensitivity analysis on the utility function parameters.

[20] We assumed time costs to be a function of average road speed (30 mph), average number of workers per house (2), average wage per person ($30/hour), value of time as a percent of wage (50%), and the road network indirectness coefficient (0.3) (this is the ratio of network distance to the Euclidian distance).

costs are \$0.54/mile (Bureau of Transportation Statistics, 2007), and are assumed to remain constant as the region grows.[21]

Table 1. Key Parameter Values

Number of farms	50
Mean (std. dev) farm size, in acres[1]	128 (71)
Mean (std. dev) agricultural return, in \$/acre[1,2]	\$2,486 (\$249)
Housing construction cost per square foot[3]	\$85- 165
Infrastructure cost per housing unit[4]	
One acre lots or smaller	\$10,000 - \$20,000
2 acre lots	\$23,000
5+ acre lots	\$30,000 - \$40,000
Household Income Distribution[5]	
Income range	\$40,000 - \$200,000
Low income range	\$40,000 - \$59,999
Middle income range	\$60,000 - \$99,999
High income range	\$100,000 - \$200,000
Mean (Std. dev.)[6]	\$86,493 (\$39,302)
Share of income on housing expenditure , $\beta+\gamma$[7]	
Low income consumers	.35 - .42
Middle income consumers	.27 - .34
High income consumers	.18 - .26
Proportion of housing exp. on land, $\gamma/(\beta+\gamma)$[8]	.10 - .90
Transportation costs (\$/mile)	
Time	\$1.30
Out of pocket	\$0.54

[1]Data from Census of Agriculture (2007).
[2]Agricultural return is the discounted net present value of average farm income divided by total farm acreage for mid-Atlantic states (Delaware, Maryland, Pennsylvania, and Virginia).
[3]U.S. Census Bureau, Manufacturing, Mining and Construction Statistics. http://www.census.gov/const/www/charindex.html#singlecomplete.
[4]From Frank (1989), Fodor (1997), Juntunen and Knaap (forthcoming).
[5]Based on median household incomes for suburban counties in the Mid-Atlantic region (Delaware, Maryland, Pennsylvania, and Virginia) from the 2000 Census.
[6]Household income is log-normally distributed.
[7]Safirova et al. (2006). Calculations in that study based on U.S. Bureau of Labor Statistics' Consumer Expenditure Survey.
[8]Carliner (2002). Range expanded to allow for more heterogeneity.

[21] Travel costs may increase as population grows due to congestion but we do not consider that possibility here.

IV. Baseline Model Results

The model was run 30 times and each run tracked growth over a 20-year simulation period. Farmers' locations and agricultural returns, and the assignment of prediction models for farmers and developers were held constant across all runs, as were the distribution and location of housing types in the SDD. Draws from income and consumer preference distributions were allowed to vary randomly across each of the 30 runs. Holding landscape features constant across runs eliminated sources of geographic variability, but allowed for stochastic variation in development patterns that resulting from agent heterogeneity.

Stochastic elements in the model limit the insight of any single model realization. Instead, we show average outcomes, including maps of the most likely, or 'average', development patterns.[22] Figure 3 shows these maps for two periods, T=10 and T=20, with the colors denoting the housing types as shown in the label at the side of the maps; type 18, for example, shown in dark red, is the largest house and lot type (2,500 square foot house on a 10-acre lot) while type 1, shown in dark blue, is the smallest house and lot type (1,500 square foot house on a ¼ acre lot). The darkest blue area on the maps is the undeveloped farmland remaining at each time step. Table 2 shows the mean and standard deviation of the number of lots of each type developed by the final simulation period, T=20, along with the mean and standard deviation of housing rents.

As the table and figure make clear, the relatively large 1- and 2-acre lots are the most prevalent. Of the 2,573 houses built by T=20, 72 percent are located on lots that are 1 acre or larger. This outcome results from a combination of relatively low land to housing costs and infrastructure costs that increase with lot size but at a decreasing rate (see Table 1). In ex-urban areas in the mid-Atlantic states, these relatively large 1 and 2 acre lots are quite common.[23] Housing rents, as expected, are higher for larger houses and for houses that sit on larger lots.

[22] For each time step displayed, the development pattern consists only of cells that were developed above a threshold frequency, which was calibrated to produce an 'average' development pattern that closely approximated the calculated average percent-developed area and dispersion across 30 runs (see Magliocca et al. (2011b) for more detail). Within each of those cells, the housing type with the highest probability of occurrence is shown on the maps in Figure 3.

[23] In the McConnell et al. (2007) study, one county on the fringes of Washington, DC, had an average lot size of 2.6 acres. Lichtenberg et al. (2007), using data from suburban and ex-urban counties in Maryland, report an average lot size of 0.4 acres in areas with access to public sewers and average lot size of 3.0 acres in areas with septic systems. Chester County, Pennsylvania, on the outskirts of Philadelphia reports an average lot size for single-family homes of just over 1 acre (Chester County Planning Commission 2010).

These rents are the outcome of market interactions between farmers, the developer, and consumers.

Results from this baseline model conform with observed regularities of urban development patterns and also with the general patterns predicted by economic theory. We do not show all of these results here due to space constraints, but we can summarize some of the time and spatial outcomes of the development process. Average land prices rise gradually over time, with the average price starting at $2,353 per acre in the first period and rising to $3,213 per acre by the final period. There are fluctuations in price over time, due to changes in farmers' expectations about what they can get for their land, and changes in the mix of the most profitable housing types and therefore in what developers will bid for land. However, the trend in land prices is upward. Results also show a declining rent gradient—i.e., average per-acre land prices tend to decline with distance from the SDD. Farms within ½-mile from the SDD sell for an average price of $4,214 per acre while farms within ½-mile from the outer edge of the region sell for an average price of $2,929 per acre.[24] We also find that average lot sizes increase with distance from the SDD—i.e., there is a declining density gradient.

The farms most likely to sell first are well south of the SDD, and developers build houses on mostly 1- and 2-acre lots there. By period 10, as shown in the map in Figure 3, there is some development in the North near the SDD but much of it still takes place in the South, where farms are comparatively cheaper. Agents' expectations about future prices also play a role. Because developers form predictions about future housing prices in part using evidence about past prices in the local region, profitable development in a particular region tends to lead to more development in the future in that same region. Eventually this development increases land prices, which shifts development to other areas, but some path dependence in development patterns is observed.[25]

The dispersed patterns of development that show up in the maps are consistent with what we see in many communities on the fringes of major U.S. metropolitan areas. Chen et al. (2009) argue that cities are no longer held together by agglomeration economies and high transportation costs, and that development patterns are characterized more by suburban sub-centering and

[24] More information on land prices for the baseline case is provided in Magliocca et al. (2011a; 2011b).

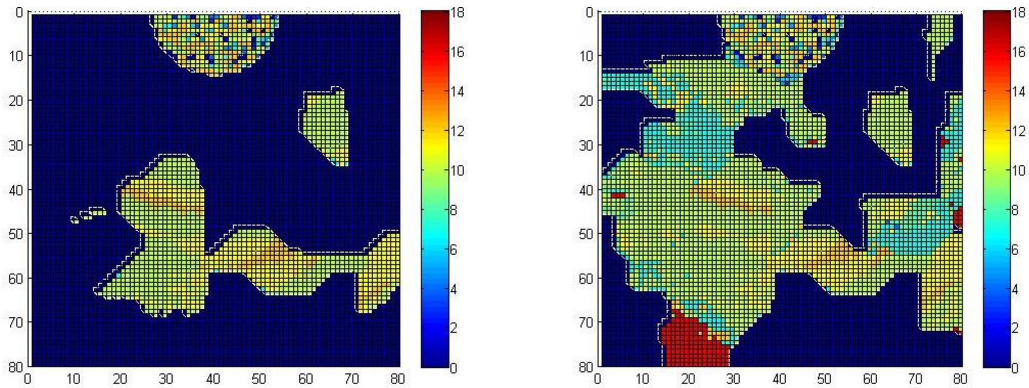
[25] In O'Sullivan's (2009) agent-based model of residential sorting, he finds that segregation of neighborhoods can occur because of what he refers to as "self-reinforcing changes" in household locations. This is similar to the path dependence we are referring to.

fragmented land development patterns. The results are also consistent with some empirical work. McMillen (1989), for example, in a multinomial logit model using data from in an urban fringe county near Chicago, finds that a decentralized pattern of residential land use is the norm there and that distance to established centers is not a significant factor in explaining whether parcels are more likely to be developed.

Table 2. Number of Houses and Annual Rents, by Type of Housing, at T=20

			Number of Houses		Annual Rents	
Housing Type	**Lot Size (acres)**	**Housing Type Description**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
1	¼ ac	Small house	89	58	$7,737	$797
2		Medium house	51	41	$12,157	$884
3		Large house	104	77	$14,502	$788
4	½ ac	Small house	144	109	$9,253	$1,427
5		Medium house	172	124	$12,382	$1,431
6		Large house	155	76	$15,946	$982
7	1 ac	Small house	429	185	$12,219	$689
8		Medium house	231	110	$14,786	$606
9		Large house	141	76	$18,560	$857
10	2 ac	Small house	475	88	$19,653	$629
11		Medium house	358	77	$21,342	$653
12		Large house	183	2940	$24,740	$717
13	5 ac	Small house	0	0	--	--
14		Medium house	0	0	--	--
15		Large house	0	0	--	--
16	10 ac	Small house	30	32	$30,461	$4,374
17		Medium house	12	25	$32,582	$3,425
18		Large house	1	3	$33,047	$2,959
Total			2,573			

Figure 3. Expected Spatial Development Patterns at T=10 and T=20



Note: Color scale denotes housing type, where type 1 is small house on ¼-acre lot, type 2 is small house on ¼-acre lot, and so forth up to type 18, which is a large house on a 10-acre lot; darkest blue is undeveloped farmland (see types listed in Table 2).

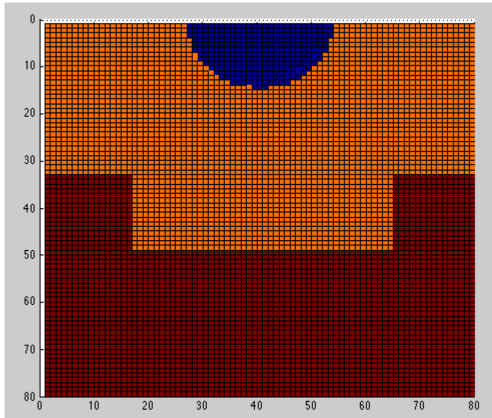
V. Zoning Results

To examine zoning policies that are typical of exurban jurisdictions, we impose large lot zoning rules in the outer rural region (the South); the inner area closer to the SDD (the North) remains unzoned in our policy simulations. Figure 4 shows the zoning map, where the dark brown area is the zoned region. The zoned region is about 1.4 miles from the edge of the initially developed area, the SDD.[26] As described earlier, we include two zoning policy simulations: a 2-acre and a 5-acre minimum lot size restriction.

The lot size regulation alters the developer's perceived profits from development and the prices offered to farmers for their land. Whether the developer chooses to change the location of development -- i.e., buy land and build in the Northern unzoned region rather than in the zoned region—and/or whether they choose to change the types of houses built (lot size and house size) depends on consumer preferences, construction costs, and land costs. As we expect, results depend on the stringency of the zoning.

[26] The zoned area was chosen to be at the far edge of the modeled region, and its size and shape was chosen to be about half of the overall land area.

Figure 4. Zoning Map



V.1. Number of Lots, Acreage, House Types, and Spatial Patterns of Development

Figure 5 shows the expected spatial pattern of development with maps for the two zoning cases at T=10 and T-20. For comparison purposes, we repeat the baseline maps from Figure 3. Figure 6 shows the number of units built at each time step, T=5, 10, 15, and 20, by lot size type and by region, North and South. Table 3 shows the total number of lots and acreage developed.

The maps make clear that the two zoning rules have quite different impacts on the spatial patterns of development. In the 2-acre zoning case, the location of development in T=10 is almost identical to the baseline scenario—i.e., most of the same farms are sold for development with and without zoning. The difference is that the land in the South in the 2-acre zoning case is developed entirely with 2-acre lots whereas in the baseline, a mixture of lot sizes is built. By the final period, T=20, development in the 2-acre zoning case is still mostly in the South.

When 5-acre minimum lot size zoning is imposed in the south, development clearly shifts to the North. As we saw in Table 2, no 5-acre lots are built in the baseline scenario; the combination of consumer preferences and housing construction costs led to this lot size being a sub-optimal choice for developers. As a result, the 5-acre zoning severely constrains developers. By T=10, all development takes place in the Northern unzoned region. This result is consistent with the findings in Sullivan (1986) where zoning in the suburbs shifts development to the city. By T=20, almost all of the farms in the North have been sold and development covers nearly 80 percent of the land area. This approach to “build-out” in the North leads to some development beginning to occur in the zoned South in the later time periods. We find, however, that development in the South does not occur until the last few simulation periods.

Figure 6 highlights the difference in lot types for the three cases, for four time periods. In all three cases, a mixture of lot types is chosen in the Northern region, which is unzoned in all cases. Interestingly, however, this region ends up with many more of the relatively large 1- and 2-acre lot sizes in the 5-acre zoning case. These lot types, which are prevalent in the South in the baseline, essentially shift northward when the southern land is zoned for 5-acre minimum lot sizes.

Figure 5. Spatial Patterns of Development, With and Without Zoning

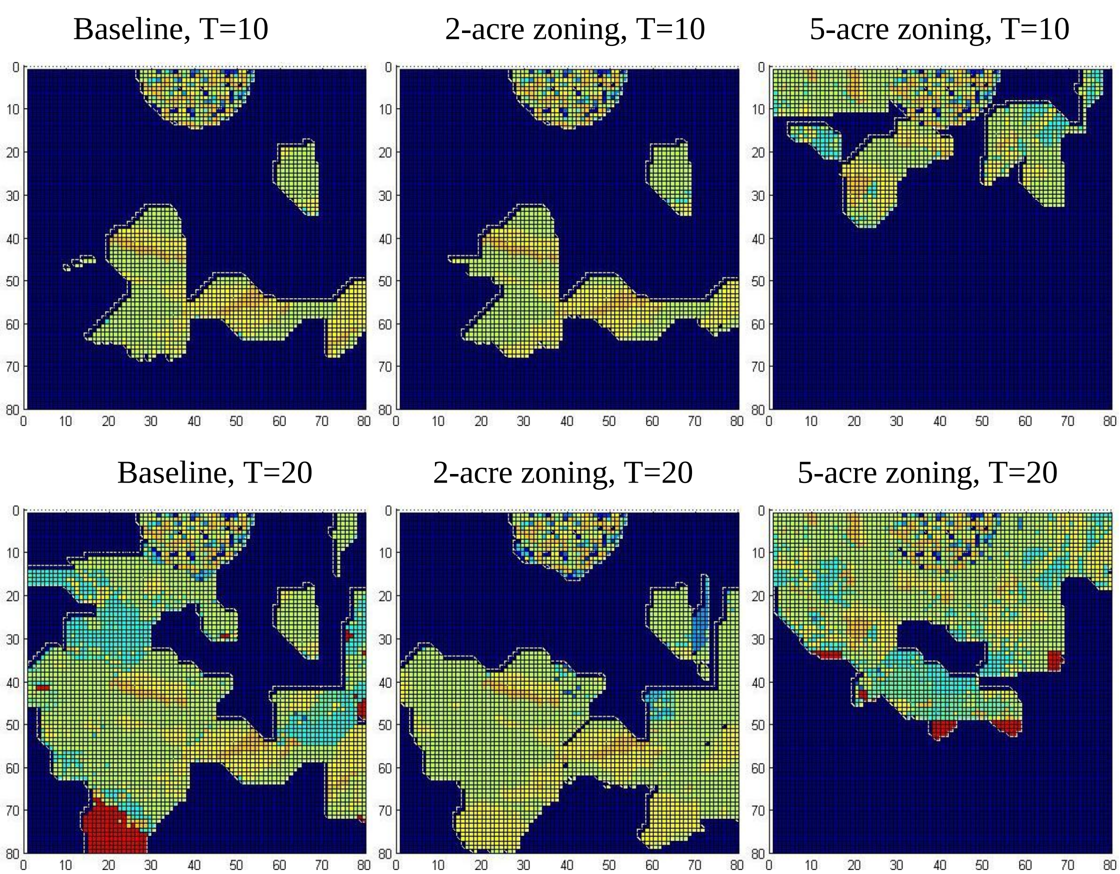
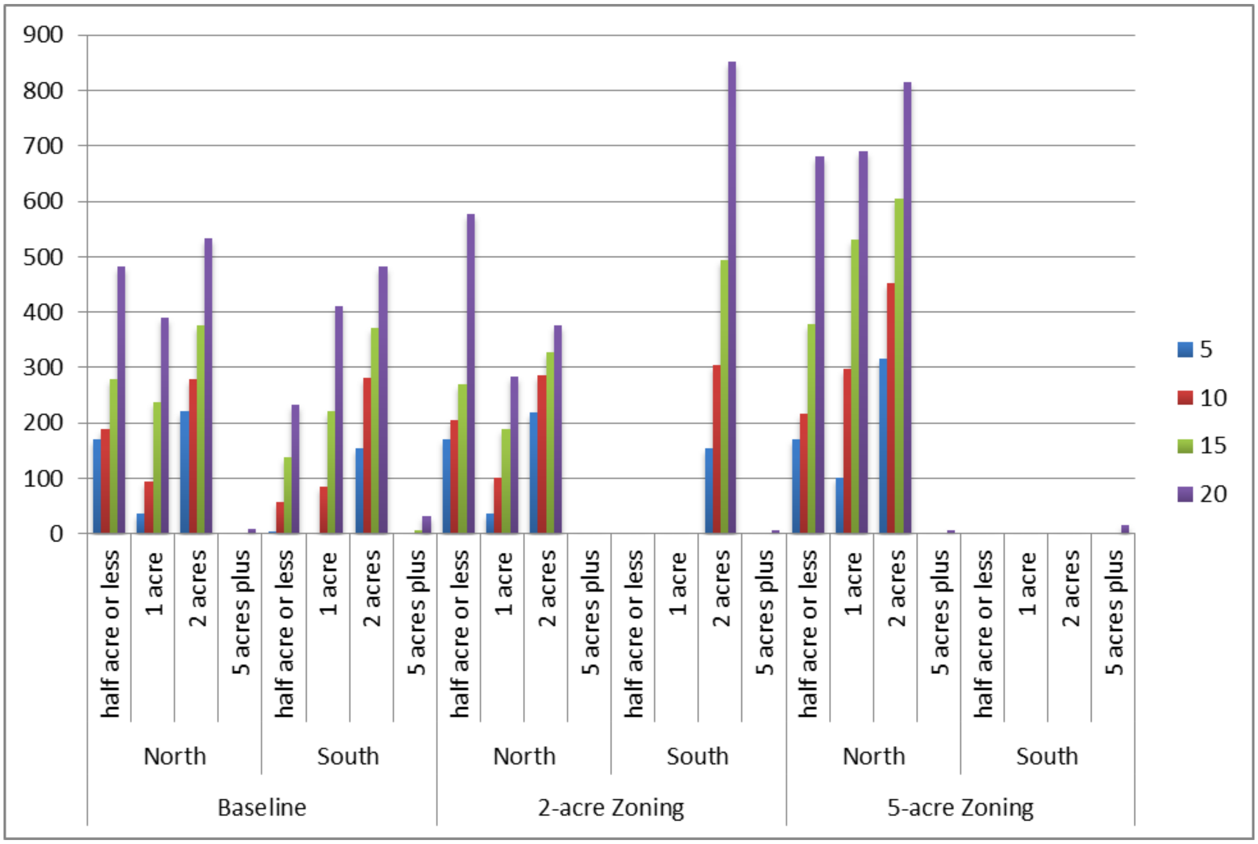


Figure 6. Numbers of Houses Built, by Lot Size, Region and Zoning Rules



It has been argued that large lot zoning can be used to slow growth and protect open space. Many observers feel that the policy has backfired, however, citing cases where the number of lots built drops with zoning but developed acreage actually increases thus exacerbating sprawl (Heimlich and Anderson, 2001). Table 3 shows the total number of lots and total acreage developed by time periods T=10 and T=20 (again, these are averages over the 30 model runs). Our results do not support the contention that large lot zoning increases total land conversion in either the 2-acre nor 5-acre cases. In both, the total number of lots developed and total acreage developed falls relative to the baseline. By T=20, 19 percent fewer lots are built in the 2-acre case compared with the baseline, and 14 percent fewer in the 5-acre case. Overall, 15 percent less land is converted from agriculture to development with 2-acre zoning and 21 percent less with 5-acre zoning.

It is interesting to note, though, that there is a bigger drop in lots than acreage in the 2-acre zoning case (19 percent versus 15 percent), but the reverse situation holds in the 5-acre case—acreage developed declines more than the number of lots (21 percent versus 14 percent).

The result in the 2-acre case occurs because a substantial number of 2-acre lots continue to be built, and because some building in the zoned area that was 1-acre lots in the baseline becomes 2-acre lots. This is the scenario that many critics of large lot zoning point to—development that does occur takes up more land area. In the 5-acre case, virtually all of the development moves to the Northern unzoned area, leaving almost all of the Southern acreage undeveloped. By the final period, only 5 percent of the land in the Southern region has been developed compared with 59 percent in the baseline; in the 2-acre zoning case, 57 percent of the land in the South is developed.

These findings reveal that it is the restrictiveness of zoning regulations relative to the underlying market conditions for density of development that are important for how zoning affects spatial and density outcomes. When the zoning rule is set for densities that are close to the underlying demand, as in the 2-acre case here, the changes in spatial patterns are minimal. In the case of 5-acre minimum zoning, the effects on what becomes economic to build in the south are substantial and more radical changes in both types of housing and spatial patterns occur.

Table 3. Total Number of Lots and Acreage Developed in Baseline and Zoning Cases

	Baseline		**2-acre Zoning**		**5-acre Zoning**	
	T=10	T=20	T=10	T=20	T=10	T=20
Total Lots	989	2,573	899*	2,096*	969	2,205*
Total Acres	1,393	3,553	1,355	3,018*	1,278*	2,798*

***** denotes statistically significantly different from the baseline at the 0.01 level; 2-acre and 5-acre results are statistically significantly different from each other at T=20 but not at T=10.

V.2. Density and Sprawl

As we explained above, we observe a declining density gradient in the baseline case as predicted by economic theory. Figure 7 shows this density gradient—i.e., average number of houses per acre at of all land at various distances starting at the edge of the SDD—for all three scenarios. This is a measure of the density of housing across all of land in concentric rings from the SDD. In all three cases, density declines with distance from the SDD, but it is not a smooth declining function of distance because of the many other factors in our model that affect development decisions and because of the fact that in our model entire farms are sold for development rather than individual acreage. The figure makes clear that the 2-acre zoning density gradient has the same general shape as the baseline density gradient but is shifted left, implying lower densities at most distances. Consistent with results in Pasha (1996), density is lower than the baseline at distances farther from the SDD. The 5-acre zoning requirement generates a density gradient that starts off with much higher density levels than the baseline—reflecting the shift to smaller-lot development in the Northern region that we showed above—but then has a sharp drop-off at the distance where the zoning constraint begins.

Figure 7. Average Housing Density by Distance from the SDD, T= 20

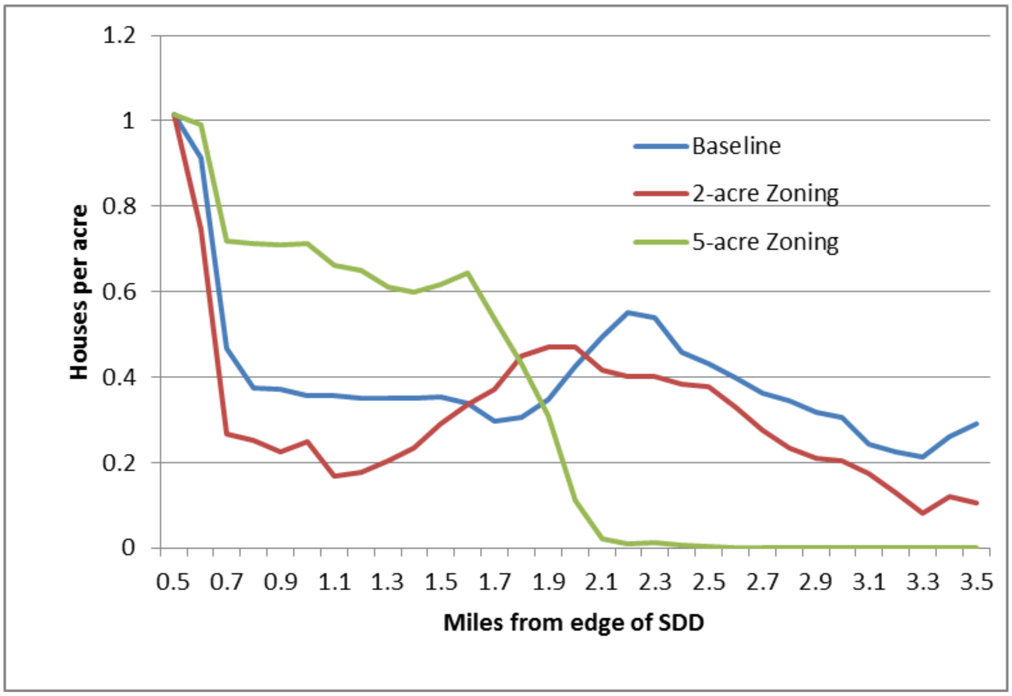


Table 4 sheds additional light on the density of development and includes statistics to measure the degree of sprawl. The estimated slope of the density gradients (as shown in Figure 7) in the first row of the table shows that the two zoning cases have steeper density gradients than the baseline, with the average slope in the 5-acre zoning case almost twice as steep as the baseline. We also show mean lot size of the developed regions, which is calculated as total acres in development divided by the total number of houses developed. Mean lot size is slightly larger in the 2-acre zoning case, with average lot sizes by year 20 of 1.44 acres compared to 1.38 acres in the baseline (significantly different from each other only at the 10% level). Lot sizes are smallest for the 5-acre zoning case at 1.27 acres, and this difference is statistically different from the baseline at the 1% level.

The mean dispersion is similar to calculations by Burchfield et al (2006) and Irwin and Bockstael (2007) and is a measure of the average degree of dispersion, or scatteredness, of development. We calculate the share of cells that are developed in a 1-kilometer radius around each 1-acre cell and then compute the average over the entire landscape. The 2-acre zoning case has slightly greater residential dispersion than the baseline, but the 5-acre zoning case has much less dispersion than either the baseline or the 2-acre case. The maximum linear distance of development metric, as shown in Table 4, says something about how far away from the SDD development is occurring. The numbers support the maps above in showing that the 2-acre development patterns are similar to the baseline while the 5-acre case results in development much closer to the SDD.

Table 4. Measures of Sprawl

	Baseline	2-acre Zoning	5-acre Zoning
Estimated slope of density gradient	-0.18	-0.19	-0.37**
Mean lot size by year 20 (acres)	1.38	1.44	1.27*
Mean dispersal index	0.27	0.29**	0.17*
Maximum linear distance of development (in miles)	3.38	3.30**	2.21*

***** denotes statistically significantly different from the baseline at the 0.01 level; ** denotes statistically significantly different from the baseline at the 0.05 level.

V.3. Effects on Land and Housing Prices

A sizeable literature, both theoretical and empirical, has focused on the extent to which zoning, including minimum lot size restrictions, has altered land and housing prices. Pogodzinski and Sass (1990) provide a review of the early literature and emphasize that model assumptions and the way that zoning is incorporated into models explains much of the differences in results. In a more recent review that focuses largely on empirical work, Quigley and Rosenthal (2005) find evidence to support the notion that land use regulations tend to increase house prices.[27] A series of empirical studies by Ed Glaeser and colleagues reaches the same general conclusion,

[27] Quigley and Raphael (2004), in their assessment of U.S. housing affordability and the key factors affecting house prices, cover some of the territory as well.

finding that most metropolitan areas are not seeing house prices rise because they are “running out of land” but because of land use regulations.[28]

As emphasized by Quigley and Rosenthal (2005), however, it is not a foregone conclusion that zoning will increase land prices. While bid prices should rise because of the supply restriction, the fewer lots allowed per acre will tend to lower land values. It is not clear, a priori, which of these effects will dominate.[29]

Figure 8 shows average land prices by region in our three scenarios. First, we compare the 2-acre zoning case to the baseline. Zoning increases land prices relative to the baseline in both the north and the south. The effect in the north is much larger, however, with the average price 24 percent higher than in the baseline. The increase in the north highlights the important implications that zoning in one region can have on adjacent regions (Pollakowski and Wachter 1990, Dalton and Zabel 2009). As population grows in our model, the lot size limits in the south mean that fewer people can locate there; in addition, the types of housing that can be built (larger lots) do not satisfy all of the consumer demand. Those consumers demanding lots smaller than 2 acres are pushed into a more limited land area in the North. The smaller impact on land prices in the south—prices are higher than in the baseline but the difference is small -- highlights the offsetting impacts that zoning has on land values in the zoned region: the increase in the bid-price for land due to the supply restriction roughly offsets the reduction in undeveloped (agricultural) land values due to the fact that fewer houses can be built on a given acreage.

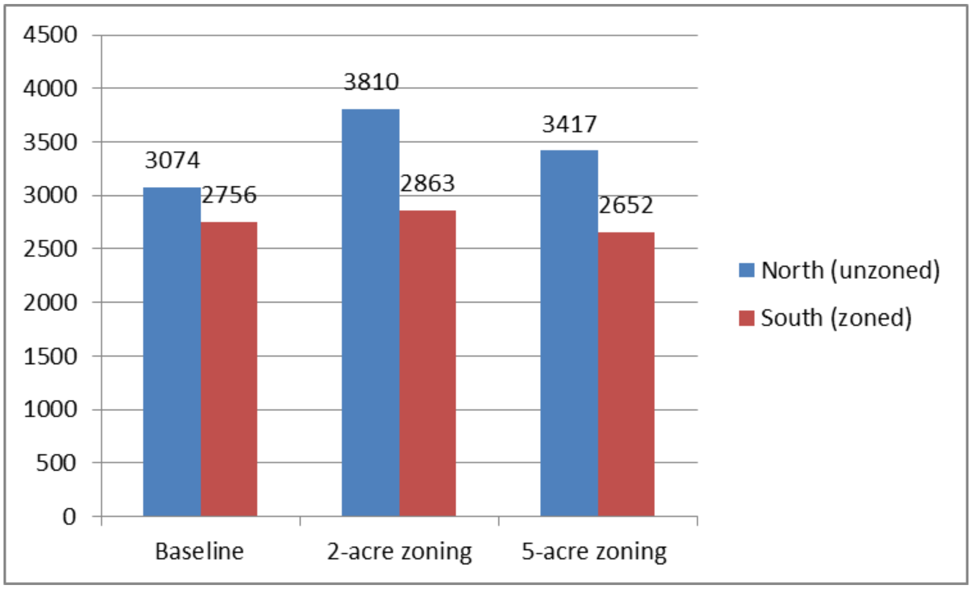
The story is similar in the 5-acre zoning case: land prices rise in the unzoned north as households bid for land there, though the effect on prices is not as great. This is in part because the lot sizes and house sizes tend to be smaller than in the 2-acre zoning case. One very different result in the 5-acre case is that land prices actually fall in the south meaning that in this case the substantial restriction in the type of housing that can be built (only 5 and 10 acre lots) dominates the effects on land prices. Our results thus emphasize the point made by Quigley and Rosenthal (2005) that there are potentially offsetting effects of zoning on land prices, and it appears from

[28] See Glaeser and Gyourko (2003) for a study using national data, Glaeser et al. (2005) for a study of Manhattan, and Glaeser and Ward (2009) for analysis of data from 167 municipalities and townships around Boston.

[29] If zoning internalizes local land use externalities—the argument often put forward in support of zoning (Crone 1983) —then housing demand will rise, driving up house prices, which in turn drives up land prices. Thus even if higher prices are observed, it is hard to know whether it is due to this externality-driven demand effect or due to a supply effect from the land-use restriction. Our model does not incorporate externalities and thus does not allow for this effect.

our results that those effects are likely to differ with the type and stringency of the zoning regulations.

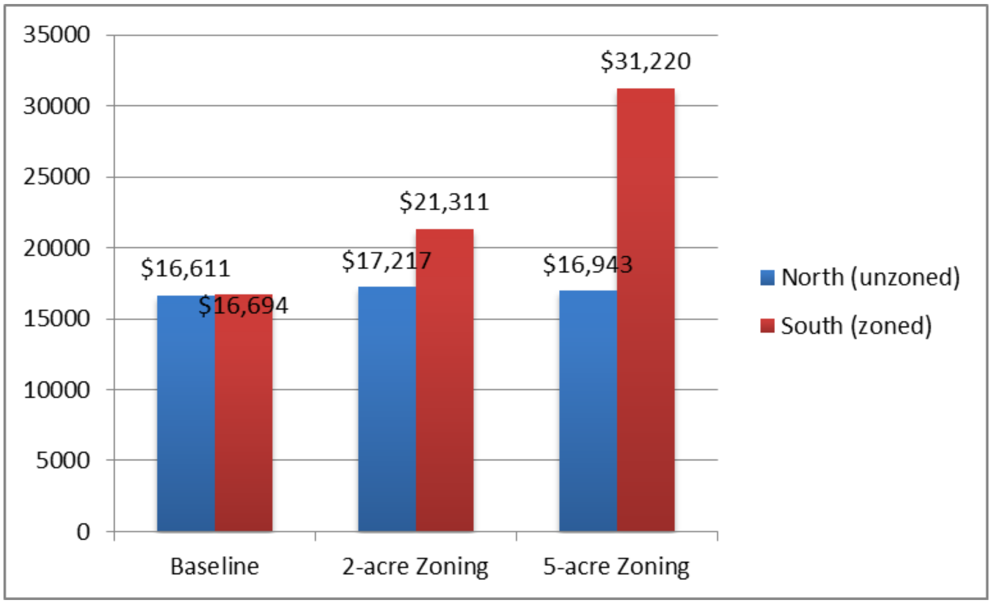
Figure 8. Average Land Prices for All Land Sales, in Baseline and Zoning Cases (in $ per acre)



Note: All land prices significantly different from each other at the 1% level.

Figure 9 shows weighted average housing rents in the final period for the three cases. Zoning increases average rents in both regions but particularly in the South as a result of the larger required lot sizes. Housing rents are 28 percent and 87 percent higher in the 2-acre and 5-acre cases, respectively, even though land prices are about the same or even lower in the 5-acre case. This is a direct result of the requirement that more acres must be used for each house. In fact, in the 5-acre zoning case, most of the houses built in the Southern zoned area have 10-acre lots thus the land costs rise significantly. It is important to note, however, that very few of these houses are being built and only in the latter part of the simulation period as demand pressures combined with land scarcity in the North push developers and consumers to the zoned region. Average housing rents in the northern unzoned region rise very slightly. An interesting finding from the model is that the upward pressure on housing rents is dampened by the developer altering the housing type mix. There is a shift toward smaller houses and houses on smaller lots, which are less costly to build. This choice over housing type is a key feature of our model.

Figure 9. Weighted Average Annual Housing Rents in Final Period, in Baseline and Zoning Cases



V.4. Effects on Income

The higher rents caused by zoning change the income distribution in the region. As we explained in the model description, although the number of people seeking to buy houses increases by 10 percent annually, not all of those people are able to get into houses in each period. As housing prices are driven up due to the zoning restrictions, fewer people from the lower end of the income distribution get into houses and the average income of residents rises. Thus, both types of zoning in our model appear to have exclusionary aspects, driving up house prices and incomes of residents (Bogart 1993; Ihlanfeldt 2004).

Table 5 shows the average yearly income of residents in the three scenarios for both the North and the South regions. In the South, the highest average incomes show up in the 5-acre zoning case. This is consistent with South housing prices, which are highest in the 5-acre case. But we hasten to point out, as we did above, that there are very few houses built in this region with 5-acre zoning and only in the later periods of the simulation. Average incomes in the South are also significantly higher in the 2-acre case than the baseline. Moreover, in the 2-acre scenario, these results have more economic significance since a substantial amount of development continues to take place in the South, in contrast to the 5-acre scenario and thus a large number of higher-income households are in the region. These findings appear to be consistent with the exclusionary zoning story—2-acre minimum lot size rules drive up house prices, lead to lower density development, and increase the average incomes of residents.

In the North, the highest average incomes are in the 2-acre zoning case and this too is consistent with our findings for house prices—in the North, the 2-acre zoning case generated the highest average house prices of the three scenarios. These higher house prices drive up incomes. The average income of residents in the North in the 5-acre case, however, is also significantly above that of the baseline.

Table 5. Average Income of Residents in Baseline and Zoning Cases (year 20)

	Baseline	2-acre Zoning	5-acre Zoning
North (unzoned)	$89,415	$98,652*	$96,893*
South (zoned)	$96,403	$112,430*	$152,182*
All	$92,446	$104,496*	$97,621*

* denotes statistically significantly different from baseline at 0.01 level; also the North and South areas are statistically significant from each other at the 0.01 in all cases; and 2-acre and 5-acre average incomes are significantly different from each other at the 0.01 level in the South, at the 0.10 level in the North.

VI. Conclusion

This study examines the effects of large lot zoning on the density and spatial patterns of development in a representative exurban area over time. The agent-based model that we use allows for a richer analysis of the results of zoning than previous studies in a number of ways. The spatial patterns of development both with and without zoning can be examined at the 1-acre cellular level across the entire modeled landscape, rather than by either simple linear distance from a central business district, by crude delineations such as city and suburb, or across large jurisdictions that are assumed to be homogeneous. The model runs show how spatial patterns evolve over time with individual agent decisions creating aggregate land use patterns from the bottom up. Agents optimize as in other economic models, but they are heterogeneous in a variety of ways that are likely to affect their housing and land market interactions, including in how they form expectations of future prices. Some path dependence in outcomes emerges as a result of these expectations, but fundamental economic features—agricultural productivity, consumer preferences and incomes, and developer costs—are also central to the results.

The model allows for a more nuanced interpretation of minimum lot size zoning than in most models. For one thing, the dynamic aspects of the model highlight how zoning makes its impacts felt gradually over time as population and demand pressures grow. It also allows for the effects of spillovers through the land and housing markets from one region to another. Additionally, the degree of detail in agent's decision-making processes—for example, the developer's and consumers' considerations of house size, lot size, and location—allows us to analyze a number of different features of the zoning outcomes such as the number of houses built, the lot sizes for those houses, and the location of development.

One key result is that the type and stringency of the zoning matters. We modeled two alternative zoning restrictions, imposing them on an outlying sub-region. The first, a 2-acre minimum lot size rule, ends up looking exclusionary in nature—it keeps the newly developing region in low-density development, raises house prices and raises the average income of residents. The second is a more restrictive rule—5-acre minimum lot sizes -- and it tends to keep zoned land undeveloped and push new houses to the unzoned region. This type of zoning acts as more of a growth control measure. The 2-acre case produces large lots overall and more sprawl development. The 5-acre case results in smaller lot sizes, and much contained development.

Empirical studies of minimum lot size rules have mostly focused on the impact on land and housing prices and most have found that prices increase with zoning. Here again our model is able to provide some more nuanced results. For example, our results highlight the offsetting effects of zoning on land values—i.e., we find that the lower development value of the land in the zoned region—fewer lots allowed per acres—offset by the higher bid price from the supply restriction. The degree to which it is offset varies across the two cases, however. In the 2-acre zoning case, the average land price is roughly the same as the baseline, but in the 5-acre case, the average land price is lower than the baseline, indicating that the lower development value of the land more than offsets the higher bid price. We also see the spillover impact on land prices in the unzoned region, where zoning in the south increases prices in the north. And the fact that the model includes a choice over lot and house sizes allows for housing price impacts from zoning to be mitigated, in part, by the developer shifting to smaller houses and/or houses on smaller lots. We observe this shift in our results.

Much work remains to be done to fully bridge the gap between the traditional economics and agent-based worlds. While we feel that this paper is a useful step in the process, further refinements of the model are likely to be in order. By abandoning the central feature of spatial equilibrium models, that all locational advantages and disadvantages are fully capitalized into equilibrium house (or land) prices, one is left to develop rules for assigning consumers to houses and for transactions between the developer and landowners. While our rules are based on standard optimizing behavior from microeconomics and on some common sense aspects of competition and bidding in markets (e.g., greater numbers of bidders for a house tends to drive up its price), thoroughly assessing how these rules affect the model outcomes will be important.[30] In addition, our land price prediction models are extended from approaches used in the ABM finance literature—a field in economics that has more fully embraced the ABM approach. Currently there is little information on how land owners and developers form expectations about prices, or how farmers make decisions about when and at what price to sell. Empirical evidence on these issues would allow us further refine and improve the model.

[30] In a companion paper, we conduct sensitivity analyses of several key parameters of the model (et al. 2011a) — farmland productivity, travel costs, and preferences for housing types. The results are intuitive and lend support to the model.

References

Arthur, W. B., 2006. Out-of-equilibrium Economics and Agent-based Modeling, in L. Tesfatsion and K.L. Judd (Eds.). Handbook of computational economics: Agent-based computational economics (Chapter 2, pp. 1551–1564). Amsterdam: Elsevier B.V.

Arthur, W. B., 1994. The El Farol Problem, American Economic Review Papers and Proceedings 84: 406 (May).

Axtell, R. 2005.,The Complexity of Exchange, The Economic Journal 115(504): F193-F210.

Bayer, P. ,Timmins, C., 2007. Estimating Equilibrium Models of Sorting Across Locations, The Economic Journal 57(3): 462-77.

Bogart, W.T., 1993. 'What Big Teeth You Have!' Identifying the Motivations for Exclusionary Zoning, Urban Studies, Vol 30: 1669-81.

Burchfield, M., Overman, H.G., Puga, D., Turner, M., 2006. Causes of Sprawl: A Portrait from Space. Quarterly Journal of Economics. No. 121: 587-633.

Calabrese, S., Epple, D.,Romano, R,., 2007. On the Political Economy of Zoning. Journal of Public Economics. 91(1-2): 25-49.

Calabrese, S., Epple, D.,Romano, R.., 2006. Non-Fiscal Residential Zoning, in W. Fischel (ed), The Tiebout Model at Fifty: Essays in Public Economics in Honor of Wallace Oates, Lincoln Institute of Land Policy: Cambridge, MA.

Coate, S., 2010. Property Taxation, Zoning and Efficiency. Working paper, Cornell Department of Economics, Ithaca, New York.

Carliner, M., 2002. New Home Structures and Land, Housing Economics. January.

Chen, Y, Irwin, E., Jayaprakash, C. 2011. "Incorporating Spatial Complexity into Economic Models of Land Markets and Land Use Change." Agricultural and Resource Economics Review. 40(3).

Chen, Y., Wrenn, D., Jayapradash, C., Irwin, E., 2009. Measuring and Simulating the Spatio-Temporal Land Use Pattern in the Exurbs of the Baltimore Region. Draft paper for the Regional Science Association International Meetings, San Francisco, November 18-20.

Chester County (Pennsylvania) Planning Commission, 2010. *Chester County Landscapes: Progress Report 2010*—Landscape Index. Available at http://www.chesco.org/webapps/planning/flipping_book/index2010/files/index2010.pdf.

Crone, T. M., 1983. Elements of an Economic Justification for Municipal Zoning, Journal of Urban Economics 14: 168-183.

Dalton, M., Zabel, J., 2009. The Impact of Minimum Lot Size Regulation on House Prices in Eastern Massachusetts. Economics Department, Tufts University.

Epple, D.Sieg, H., 1999. "Estimating Equilibrium Models of Local Jurisdiction," Journal of Political Economy 107(4): 645-81.

Filatova, T., Parker, D.C.,van derVeen, A., 2009. Agent-based urban land markets: Agent's pricing behavior, land prices and urban land use change, Journal of Artificial Societies and Social Simulation 12(13).

Filatova, T., Parker, D.C., van derVeen, A.., 2007. Agent-based land markets: Heterogeneous agents, land prices, and urban land use change, Proceedings of the 4th Conference of the European Social Simulation Associations (ESSA'07), Toulouse, France.

Fischel, W., 2000. Zoning and land use regulation, in: B. Boudewijn, G. De Geest (Eds.), Encyclopedia of Law and Economics, Volume II: Civil Law and Economics, Edward Elgar, Cheltenham, pp. 403–423.

Fodor, E., 1997. The Real Cost of Growth in Oregon, Population and. Environment 18(4) March.

Frank, J. E., 1989. The Costs of Alternative Development Patterns: A Review of the Literature. Urban Land Institute. Washington, D.C.

Glaeser, E.L., Gyourko, J., 2003. The Impact of Building Restrictions on Housing Affordability, Federal Reserve Bank of New York Economic Policy Review, 21-39 (June).

Glaeser, E. L. and Ward, B.A., 2009. The Causes and Consequences of Land Use Regulation: Evidence from Greater Boston, Journal of Urban Economics, 65 (3): 265-278.

Glaeser, E. L., Gyourko, J., and Saks, R.., 2005. Why is Manhattan So Expensive?: Regulation and the Rise in House Prices, Journal of Law and Economics 48(2): 331-370.

Glaeser, E. L., Schuetz, J., Ward, B., 2006. Regulation and the Rise of Housing Prices in Greater Boston, A study based on new data from 187 communities in eastern Massachussetts. Harvard University, Pioneer Institute for Public Policy Research, Boston.

Gottlieb, P. D.,Adelaja, A., 2009. The Impact of Down-Zoning on Land Values, Agricultural Finance Review, 69(2): 206-277.

Heckbert, S., Baynes, T., Reeson, A., 2010. Agent-based Modeling in Ecological Economics, Annals of the New York Academy of Sciences 1185: 39-53.

Heimlich, R. E., Anderson, W.D., 2001. Development at the Urban Fringe and Beyond: Impacts on Agricultural and Rural Land. USDA, Economic Research Service, Agricultural Economic Reports: No. 33943.

Ihlanfeldt, K.R., 2004. Exclusionary Land-Use Regulations Within Suburban Communities: A Review of the Evidence and Policy Prescriptions. Urban Studies, Vol. 41:261-83.

Irwin, E., 2010. New Directions for Urban Economic Models of Land Use Change: Incorporating Spatial Dynamics and Heterogeneity, Journal of Regional Science 50(1): 65-91.

Irwin, E.,Bockstael,N., 2007. The Evolution of Urban Sprawl: Evidence of Spatial Heterogeneity and Increasing Land Fragmentation, Proceedings of the National Academy of Sciences, 104(52): December.

Juntunen, L.,Knaap, G.,. 2011. Fiscal Impact Analysis and the Costs of Alternative Development Patterns, Oxford Book of Planning and Urban Economics, Oxford University Press, forthcoming.

Kuminoff, N. V., Smith, V.K., Timmins, C.. 2010. The New Economics of Equilibrium Sorting and its Transformational Role for Policy Evaluation, NBER Working Paper 16349 (September).

Lichtenberg, E., Tra, C., Hardie, I., 2007. Land Use Regulation and the Provision of Open Space in Suburban Residential Subdivisions, Journal of Environmental Economics and Management 54: 199-214.

Liu, X.,Lynch, L., 2010. Do Land Use Regulations Rob Rural Landowners' Equity? University of Maryland Department of Agricultural and Resource Economics Working Paper.

Magliocca, N., V. McConnell, and M. Walls. 2011a. "Explaining Sprawl with an Agent-Based Model of Exurban Land and Housing Markets." RFF Discussion Paper No. DP 11-33, Resources for the Future, Washington, D.C. Magliocca, N., McConnell, V., Walls, M.,, Safirova, E.,. 2011b. An economic Agent-Based Model of Coupled Housing and Land Markets, Computers, Envioronment, and Urban Systems 35(3): 183-191 (May).

McConnell, V., Walls, M., Kopits, E., 2006. Zoning, TDRs, and the Density of Development, Journal of Urban Economics 59 (September): 440–457.

McMillen, D. P.,1989. An Empirical Model of Urban Fringe Land Use, Land Economics 65(2): 138-145 (May).

McMillen, D. P.,McDonald, J.F., 2002. Land Values in a Newly Zoned City, Review of Economics and Statistics, 84: 67-72 February.

McMillen, D. P., McDonald, J.F., 1991. Urban land Value Functions with Endogenous Zoning, Journal of Urban Economics 29: 14-27.

Mills, E. S., 2005. Why Do We have Urban Density Controls? Real Estate Economics 33(3): 571–585.

Moss, W.., 1977. Large Lot Zoning, Property Taxes, and Metropolitan Area, Journal of Urban Economics 4: 408-427.

O'Sullivan, A., 2009. Schelling's Model Revisited: Residential Sorting with Competitive Bidding for Land, Regional Science and Urban Economics 39: 397-408.

Parker, D. C., Filatova, T., 2008. A Conceptual Design for a Bilateral Agent-based Land Market with Heterogeneous Economic Agents, *Computers*, Environment and Urban Systems 32: 454-463.

Parker, D. C., Manson. S., Janssen, M., Matthew Hoffmann,and Peter Deadman., 2003. "Multi-agent Systems for the Simulation of Land-use and Land-cover Change: A Review," Annals of the Association of American Geographers 93(2): 314–337.

Pasha, H.., 1996. Suburban Minimum Lot Zoning and Spatial Equilibrium, Journal of Urban Economics 40(1): 1-12.

Pogodzinski, J. M.,Sass, T.R., 1990. The Economic Theory of Zoning: A Critical Review, Land Economics 66(3): 294-314 (August).

Pollakowski, H. O., Wachter, S.O., 1990. The Effects of Land-Use Constraints on Housing Prices, Land Economics 66 (3): (August).

Quigley, J., Raphael, S., 2004. Is Housing Unaffordable? Why Isn't It More Affordable? Journal of Economic Perspectives 18(1): 191-214 (Winter).

Quigley, J., Rosenthal, L., 2005. The Effects of Land-Use Regulation on the Price of Housing: What Do We Know? What Can We Learn? Cityscape 8(1): 69-138.

Safirova, E.,, Houde, S,. Lipman, D.A.,,Harrington, W.,Baglino. A., 2006. Congestion Pricing: Long Term Economic and Land-Use Effects, Resources for the Future Discussion Paper 06-37 (September).

Sullivan, A. M., 1984. Large-Lot Zoning as Second-Best Policy, Journal of Regional Science 24(4): 581-589.

White, M., 1975. The Effect of Zoning on the Size of Metropolitan Areas, Journal of Urban Economics 2: 279-290.