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Analysis

Exploring sprawl: Results from an economic agent-based model of land and housing markets

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ABSTRACT

This paper uses an economic agent-based model of land use in a growing community on the urban fringe to explore the importance of key economic variables on the spatial patterns of development over time. Understanding dispersed patterns of urban development is important for designing policies for mitigating the environmental and other adverse effects of urban “sprawl”. The model includes as agents heterogeneous farmer/landowners and housing consumers, and a representative developer who buys land and builds houses. Underlying economic behavior of consumer utility maximization and developer and farmer profit maximization is assumed. A unique feature of the model is that housing is characterized by variation in both lot size and house size, allowing for exploration of the effects of changes in key parameters on both land and housing markets and the interaction between them. The paper explores the relative importance of consumer preferences, spatial distribution of agricultural productivity, and travel costs in creating sprawling development patterns. Consumer preferences for large lots do result in more land in development and lower density, but leap frog development in the model appears to be driven by other economic influences as well. And, in general, more stable housing prices mute the effect of more variable land prices and tend to dampen the effects of economic shocks to the urbanizing area.

1. Introduction

Residential development patterns defined by discontinuous or “leapfrog” development and large average lot sizes are characteristic of American exurbia. Some of the costs associated with these “sprawl” patterns of development may include increased congestion and air pollution from greater vehicle travel, reduced ecosystem services from either deforestation or reduced connectivity of natural areas, and loss of local farmland (Camagni et al., 2002; National Research Council, 2000; Pickett et al., 2011). Communities across the United States have implemented a variety of programs and policies to combat sprawl. But evaluation of these efforts is difficult because the complexities of the urban development process make it hard to disentangle the effects of the policies from other influences on urban structure over time (Quigley and Rosenthal, 2005). Many traditional urban economic models that might be used for such policy analyses fall short in their ability to incorporate heterogeneity in agents and the landscape, and the dynamic process of development over time. Modeling approaches used in other disciplines often do not capture the fundamentals of markets and prices.

In this paper, we use a simulation model of land and housing markets to examine dispersed development patterns, and variables that may influence those patterns. The model builds in important features of urban economic models—namely, agent optimizing behavior and market prices—but has more heterogeneity in agents and the landscape than these traditional economic models typically have. The model is an economic agent-based model (ABM), in which macro-scale patterns emerge from many explicitly modeled micro-scale interactions among individual agents. The agents in the model include farmer/landowners, a developer who buys land and builds houses, and consumers who purchase housing. Agent heterogeneity is incorporated in preferences, income, and price expectations, and the landscape reflects heterogeneous productivity of land in farming and is modeled at the 1-acre “cellular” level. We model a hypothetical exurban area calibrated to data from the Mid-Atlantic region of the United States and use the model to study the timing and patterns of land conversion from agriculture to housing development as the population grows over time.

Urban economics models in the Alonso–Muth–Mills tradition do not typically derive sprawl as an equilibrium outcome (Alonso, 1964; Muth, 1969; Mills, 1967). Variations of the model have incorporated such

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features as spatially varying amenities, traffic congestion, endogenous open space, zoning, housing development costs that vary spatially, or lags in the development process. These models have been able to generate equilibria with some of the features of sprawl, such as increasing density gradients, dispersed development patterns, spatial externalities, and leapfrog development (Pasha, 1996; Peiser, 1989; Bar-Ilan and Strange, 1996; Irwin and Bockstael, 2002; Wu and Plantinga, 2003; Turner, 2005; Wu, 2006; Caruso et al, 2007; Newburn and Berck, 2011). Dynamic versions of the model with either myopia or perfect foresight about future land prices can also generate spatial patterns that differ from the standard result (Wheaton, 1982). However, due to challenges in finding an analytical solution and/or model complexity, traditional urban models characterize either some agent heterogeneity or some heterogeneity in geography but not both (Parker and Filatova, 2008; Huang et al., 2014).

Newer equilibrium sorting models in the Tiebout (1956) tradition allow for more spatial variation, focusing on the sorting of individuals across communities with different levels of public goods and accompanying taxes (Epple and Sieg, 1999; Bayer and Timmins, 2007; Kuminoff et al., 2010; Epple et al., 2010). But the models do not address sorting within communities and at the finer level of geographic detail that is essential for understanding the effects of sprawl. Moreover, they abstract from the dynamic aspects of development.[1]

Another strand of the economics literature uses econometric approaches to identify the influences on land use transitions over time (Bockstael, 1996; Lewis and Plantinga, 2007, and Lawler et al., 2014). A similar approach in the geography literature relies on heuristic rules for when and where development will occur (Wu, 2002; Veldkamp and Fresco, 1996) or on empirically-based probabilities of land use change (Allen and Lu, 2003). All of these models are based on data from a particular region, but it is often quite difficult to calibrate predicted land use changes to actual changes, and the models lack some generality in their findings. In addition, they cannot fully account for heterogeneity either in consumer characteristics and preferences, or in particular land use types.

Our model is part of the family of agent-based models of urban growth that have become more prevalent over the last several years (Huang et al., 2014). Because ABMs take a bottom-up simulation approach, they can overcome some of the limitations of traditional urban economic models to represent fine-grained, spatially heterogeneous processes and features such as localized sorting (Parker and Filatova, 2008; Huang et al., 2014). Existing urban ABMs vary in their level of agent heterogeneity, realism of market interactions, and particular features of interest. For example, Filatova et al. (2011b) incorporate endogenous price formation and competitive bidding mechanisms to model the transactions of farmer/landowners and consumers and trace out the conversion of rural land to developed uses. Robinson et al. (2013) focus on the role of heterogeneous developers within a land market framework of bilateral price negotiations. Sun et al. (2014) explore how varying levels of market sophistication influence development patterns, and Huang et al. (2013) investigate the effects of various sources of agent heterogeneity on market outcomes.[2] Ettema (2011) and Geanakoplos et al. (2012) develop economic housing market ABMs but do not incorporate land markets and land use change.

Our dynamic economic ABM shares some elements with these models, but is also unique in that it explicitly models both housing and land markets and the interactions between them. While we abstract from some of the features included in other ABMs (e.g., multiple developers, subdivision-level developments, and endogenous relocation), the model includes heterogeneity across agents and the landscape, and is capable of investigating how changes in landscape and consumer preference heterogeneity drive housing market dynamics, and how those dynamics translate into alternative land prices, timing of land sales, path dependence,[3] and location and density of development. Huang et al. (2013) find that the more sources of heterogeneity in an ABM model, the more complex the collective effects on model outcomes, including possible offsetting effects. This paper builds on previous work with the model (Magliocca et al., 2011, 2012) to explore the effects of agent and landscape heterogeneity, focusing on key economic inputs to the model and their effects on the landscape. We pay particular attention to the effects of consumer preferences for lot size and house size on land and housing market outcomes.

The model simulations reveal some aspects of sprawl—namely, development occurs in a leapfrog pattern in which some agricultural land remains near the city center while areas farther away are developed. At the same time, the model also confirms some of the key features of traditional urban economic models, such as generally declining average density and land price gradients. Moreover, alternative scenarios in which we alter agricultural productivity and travel costs to the city center confirm results predicted by economics: productivity helps determine which farms are first to convert to development and higher travel costs lead to more development closer to the city center. Other results are more unexpected but plausible. For example, variations in agricultural productivity decline as a factor in land prices as the area grows over time; farmer expectations of the value of land in development become more important in determining prices and development patterns.

A long-standing debate in the urban planning and economics literatures concerns the question of whether, and to what extent, sprawl development patterns in the U.S. are merely a result of consumer preferences and land values or are a consequence of market failures (Irwin and Bockstael, 2002; Ewing, 1997; Gordon and Richardson, 1997). We examine the role of consumer preferences in our model by analyzing scenarios in which the distribution of preferences for lot size and house size are altered from the baseline model runs. We find that when lot size is relatively less preferred to house size, denser development results; if lot size is relatively more preferred than house size, the opposite is true—i.e., development tends to be less dense. Leapfrog development continues to occur in these alternative scenarios, however. Many observers have pointed out that sprawl is characterized by different features—low average density, dispersed development, and leapfrog development, for example. In our model with many sources of heterogeneity represented, we find that consumer preferences affect density, but scattered and leapfrog development is also due to other factors that influence land values.

The changes in model parameters that we examine here—agricultural productivity, travel costs, and consumer preferences—also have implications for prices. A general observation across all of the scenarios is that land prices always show much more variation than housing prices. This is because consumers can adjust their choices of housing types and location in response to perturbations to the model; these adjustments, combined with the fact that we allow for entry and exit to the area, keep housing prices from rising too much. These findings about prices make economic sense: the fixed factor tends to bear the burden of economic or policy changes.

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[1] Bayer et al. (2011) is an exception; the authors build in housing market dynamics in an equilibrium sorting model.

[2] Some of these papers were written by researchers in the National Science Foundation-funded SLUCE project. SLUCE stands for Spatial Land Use Change and Ecological Effects. For more information, see http://vserver1.cscs.lsa.umich.edu/sluce/.

[3] Path dependence refers to a pattern in system dynamics in which the sequence of past events makes the occurrence of particular events more or less likely in the present and/or future. For example, in exurban context, the development of a parcel of land establishes infrastructure and market demand in that area, which makes it more likely that further development will occur there in the future (Brown et al., 2005).