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New Directions for Urban Economic Models of Land Use Change: Incorporating Spatial Heterogeneity and Transitional Dynamics

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Introduction

Key policy questions concerning global environmental change center on the multiple feedbacks between humans and natural systems (Grimm et al. 2008a; Levin 2006; Lui et al. 2007; Pickett et al. 2001; Turner et al. 2007), including the cumulative environmental impacts of individual and community resource decisions and the behavioral responses of individuals to policies that seek to manage these impacts (Daily et al. 2009). Among human-induced impacts, land use is second only to climate in its effects on the functioning of the Earth's terrestrial and aquatic ecosystems (Grimm et al. 2008a). Urban and urbanizing land, while only a small fraction of the total land area worldwide, generates a disproportionate share of environmental impacts (Alberti 2005; Collins et al. 2000). A growing interest in the underlying processes of land use and land cover patterns among biophysical scientists has led to increased emphasis on a "more humanist perspective" within these sciences (e.g., Wu and Hobbs 2002) and for integration of socioeconomic and demographic models of human settlement, consumption and land management dynamics with biophysical models (Grimm et al. 2008b, Pickett et al. 2001). In a recent list of the "ten top research questions" in landscape ecology, for example, research on the causes and processes of land use and land cover change was described as one of the most important and challenging research areas (Wu and Hobbs 2002). Research funding agencies, most notably the National Science Foundation, now allocate considerable funds annually to interdisciplinary research on human-environment interactions.

In many ways, economists are well-positioned to respond to these calls for greater integration of behavioral land use and biophysical models and indeed some have done so. Questions of household and firm location decisions, land use and land development decisions are central to urban and regional economics and have spawned a rich and diverse body of theoretical and empirical work. However, differences in research questions, methods and data traditionally led ecologists and economists to emphasize different aspects of land use and land cover change. Many of these differences persist today. For example, economists have focused on development decisions by landowners or location decisions of households and firms at an individual level within an aspatial or highly stylized spatial setting. This approach has permitted consideration of key dimensions of decision making, e.g. durability of capital (Harrison and Kain 1974; Anas 1978), intertemporal decisions (Arnott 1980; Capozza and Helsley 1989; Fujita 1982; Ohls and Pines 1975) and uncertainty (Mills 1981; Capozza and Helsley 1990), and how these features influence the resulting price gradient and land use pattern. These models posit that transportation costs generate smooth spatial variation across an otherwise featureless plane. Other forms of spatial heterogeneity, particularly those that are discrete and locally varying, have been considered in empirical modeling, but largely abstracted from in theoretical models of land use. On the other hand, ecologists consider spatial heterogeneity at all spatial scales to be a central causal factor in ecological systems (Alberti 2005; Grimm et al. 2008b; Pickett and Cadenasso 1995; Pickett et al. 2001) and the spatial and temporal dynamics of land use are viewed as fundamental questions.

The goals of this paper are two-fold: (i) to assess the usefulness of urban economic models for the study of human-environment interactions and for policy analysis in this area and (ii) given the current limitations of these models in this regard, to discuss the advantages of integrating economic fundamentals with agent-based models that permit greater policy realism and model flexibility. In assessing the utility of current economic models of urban land use, I find that meaningful progress has been made in econometric-based models that account for multiple sources of spatial heterogeneity and that then use spatial simulation to generate land use pattern predictions. In addition, economists have started grapple with the theoretical and policy implications of greater spatial complexity generated by local land use externalities. However, little progress has been made in developing structural economic models that incorporate spatial heterogeneity and link individual decisions to dynamic land use patterns that evolve over time. This is largely due to the central assumption of urban economic models, that urban spatial structure can be reasonably characterized by spatial equilibrium. While this assumption greatly facilitates modeling of land markets, it creates an obvious roadblock to modeling the transitional (i.e., out-of-equilibrium) dynamics of land use patterns. As a result, many of the recent spatial models of land use that characterize its evolution over time have been developed outside of economics, spurred by a diversity of research interests across a variety of disciplines. Agent-based models (ABMs) of land use change are at the forefront of the most recent wave of simulation-based modeling and increasingly are being adapted by every discipline save economics as the land use modeling method of choice. Economists have been slow to embrace this approach, perhaps because these models typically omit any explicit representation of land markets and thus have not attracted the interest of economists. On the other hand, the methodology permits structural modeling individual behavior, multiple sources of spatial and agent heterogeneity and, because the simulation approach allows one to "step the system through time," ABMs provide a ready means to modeling transitional dynamics. The gains to applying urban land use ABMs to policy analysis are substantial due to greater model flexibility and realism that allow one to investigate, for example, heterogeneous individual responses to a spatially delineated policy and their cumulative effect of the policy on ecosystem services. While the fixed costs of learning a new method and the hard work of integrating economic fundamentals into these "bottom-up" models are not trivial, I conclude that the consequences for economists remaining on the sidelines are far more costly.

Before proceeding, it is useful to clarify terminology. First, the word **structural** is used in the economic sense of a model with structural parameters that correspond to an economic process, e.g., the parameters of a land developer's cost function or of a household's demand function. Structural models are akin to what ecologists call **process-based** models and are distinguished from **pattern-based** models. Much like reduced form models in economics, pattern-based models describe correlations between observed patterns and other observable variables. Patterns, either static or evolving over time, are the outcomes of processes. Patterns are revealed by spatial land use/land cover data, but processes are not. A process-based model focuses on the structural foundations of the observed outcomes that in aggregate generate the observed land use pattern. Second, a distinction is made between processes that are in **equilibrium** (constant over time) versus those that are dynamic (transitioning over time). Economists also use the word dynamic to mean forward-looking expectations, i.e., individual decisions are dynamic if they consider future expected benefits and costs. It is common to have an economic model of dynamic decision making at an individual level (e.g., intertemporal choice of land development) that describes a static spatial equilibrium at an aggregate level. To avoid confusion, we refer to dynamic decision making at an individual scale as **forward-looking behavior** and use the term **transitional dynamics** to refer to a process that is not in equilibrium. Third, we use the term **spatially heterogeneity** to mean spatial variations at local scales, e.g., land parcel or a local neighborhood around a given location. Lastly, the term **spatial dynamics** is used to imply a transitional dynamic process of changes in spatial pattern over time.

Some Ecological Considerations of Urban Land Use Pattern

To motivate the need for dynamic models of land use change that incorporate multiple sources of spatial heterogeneity, it is useful to consider some basic ecological principles from landscape and urban ecology that highlight the importance of space and spatial dynamics. Ecologists' study of landscape processes and patterns emphasizes the critical role of space at all spatial scales. Multiple local sources of spatial heterogeneity create discrete differences in ecosystem function across the landscape. This has led landscape ecologists to focus on the spatial heterogeneity of landscapes as a primary aspect of linking ecosystem processes and pattern. The spatial landscape "patch" is a basic building block for ecological landscape research. A landscape patch is defined as a relatively homogeneous area that differs from its surroundings in terms of key ecological features, including land use and land cover (Forman 1995). Depending on the landscape and level of urbanization, patches with natural vegetation (e.g., forests, grasslands, wetlands) may vary from large contiguous blocks in more rural areas to smaller, more isolated patches in urban areas to larger, but highly fragmented patches in suburban and exurban areas. For example, in a novel study of land cover patches distinguished by differences in vegetation structure and other relevant factors, Cadenasso et al. (2009) report that the average patch size in an urbanized watershed in Baltimore, Maryland was approximately 18 acres, ranging from less than a quarter of an acre to just under 1800 acres in size. Ideally a behavioral model of land use change would be capable of generating land use and land cover change predictions at a similar minimum resolution (e.g., a quarter acre plot) to facilitate integration with a biophysical model based on this definition of land patches.

From an ecological perspective, urban development affects the patch structure of natural areas by altering its spatial pattern. Patch structure, including the shape, size edge and connectivity of natural patches, is important to species habitat, resource availability, competition and hence species survival (Alberti 2005). Connectivity of natural patches is critical for facilitating the movement of resources and organisms (Turner and Gardner 1991). Spatial patch dynamics (i.e., changes in the configuration of patches over time) is equally critical for ecosystem function (Pickett and Rogers 1997). For example, the water quality of urban streams is largely determined by the dynamics of soil erosion, sediment transport and alterations in the timing and delivery of nutrient transport (Pickett et al. 2001). The timing and quantity of nutrients delivered and the ability of streams to effectively process nutrients are strongly influenced by the spatial pattern of land uses in the watershed, e.g., the presence of riparian buffers, and their changes over time (Groffman et al. 2003).

Cadenasso et al. (2006) outline three critical dimensions of spatial complexity of ecosystem structure: heterogeneity (patch patterns), connectivity (patch functions) and contingency (patch history). Complexity in ecosystems is characterized by increasing spatial and temporal complexity in any of these three dimensions. Complexity in heterogeneity is described by the shifts in the mosaic of spatial patches across time and space; complexity in connectivity is embodied by dynamic interactions among patches that influence the functional dynamics of patches at individual and aggregate scales; and complexity in historical contingency is characterized by historical "legacy effects," in which past states influence current functioning, and slowing emerging effects that influence current functioning and result from the evolution of one or more variables over a long period of time. They argue that all three dimensions are critical to the empirical study of urban ecosystems that are characterized by many interacting ecological and social processes at multiple spatial and temporal scales.

In summary, an understanding of the ecological processes that generate changes in ecosystem services requires an approach that accounts for spatial heterogeneity and interactions across multiple spatial and temporal scales. Likewise, an understanding of how individual decisions and actions impact ecological processes requires a model that can account for the location of human activity and changes in these activities at multiple spatial and temporal scales.

Economic Models of Urban Land Use Pattern with Spatial Heterogeneity

A non-scientific review of the recent literature on urban land use modeling published since 2003 reveals two striking facts (see Table 1 and Figure 1):

- Many researchers other than economists are actively modeling urban land use patterns. In fact, out of the 100 papers that most closely met the criteria of developing an empirical, analytical or simulation model of urban land use change, only 26 were published in an economics journal.

- Modeling methods vary dramatically across disciplines. Differences across disciplines are most evident between economics and quantitative geography (or GI Science as it is now called). Over 60 percent of the papers published in economics journals were statistical, either in their entirety or with a spatial simulation extension; another 30 percent were analytical, either entirely or with a simulation extension. In contrast, 94 percent of the papers published in geography were simulation models, specifically either cellular automata (CA) or agent-based models (ABMs).

To be fair, CA and ABMs often use statistical analysis to parameterize the model and ABMs can be grounded in one or more theories of agent behavior. However, the distinctions shown in Figure 1 are nonetheless meaningful, as I explain in further detail below, and signal substantial differences in perceptions of the fundamental features of urban land use processes.

In reviewing models of urban land use change, I focus on economic models that generate predictions of land use pattern derived from structural economic models of land development decisions or residential location choice. In addition, the focus is on models that have explicitly incorporated spatial heterogeneity of landscape characteristics at a local (e.g., land patch or parcel) scale. This precludes much of literature in urban and regional economics on location and land use, including the canonical urban economic model, the monocentric model. Because this model only allows for a single source of spatial heterogeneity—transportation costs to a central location—it is of limited value in addressing ecological questions and I do not focus on it here. However, I do review several models that have extended this basic model to include other sources of spatial heterogeneity and thus, this model remains an important foundation for more realistic spatial models.

Econometric Land Use Models with Spatial Simulation

Econometric models of land use change derive from economic models of individual land use decisions in which landowners choose a land use in a given time period such that net expected returns over time are maximized. The theoretical framework for these models is well-established in urban economics (e.g., Arnott 1980; Arnott and Lewis 1979; Capozza and Helsley 1989, 1990; Capozza and Li 1994). While the models vary in their assumptions about space, expectations, durability of capital and uncertainty, they are forward-looking given that landowners make intertemporal land use decisions conditional on expectations over changes in land rents, e.g., due to population growth.

Econometric-based models of spatially heterogeneous land use patterns proceed in two steps. First, the econometric model is specified based on hypotheses regarding the factors that influence expected land rents, which typically include multiple spatially heterogeneous landscape and location features and policy constraints. This model is then estimated using spatial micro panel data on land use over time at the scale of land ownership, e.g., land parcels, and additional spatially detailed data on the factors hypothesized to influence expected land rents. A variety of estimation models are possible, including binary or multinomial discrete choice models (Bockstael 1996; Nelson and Hellerstein 1997), duration models that account for time-varying variables (Irwin and Bockstael 2002; Towe et al. 2008) and option value models that account for the influence of uncertainty over future prices (Cunningham 2007; Towe et al. 2008). Second, parameter estimates are used to simulate hypothetical changes in land use pattern, e.g., under baseline and alternative scenarios, using a spatially explicit, GIS-based model of the actual landscape. This permits the role of individual-level factors in generating regional land use patterns, including land use policies and other spatially heterogeneous features of the landscape, to be investigated. The results can then be compared using spatial statistics or landscape metrics to draw conclusions regarding the predicted influence of these factors on the concentration, fragmentation or other spatial dimensions of land use. This two-step approach has been used to model urbanization and sprawl (e.g., Carrion-Flores and Irwin 2004; Irwin and Bockstael 2002); the effects of land policies on urbanization patterns (e.g., Irwin et al. 2003; Irwin and Bockstael 2004; Langpap et al. 2008; Lewis et al. forthcoming; Newburn and Berck 2007); and the conversion of forest and agricultural land (e.g., Lewis and Plantinga 2007). Because of their ability to account for multiple sources of spatial heterogeneity, ecological features can be readily incorporated. In addition, the land use simulations can be linked with environmental impact models in which land use is the driver of environmental change to permit a fuller examination of the predicted effects of policy and other variables on ecosystem services. This approach has been used, for example, to study the impacts of conservation payments on landowner decisions and biodiversity loss (Lewis et al. 2008), the effectiveness of targeting strategies on land conservation (Newburn et al. 2006) and the effect of land use policies on watersheds (Langpap et al. 2008).

A number of econometric challenges arise in estimating these models, including spatial dependence, endogenous regressors, spatial instability of parameters, and selection bias. If ignored, these problems will lead to biased or inconsistent estimates and are thus inappropriate for hypothesis testing and spatial prediction. Making a concerted effort to obtain consistent, unbiased estimates is critical for the land use simulation, since the goal of the simulation is to understand the underlying causal mechanisms of land use patterns. Methodological issues also arise in the simulation used to generate land use pattern predictions. For example, Lewis (2008) points out the importance of accounting for uncertainty in the simulation predictions rather than treating the predicted probabilities as deterministic.

While the modeling approach is rigorous and the results have generated useful insights, this approach provides only a limited means to modeling land use dynamics (Parker et al. 2003). Because they typically do not account for individual heterogeneity that may influence decisions, e.g., age, experience and expectations, the approach is unlikely to fully identify parameters of the underlying structural model. In addition, empirical models cannot capture recursive interactions or feedbacks across multiple spatial or temporal scales particularly well and thus they are not well-suited for modeling the full evolution of spatial systems over time. Thus empirical-based simulations are valid for shorter time periods (e.g., 3-5 years) over which the underlying processes can reasonably be assumed to be stationary.

It is worth pointing out that this two-step statistical-based approach bears many similarities to empirical spatial cellular automata (CA) models in which the landscape is represented by an array of equal-sized cells, each of which corresponds to a land use. These models have enjoyed tremendous popularity in geography, environmental science and other related disciplines (Table 1 and Figure 1). Data on land use change over time are used to empirically estimate the cell-based land use transitions. The model is then simulated forward in time using the empirically derived transition probabilities to generate predictions of land use patterns and change. The second stage is very similar to the simulation approach described above although the spatial unit of analysis is different, e.g., parcel-based models use actual land ownership boundaries rather than cells. The first stage estimation approach differs in more substantive ways however. Recent advances in econometrics have focused on causal inference methods that are a substantial improvement over simple multivariate regression analysis. As detailed above, most researchers pay close attention to separating causality from correlation in econometric land use models. It is essentially not possible to do this using raster (cell-based) data, which divide up the landscape arbitrarily rather than maintaining a correspondence to ownership boundaries. Most often multiple cells correspond to the same land parcel and thus assuming independence among these cells is not appropriate. For the same reason these models are likely to generate biased estimates of neighboring cell interactions. Other issues of endogeneity arise, e.g., with respect to roads or neighborhood-level features that are influenced by local land use changes. The multivariate regression methods that are typically employed in the CA literature cannot control for these sources of bias. In such cases, parameter estimates reveal correlations, but not causal relationships. This substantially limits the usefulness of the simulation if the purpose is to uncover the causal effects of hypothesized socioeconomic or biophysical factors on land use pattern.

Spatial Equilibrium Models of Urban Land Use Pattern

As Ed Glaeser writes in his 2008 book "Cities, Agglomeration and Spatial Equilibrium," the spatial equilibrium assumption is the bedrock of urban economics upon which everything else stands. The concept is motivated by the basic mobility of people and firms from one location to another. This simple fact implies that, given a sufficiently long period of time over which locations are negotiated, people with identical preferences are indifferent to their location despite the fact that attributes associated with location (e.g., access to employment, neighborhood amenities) are spatially heterogeneous. Prices adjust to locational differences and therefore in equilibrium, prices perfectly offset location advantages and disadvantage so that people are spatially indifferent and utilities are equalized across space. This assumption provides a simple, but powerful means of accounting for the process of capitalization.

Spatially heterogeneous models of urban land use patterns use the assumption of a spatial equilibrium as a means to account for the influence of additional sources of spatial variation on equilibrium prices. A common starting point is the basic monocentric model, in which transportation costs to a central business district generate spatially differentiated land rents. The spatial equilibrium implies that land rents will adjust such that the marginal increase in transport costs from locating farther away are exactly offset by the decrease in land rents. There is a long history in urban economics of then incorporating other features of space into this model, e.g., traffic congestion, local public goods and neighborhood crowding (e.g., Fujita 1989). Analytical tractability requires that these features also vary with distance to the central business district and thus the model is unable to account for variations in pattern at a local scale.

Incorporating local variations into this model requires spatial simulation to account for the multiple sources of spatial heterogeneity. Wu and Plantinga (2003) and Caruso et al. (2007) provide good examples of this approach. While the models differ in their details, they both start with the static monocentric model assumptions and then incorporate additional sources of spatial heterogeneity by assuming households' have preferences over these additional landscape features. Equilibrium land rents are a function of both distance to the central business district and these other spatial features. Wu and Plantinga (2003) consider access to exogenously determined open space (e.g., public parks) whereas Caruso et al. (2007) consider the local endogenous spillover effects of surrounding open space and development. Given an analytical expression for land rents as a function of heterogeneous space, spatial simulation is used to derive the implications for locally varying land use patterns. Wu and Plantinga (2003) use this approach to describe the long run spatial equilibrium patterns that result within the context of an open city model. On the other hand, Caruso et al. (2007) model the evolution of land use patterns over time. Specifically, they assume that a single household enters the region in each time period and makes a utility maximizing location decision. The spatial equilibrium assumption is imposed after each new entrant as a means of accounting for the adjustments of prices to the new land use pattern. Because their locally varying landscape features are endogenous to residential location, the spatial simulation plays an additional, critical role of accounting for the incremental change in land use pattern that are capitalized into land rents that then influence the next round of decision making. The model is then simulated over many periods to study the implications of these multiple sources of spatial heterogeneity for the evolution of residential development patterns.

Turner (2005) presents a game theoretic model of household location with local open space spillovers and CBD commuting costs. Rather than spatial simulation, the resulting equilibrium land use pattern is deduced by a series of proofs. Differences in market conditions and the timing of residential moves result in differences in price gradients and the timing of development at a particular location, but in all cases, the model yields predictions of a densely occupied center, scattered development in the suburban areas and vacant land beyond the outer suburban edge. In comparing the role of local open space externalities in deviations from the optimal land use pattern,[2] Turner finds that this external benefit generates development that is not sufficiently scattered, a result that suggests a role for government in establishing small parks throughout a metro region.

From the perspective of modeling land markets, the spatial equilibrium assumption provides a simple but powerful means of capturing the capitalization process. It is, however, a long run equilibrium assumption. In reality, cities and regions are unlikely to be in a spatial equilibrium, but rather tending towards this long run equilibrium. Given the endogenous feedbacks that typify urban systems and the frequency of external shocks (as evidenced by recent global economic events), it is even possible that urban systems are relatively far from equilibrium some or most of the time. There is clear evidence of the capitalization process at work, e.g., prices of housing located near desirable amenities are higher and wages in undesirable locations are higher, and economists often point to these empirical realities as evidence of spatial equilibrium. However, while capitalization certainly demonstrates that an urban system is tending towards a spatial equilibrium, it is impossible to conclude based solely on this evidence whether the system is in or even near equilibrium.

While abstracting from transitional land use dynamics may be reasonable for research questions within the realm of economics, it raises substantial challenges with respect to the integration of economic and ecological dynamic models. There is no reason to suspect that ecological processes will evolve at the same rate as economic processes, much less that an ecological process will reach an equilibrium that corresponds with the economic spatial equilibrium. Unless the time scales divergence is small, integration of these divergent processes requires a model with transitional dynamics in which the differences can be explicitly accounted for (Irwin et al 2007). A naive model that ignores these differences or adopts a simplifying assumption that treats one process as fixed and the other as dynamic can generate qualitatively different dynamics and misleading policy prescriptions (Chen 2009).

[2] See Parker (2007) for a comprehensive treatment of negative spatial externalities generated by local land uses and the implications for land markets and government intervention.

Agent-Based Models of Urban Land Use Pattern

An emerging view among some economists describes the economy as a dynamic adaptive system (Tesfatsion 2006), in which an understanding of the transitional dynamics of the system is as important if not more so than the long run equilibrium that the economy tends towards. This viewpoint has been at the edges of urban and regional economic theory and modeling for a long time. In fact, regional scientists during the 1970's and 1980's sustained an active area of research that adapted physical models to the complex dynamics of regional economies (e.g., De Palma and Lefevre 1985). Renewed interest in urban and regional systems as complex, adaptive systems has come from the growing interdisciplinary field of complexity theory, a field that has been championed by research organizations such as the Santa Fe Institute and research programs such as the National Science Foundation's annual Coupled Natural-Human Systems competition. While most economists have been slow to warm to this vision of urban systems, it has gained substantial currency among many other scientists, including geographers and biophysical scientists whose worldview is perhaps more closely aligned with transitional dynamics.

Agent-based models (ABMs) are a relatively new modeling method and are increasingly being used by social scientists interested in linking the behavior and interactions of heterogeneous agents with complex dynamics at higher scales of aggregation. The advantages of such models over conventional models of economic decision making have led to their increasing use in some areas of economics, including finance and other areas of business economics (e.g., see the recent <u>Handbook of Computational Economics,</u> 2006). Parker et al. (2003) provide review the applicability of AMBs to modeling land use and land cover change. The reasons are compelling if one is interested in the dynamics of spatially heterogeneous patterns over time and linking these patterns with the behaviors of households, land developers, firms and other agents that influence land use. In particular, because ABMs are carried out in a simulation environment, they can readily incorporate sources of spatial and agent heterogeneity that are intractable in analytical models. In addition, the simulation-based approach permits one to step agents through time and derive aggregate land use patterns from the bottom-up.

A rigorous treatment of urban land markets in this framework has yet to be developed. This is in part because urban economic models that rely on the assumption of a spatial equilibrium provide little guidance in modeling the evolution of land markets when this condition does not hold. Without spatial equilibrium, how is capitalization best modeled? The lack of economic rigor is also due to the fact that economists have been noticeably absent from this arena of model development (Table 1 and Figure 1). As a result, economic fundamentals have been ignored by most urban land use ABMs. Instead, these models tend to focus largely on spatial and agent heterogeneity and specification of the decision making rules of households and other agents in the model. For example, Otter et al. (2001) model firm and household location interactions to study the emergence of urban clusters. Several different types of households and firms are defined, distinguished by their characteristics and preferences. Competition is omitted from the model, however (once an agent locates in a cell the cell is occupied and cannot be contested by others) and thus the model lacks any representation of land markets. Likewise, Brown and

Robinson (2006) model agent decision making within a utility maximizing framework, but choices are unconstrained by land prices since they are omitted from the model. While several of the more economic-oriented models include some representation of land or housing prices, this is done in an adhoc way. For example, Benenson (1998) develops a model of urban population dynamics in which housing price is modeled as a function of the households' income and the average value of neighboring houses. Warren et al. (in press) develop a model of segregation across a central city and suburbs in which prices are modeled as a function of lot size and two variables intended to capture the relative demand for housing in a given neighborhood, the occupancy rate of housing and the net rate of population growth in the neighborhood.

A few of the integrated transportation-land use microsimulation models that consider transitional dynamics have included urban land market models. Waddell (2000) and Waddell et al. (2003) describe the design and implementation of the well-known UrbanSim model, a microsimulation model of urban development that seeks to model urban land use patterns as the result of household and business location choices and land developer decisions. The evolution of land prices over time is modeled using a two-step approach. First, the relative implicit prices associated with the heterogeneous characteristics of each location are assumed to be stable through time and calculated with a single estimation of a hedonic price function using transactions data. Second, overall price changes over time are assumed to be captured by a shifting intercept term, which is modeled as a function of relative vacancy rates in each time period in the residential and commercial real estate markets. As a means of modeling capitalization, this approach simply misses the boat. Persistent changes in the relative implicit prices (e.g., due to capitalization) will ultimately cause households to adjust their optimal bundle of housing attributes and firms to adjust their production of these attributes and the hedonic equilibrium will be renegotiated. Given the variety of tastes and incomes among households and differences in firm costs, there is no way to predict how the hedonic price function will be renegotiated over time without understanding these underlying *structural* relationships. To assume that the shape of the hedonic function remains constant and that relative price changes only reflect shifts in the intercept term ignores basic principles, such as substitution and income effects, that are key features of economic choice behavior. Other microsimulation models that incorporate some representation of urban land markets include Miller et al. (2004). These authors present a detailed agent-based model of urban land use and transportation, which they present as an alternative to the more aggregate zonal-based transportation-land use models. Individually negotiated prices are used to derive a zonal average price, which is then adjusted based on excess demand and supply for housing within each zone. However, it is unclear exactly how this adjustment is carried out.

Work by Filatova et al. (2009) and related papers by these authors (Filatova et al. 2008; Parker and Filatova 2009) represents the most serious effort to-date to explicitly model land markets within an ABM framework. [3] These authors develop an ABM of household location in which transactions between

[3] As pointed out by Parker and Filatova (2009), agricultural economists have had success in applying ABMs to agricultural land markets (e.g., Berger 2001; Happe, Kellermann and Balmann 2006). Here we focus on the application of ABMs to urban land markets.

individual buyers and sellers are modeled in terms of the process of locating trading partners, bid and ask prices and price negotiations. Like Caruso et al. (2007) and others, their model builds from the basic monocentric model set-up and introduces locally varying open space amenities as an additional source of spatial heterogeneity. The marginal amenity value of this additional source of spatial heterogeneity is reflected in the bid prices of households and thus the model provides some means of capturing capitalization. However, individual price negotiations cannot fully capture the market-wide capitalization process that arises through cumulative excess demand and supply of housing. In a related paper, Parker and Filatova (2009) provide some discussion of modeling strategies for "initializing and updating" rents, but these are admittedly adhoc.

Despite a recent explosion of ABM urban land use models, little progress has been made on modeling urban land markets and a number of challenges face researchers in further developing these models. Parker and Filatova (2009) provide a review of some of these challenges and the "open questions" that remain in adapting the fundamental microfoundations of land use and urban growth modeling in economics to spatially explicit dynamic models of land use change. While many of the open questions they pose deal with how the detailed aspects of the individual trades (e.g., the process by which ask and bid prices are set, subsequent price negotiations, how gains from trade are divided), others arise because the spatial equilibrium assumption is no longer imposed and thus an alternative mechanism is needed to capture the capitalization of location into land rents. It is clear that the current state of modeling is lacking in this regard and much more work is needed to advance the economic fundamentals of these models.

Agent-Based Economic Models: The Future Is Now So What's the Hold-Up?

Given the lack of economic rigor of most urban land use ABMs and their admittedly more complicated nature, the collective groan that rises from some economists when the words "agent-based" are mentioned is perhaps understandable. But for economists interested in spatial heterogeneity, transitional dynamics and integration with biophysical models, this response makes little sense and is ultimately self-defeating. While there is certainly a place for econometric land use models and theoretical simulation models of land use that are based on assumptions of spatial equilibrium, the need for transitional dynamic models that can incorporate key sources of spatial heterogeneity is clear. There are at least three reasons for why economists interested in land use modeling should take ABMs seriously:

- <u>Be policy relevant:</u> Increasingly the questions that policy makers are asking, from local planners to global leaders, require spatial dynamic modeling. Concerns over the impact of urbanization on ecosystem services and energy consumption have spawned new sustainability initiatives at local, regional and state levels throughout the U.S. Globally, there is greater urgency among scientists, planners and decision makers alike to understand the value that ecosystem services generate for individuals, societies and institutions (Daily et al. 2009) and incorporating these values into human decisions, e.g., via payments for ecosystem services. Designing such policies requires not only an improved understanding of ecological functioning, which is dependent on spatial land use patterns at very localized scales, but also an improved understanding of human decision making and, for example, how heterogeneous and spatially distributed landowners respond to incentives designed to improve ecosystem services. Because ecological systems evolve over short and long time scales that do not necessarily correspond to the time scales over which people adjust and make decisions, transitional dynamic models of land use that can account for divergent time scales are also needed for policy analysis.

- Follow the money: Because some of the most pressing policy questions center on questions of human-environment interdependence, competitive research funds have been increasingly directed towards interdisciplinary research. *(Insert figures from NSF)*.
- Stay in the game: Agent-based modeling is ascendant within the broader scientific community of land use and land cover researchers. This methodology has emerged as the preferred method for modeling land use among a majority of non-economists (social and biophysical researchers alike), but yet is conspicuously absent from the economics literature. Given its now established place in land use modeling and its adoption by economists in other fields (Tesfatsion and Judd 2006), it is clear that this methodology is not going away. Economists can either choose to join and in so doing make critically needed contributions to the modeling methods or stay on the sidelines. If the latter, then economists run the risk of becoming marginalized within the broader community of land use researchers, policy makers and funding agencies.

Rather than condemning these models for being overly complicated and failing to account for economic fundamentals, we economists should view this as a gold mine of opportunity for extending economic models of land use dynamics. After all, there are many aspects of ABMs that should appeal to economists' sensibilities beyond their considerable usefulness for studying policy. Primary among these is their fundamental emphasis on structural modeling of individual decision making. At the heart of these models is the specification of structural conditions, individual behaviors and interactions with others that aggregate up to influence market-level outcomes. Model specification can follow basic principles of economics and traditional models of optimizing behavior, but is also sufficiently flexible to consider other decision making rules as well. The simulation approach permits richer consideration of not only heterogeneity in space, but also across individuals and their decision making rules, a feature of economic decision making that behavioral economists are finding to be of increasing importance (e.g., Hommes 2006). Work in economics and sociology on the role of social interactions (e.g., Brock and Durlauf 1997) highlights the importance of accounting for these interdependencies in modeling economic decisions, again something that ABMs are well-suited to handle.

Given the advantages of ABMs in developing spatial dynamic models of location and land use, it is a bit puzzling why such a substantial number of economists are either reticent or uninterested in adopting this modeling approach. In part, the lack of economics in the models developed to-date has led to this reluctance, prompting many economists to dismiss the approach altogether as being non-economic. In equal part, many economists are unlikely to see the utility of such an approach and instead focus only on the fixed costs of learning yet another new method. Following Occam's razor, should we not strive for the simplest explanation? While the argument makes good sense, the need for more spatially detailed and dynamic modeling approaches in land use is now self-evident. Incorporating these features into economic models will undoubtedly make them more complicated and less elegant. In light of these necessary complications, perhaps we are better off following Einstein's dictum that "a scientific theory should be as simple as possible, but no simpler."

Lastly, I suspect that a large reason for much of the reluctance among economists is the fact that the models' outputs and predictions are based solely on simulation methods. In a world of ordinal utilities and relative value, parameterization has always made economists nervous. We prefer analytical solutions that provide "general" results. However, the reality is that analytically tractable models demand simplifications that often omit important aspects of the real world that make a qualitative different in determining individual choices and market outcomes. This trade-off between the benefits and costs of analytical tractability versus parameterization is not one that is as openly acknowledged in economics as it should be, but yet it is highly relevant for situations in which heterogeneity (in space or in agents) is important or transitional dynamics are of interest. In these cases, it may be necessary to forgo the generalizability of analytical models for the increased realism of simulation approaches.

Clearly successful development of ABMs depends critically on empirical identification of reasonable values (or ranges of values) for the behavioral parameters of the model. A simulation model is only as good as the model parameters. The fact that economists also have a comparative advantage in causal inference methods is encouraging in this respect. Economists have increasingly moved beyond simple regression analyses to more sophisticated methods that include natural experiments and other estimation techniques that permit greater possibilities of separating causality from correlation. In contrast to econometric modeling, ABMs are not solely dependent on econometric models to separate causality from correlation. Other methods include lab and field experiments, both of which are commonly used by economists.

Concluding Thoughts

If economic agent-based models can be developed that permit the assumption of spatial equilibrium to be relaxed and yet retain a correspondence between individual location or land use behavior and aggregate economic outcomes, the results would be transformative. Rather than focusing on long run equilibrium conditions, such models would spawn a variety of new research questions made possible by consideration of the full dynamics and cross-scale interactions of urban systems. These models would take economic policy analysis to a new level of realism and relevance by incorporating multiple sources of spatial heterogeneity and examining the effect of policies on the heterogeneous behavior of individuals and the resulting evolution of prices, land use and urban spatial structure over time. However, the gap between a rigorous and fully specified economic ABM of urban land use and the existing set of ABMs is substantial. While we have not enumerated all the challenges and pitfalls of this method, there are many and it will require considerable and sustained effort among economists and others who already have some expertise in this methodology to make meaningful progress. There is much that we can learn from others already engaged in this process in this regard.

Despite the challenges, the combination of the flexibility and structural-based modeling approach of ABMs with our collective knowledge of causal inference methods points a clear way forward for economists interested in land use dynamics, integrated human-environment models and policy analysis with greater realism. The appeal of highly stylized analytical models was evident several decades ago when the computing power needed to solve more complicated aggregation problems simply wasn't available. The resistance to simulation-based models would be justified if the data and methods were not available for reasonable parameterization of these models. Both are historically true; neither is true today.

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	Journal Type							
	Economics		**Geography**		**Urban Planning**		**Environ. Studies**	
Model Type	**Environ./ Resource Economics**	**Regional Science/ Urban Economics**	**Geography/ GI Science**	**Computers/ Urban Systems**	**Urban Planning/ Policy Studies**	**Urban Planning/ Ecology**	**Environ. Studies/ Ecology**	**Grand Total**
Agent Based Simulation	0	0	5	2	1	0	6	14
Cellular Automata Simulation	0	1	7	3	2	6	11	30
Statistical with Simulation	4	3	1	0	2	3	9	22
Analytical with Simulation	2	3	0	0	1	0	0	6
Statistical Only	5	5	0	0	4	2	4	20
Analytical Only	1	2	0	0	1	0	2	6
Systems Dynamics	0	0	0	0	1	0	1	2
Grand Total	12	14	13	5	11	11	32	100

Table 1: Count by model and journal Type of selected* research articles (published since 2003) on urban land use pattern modeling

* We selected the 100 "most relevant" articles judged by whether the paper presented a theoretical, empirical or simulation-based model of urban land use change that also provided some description or quantification of changes in land use pattern.

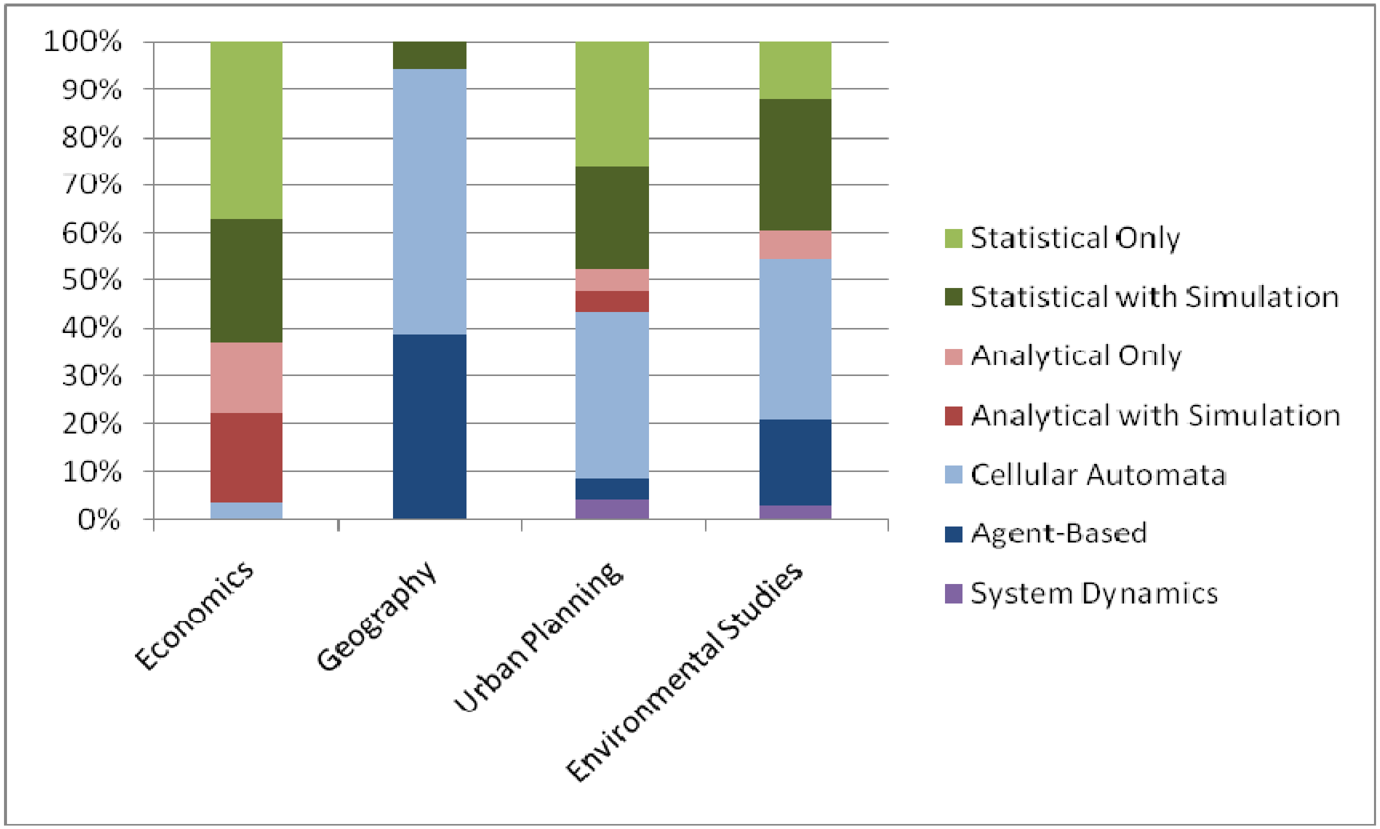

Figure 1: Relative proportion of modeling methods used within each discipline (based on raw values reported in Table 1)