Chapter 26
Do Land Markets Matter? A Modeling Ontology and Experimental Design to Test the Effects of Land Markets for an Agent-Based Model of Ex-Urban Residential Land-Use Change

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Abstract Urban sprawl is shaped by various geographical, ecological and social factors under the influence of land market forces. When modeling this process, geographers and economists tend to prioritize factors most relevant to their own domain. Still, there are very few structured systematic comparisons exploring how the extent of process representation affects the models' ability to generate extent and pattern of change. This chapter aims to explore the question of how the degree of representation of land market processes affects simulated spatial outcomes. We identify four distinct elements of land markets: resource constraints, competitive bidding, strategic behavior, and endogenous supply decisions. Many land-use-change models include one or more of these elements; thus, the progression that we designed should facilitate analysis of our results in relation to a broad range of existing land-use-change models, from purely geographic to purely economic and from reduced form to highly structural models. The description of the new agent-based model, in which each of the

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four levels of market representation can be gradually activated, is presented. The behavior of suppliers and acquirers of land, and the agents' interactions at land exchange are discussed in the presence of each of the four land-market mechanisms.

26.1 Introduction

Growing concern regarding the development of fragmented patterns of land conversion at the urban-rural fringe ("sprawl") has lead to the development of a wide variety of fine-scale spatial models of land-use change at the urban-rural fringe. Models developed using a wide variety of techniques, including those based on cellular automata (CA), neural networks, spatial econometrics, and agents, have successfully replicated the fragmented patterns of development that occur at the urban-rural fringe (Verburg et al. 2006).

These models differ greatly in terms of their level of detail and representation of real-world processes. At one end of the spectrum, CA models calibrated based on the historical spatio-temporal pattern of land-cover change can be characterized as highly inductive, pattern-based geographic approaches. At the other end of the spectrum, detailed agent-based models (ABMs) explicitly model socioeconomic processes, with correspondingly higher data demands for model parameterization and/or calibration. While these differences in modeling approaches are widely acknowledged, few structured comparisons have been undertaken to explore how the extent of process representation affects the models' ability to generate extent and pattern of change.

In this paper, we focus on a small subset of this spectrum of models – ABMs of land-use change at the urban-rural fringe driven by open space amenity values – to explore the question of how the degree of representation of land market processes affects model spatial outcomes. Land market factors such as credit availability, interest rates, the strength of demand relative to supply, and institutional details of land market function can be significant drivers of land-use change. In addition, interdisciplinary research is often conducted with the goal of producing policy recommendations for market-based mechanisms (e.g. subsidies, taxes, quotas, and insurance). Yet, these market factors have not been included in the majority of land-use change models. To our knowledge, few formal comparisons have been conducted to explore how the representation of land markets within land-use models affects projected land-use patterns.

We describe a series of model extensions to a simple land-change model with minimal market mechanisms that create a land-change model that has a simple but complete land market. We further describe a series of structured, comparative experiments that progressively introduce important aspects of land market interactions – including economic resource constraints, competition for land, strategic behavior, and endogenous land supply decisions – that seek to answer the question, "Do land markets matter?" for the spatial outcomes of land-use ABMs. In short, does a land-use change model that incorporates a process-based, land market model grounded in spatial economics produce more realistic spatial patterns of land development than a model based on reduced form representations of these influences? The paper elaborates the design of model versions with progressive introduction of market mechanisms. Future papers will present the experimental results.

We define a land market as the series of transactions and exchange of land between buyers and sellers in a bounded region. The number of buyers and the price at which they would acquire a given land parcel – their willingness to pay (WTP) – provide demand for the resource or product (i.e. land). The supply side of the market is defined by sellers' decisions to offer land for sale on the market and the price that they would accept for the land they are offering – their willingness to accept (WTA). The aggregate average price of land, the amount of land available (i.e. supply), the number of buyers and their willingness to pay (i.e. demand), the factors of production (i.e. inputs to the land and its biophysical and geographical characteristics), and the opportunity costs of taking part in land transactions versus other commodity transactions create what we call the land market and its associated dynamics over time. These land market dynamics also influence choices about factors of production (e.g. through land use and land management).

The following general conceptual questions frame our experimental approach:

- To what degree does the incorporation of constraints and competitive bidding (the focus of our first set of experiments) alter development patterns, gains from trade (the difference between WTP and WTA), and agent utility?
- Do models that exclude market mechanisms include sufficient proxies for market mechanisms to be considered reduced-form versions of fuller models, replicating results of fuller models in many circumstances? Or rather, do these models exclude important processes that influence land market outcomes in a significant way?
- Even when market outcomes are modeled, many economic models are forced to make simplifying assumptions, such as agent and environmental homogeneity, modeling only transaction prices rather than WTA/ask and WTA/bid price formation, and not modeling strategic behavior, for the sake of analytical tractability. What are the implications of these simplifying assumptions for the ability of these models to project the extent and pattern of land-use change?
- To what extent do the effects of including or excluding market processes depend on the particular socioeconomic circumstances modeled? More specifically, are there some sets of parameter settings for which inclusion of market mechanisms has a large effect, and some for which effects are relatively small? If so, what would be the real-world interpretation of the conditions that these parameter settings represent?
- How does the incorporation of heterogeneity (i.e. in agent preferences and resource constraints) and level of information (i.e. the number of sites evaluated) influence these outcomes?

This modeling exercise is part of the SLUCE II project, an interdisciplinary, multi-university project funded by the US NSF Dynamics of Coupled Natural-Human Systems program. Our new model builds from two existing models by including new economic elements in each. The first, ALMA (Parker and Filatova 2008; Filatova et al. 2009a, b), focuses on land market interactions and the microeconomic determinants of WTP and WTA. The second, SOME (Brown and Robinson 2006; Brown et al. 2008; Robinson and Brown 2009), uses survey and spatial data to develop empirically-based utility/suitability measures for residential agents, and then uses these measures to sequentially allocate land-use change events in the landscape, in the tradition of spatial statistical modeling. Our new model builds from these two existing models, expanding on both existing models to include additional economic elements.

26.2 Conceptual Overview

Our initial goal for this effort was to compare a land-use change model with and without a "land market," with the idea that a land market is a single, comprehensive concept that can be switched on or off. However, given the diversity of modeling approaches and institutional environments in which land is traded globally, it quickly became clear that "land market" does not have a single, comprehensive definition. Our discussions led us to break down the operation of land markets into several distinct elements that progressively add four important aspects of markets: *Resource Constraints, Competitive Bidding, Strategic Behavior,* and *Endogenous Supply Decisions*. Many land-use-change models include one or more of these elements; thus, the progression that we designed should facilitate analysis of our results in relation to a broad range of existing land-use-change models, from purely geographic to purely economic and from reduced form to highly structural models. We describe four levels of representation for modeling land markets (Table 26.1) and use these levels to design experiments to explore the answers to our questions (above).

The contents and motivation for each of these levels are as follows.

- **Level 0:** Level 0 is essentially a "first-come, first-served" sequential allocation model, i.e. a demand-driven model. A new land manager (or in many cases, simply a new land use) is selected for the parcel based on a utility ranking or suitability score, with parcels with highest utility or suitability selected first. This utility function reflects preferences for land attributes, a key building block of

Table 26.1 Degrees of market representation: model levels and their definitions

Level 0	Level 1	Level 2	Level 3	Level 4
No LM	Add resource constraints	Add competition	Add strategic behavior	Add endogenous supply decisions
No resource constraints, competitive bidding, strategic behavior, or endogenous supply decisions	Level 0 plus resource constraints for buyers and sellers	Level 1 plus allocation via competitive bidding	Level 2 plus strategic bid/ ask price formation	Level 3 plus modeled decision to sell rural parcel

demand in any market model. However, the utility function is the only "market" element in the model. Sequential allocation models are generally constrained by a top-down quantity of change, either total or categorical, although models can also be driven by a total population that needs to be allocated across the landscape. This type of land allocation mechanism is used with a variety of parcel-scale land-use-change models, including CA, statistical regression models, and ABMs (Verburg et al. 2006).

- *Limitations*: Level 0 models generally do not explicitly incorporate the damping and sorting effects of economic resource constraints. A corollary to this point is that these models lack any explicit land prices, even exogenous prices. They may also assume unlimited land acquisition budgets on the part of acquiring agents. As a result, economically implausible land transactions may occur, such as land being acquired by an agent who in reality lacks the economic resources to accomplish that acquisition. In the case of several land- use types, a vacant parcel can be occupied by a land use that would be outcompeted in reality by a higher-value use.
- **Level 1:** The level 1 model overcomes the limitations found in Level 0 by adding *parametric, exogenous buyer and seller land values and land budgets* to the model. These limit the ability of a buyer to acquire the highest utility parcel. A buyer can then acquire a parcel only if the parcel is affordable under her budget constraint, and a seller will accept her bid only if it is higher than his WTA. Thus, each transaction, in theory, will generate positive or neutral gains from trade.
- *Limitations*: In the level 1 model, although the acquiring agent may be able to afford the parcel, that parcel may be of higher value to another agent. The Level 1 model does not allow for competitive bidding, thus potentially preventing the higher-valuing agent from acquiring the parcel. As a result, land may not be allocated to the highest privately valued use. Although in the real world a variety of factors might mean that land is not necessarily allocated to its highest valued use, if a land market were allowed to operate, an agent with a higher value should, in theory, outbid an agent with a lower value.
- **Level 2:** The level 2 model allocates parcels via *competitive bidding*, rather than sequentially, giving the short-term opportunity for an agent with the highest valuation to acquire the parcel. This competitive bidding process also creates an endogenous land price or land rent, one that in theory reflects the highest valued use of the land. This approach is taken in several agent-based models and analytical models of land markets (see Parker and Filatova (2008) for a recent review).
- *Limitations*: In the level 2 model, buyers and seller each reveal their true valuation for the parcel (their WTP and WTA). In real land markets, these values are carefully guarded, and relative bargaining power may influence actual bid and ask prices, final transaction prices, and the final distribution of gains from trade.
- **Level 3:** The Level 3 market model adds bid and ask prices to the level two model. Once competitive bidding is introduced into a market model, buyers and sellers have an incentive to behave strategically in order to capture the highest possible amount of surplus (the difference between a seller's willingness to accept and a buyer's willingness to pay). This strategic behavior is expressed through setting of ask prices and bid prices that are respectively higher and lower than the

sellers' and buyers' WTA and WTP. The ways in which these strategic decisions are made in land markets have not been thoroughly investigated as of yet, but such decisions are clearly a function of expectations regarding future trajectories of land prices and the participation decisions of other agents in the land market. Parker and Filatova (2008) lay out possible influences on such expectations, and Filatova et al. (2009a, b) implement a simple version based on the proportion of buyers and sellers active in the market.

- *Limitations*: Although the Level 3 model allocates land to its highest valued use, it does not allow feedbacks between this highest valued use and the supply of economically scarce land for conversion to the market. Just as market conditions may lead to strategic setting of bid and ask prices, market conditions may also lead to strategic incentives regarding when to supply a parcel to the market.
- **Level 4:** The level 4 model *endogenizes land supply decisions*. Expectations regarding sales prices have a strong influence on the decision to supply land to a market, and thus, the probability of finding a parcel on the market will be higher closer to the city center, where property values are higher.

26.3 Behaviors of Suppliers and Acquirers of Land in Each Model

We now describe the detailed assumptions for the behavior of suppliers of land, acquirers of land, and land-exchange mechanisms for each of the models. We follow a slightly modified version of the MR POTATOHEAD template for land-use-change models described in Parker et al. (2008). Each models' mechanisms are summarized in Tables 26.2–26.4. MR POTATOHEAD terminology is in *italics*. Our experimental design strives, as much as possible, to keep most of the elements the same between model levels, and progressively changes one or few elements at each level.

26.3.1 Suppliers of Land

The *suppliers of land* (Table 26.2) in our first, simple model implementation are rural sellers, who are assumed in each case to put the single parcel that they own up for sale.

For Levels 0–3, the *motivation for supply* is not explicitly modeled. Motivation for supply also essentially describes the *event sequencing/triggers for land transfer* that are part of the Exchange Rules section of the Land Exchange class of the MR POTATOHEAD model. A simple rule, consistent with the approach taken in the base versions of the SLUDGE, SOME, and ALMA models, will be used to determine which rural parcels are put on the market in each time period in Levels 0–3.

Table 26.2 Suppliers of land details for different levels of market representation

		No land market	Add resource constraints	Add competition	Add strategic behavior	Add endogenous supply decision
MP element	Agent/role/scale	(Level 0)	(Level 1)	(Level 2)	(Level 3)	(Level 4)
Suppliers of land	Rural owner/seller/parcel	(No resource constraints, comp. bidding, or strategic behavior)	(Level 0 plus resource constraints for buyers and sellers)	(Level 1 plus allocation via competitive bidding)	(Level 2 plus strategic bid/ask price formation)	(Level 3 plus decision to sell parcel is modeled)
Motivation for supply		All/random (potentially dependent on distance to center)	Same as level 0	Same as levels 0 and 1	Same as levels 0, 1, and 2	Decision to supply based on expected price or price differential between WTA and expected bid price (endogenizes location differential)
Parcels supplied		Entire parcel	Entire parcel	Entire parcel	Entire parcel	Entire parcel
Resource constraint		0	In WTA	In WTA	In WTA	In WTA
WTA		Opportunity cost-exogenous parameter, set to zero	Opportunity cost-exogenous parameter, set with a positive value	Opportunity cost-exogenous parameter, set with a positive value	Opportunity cost-exogenous parameter, set with a positive value	Opportunity cost-exogenous parameter, set with a positive value
Terms offered		Opportunity cost (Ask = WTA, zero)	Opportunity cost (Ask = WTA, positive)	Opportunity cost (Ask = WTA, positive)	Ask price – endogenous dependent on price/market expectations	Ask price – endogenous dependent on price/market expectations

Table 26.3 Acquirers of land details for different levels of market representation

		No land market	Add resource constraints	Add competition	Add strategic behavior	Add endogenous supply decision
MP element	Agent	(Level 0)	(Level 1)	(Level 2)	(Level 3)	(Level 4)
Acquirers of land	Resident/buyer/parcel	(No resource constraints, comp. bidding, or strategic behavior)	(Level 0 plus resource constraints for buyers and sellers)	(Level 1 plus allocation via competitive bidding)	(Level 2 plus strategic bid/ask price formation)	(Level 3 plus decision to sell rural parcel is modeled)
Motivation for acquisition		Incoming buyer	Incoming buyer	Incoming buyer	Incoming buyer	Incoming buyer
Proximity influence		Disutility of commuting	Disutility of commuting, travel cost	Disutility of commuting, travel cost	Disutility of commuting, travel cost	Disutility of commuting, travel cost
Neighborhood influences		Open space amenities from undeveloped land	Open space amenities from undeveloped land	Open space amenities from undeveloped land	Open space amenities from undeveloped land	Open space amenities from undeveloped land
Parcels hope to acquire		Max utility from sub-sample	Max utility from sub-sample	Max utility from sub-sample	Max utility from sub-sample	Max utility from sub-sample
Resource constraint		None	Housing/transport budget	Housing/transport budget	Housing/transport budget	Housing/transport budget
WTP		Set to zero	Function of utility and budget constraint	Function of utility and budget constraint	Function of utility and budget constraint	Function of utility and budget constraint
Terms offered		Bid = WTP	Bid = WTP	Bid = WTP	Strategically set bid price	Strategically set bid price

Table 26.4 Initial conditions and land exchange mechanisms for different levels of market representation

		No land market	Add resource constraints	Add competition	Add strategic behavior	Add endogenous supply decision
MP element	Agent	(Level 0)	(Level 1)	(Level 2)	(Level 3)	(Level 4)
Land exchange	Initial sellers	All	All	All	All	Endogenously determined
	Initial buyers	Constrained to Level 2 total	Constrained to Level 2 total	Endogenously determined	Endogenously determined	Endogenously determined
Allocation mechanism		Sequential allocation	Sequential allocation	Competitive bidding	Competitive bidding	Competitive bidding

Initially, all rural parcels are initially available for acquisition.[1] The Level 4 model will endogenize the supply decision, with the potential supplier of land forming an estimate of the price at which they are likely to sell their parcel. If the difference between this expected price and the potential seller's WTA reaches a certain threshold, the parcel will be put up for sale. In each case, the *parcels supplied* will include the entire rural parcel (no subdivision), although in later work, rural parcels can be subdivided by developers.

Suppliers of land for the Level 0 model will have no *resource constraint*, where their resource constraint sets a minimum threshold for compensation for their parcel. In this first set of experiments (Level 1), we essentially define this constraint in terms of a willingness to accept (WTA), highlighting the fact that in the Level 0 model, their parcel will be supplied without compensation. In economic terms, this basically assumes no land scarcity; an economically scarce resource is defined as one for which, if the resource were available without cost, more would be demanded than is supplied. Again to keep our experiments simple, we assume that the WTA is defined by a parametrically set opportunity cost; the value of the land in its current use.[2] This value will be set to zero for the Level 0 model.

For Levels 0–2, the *terms offered* (or ask price in standard economic terminology) will simply be equal to the WTA. The actual compensation received may still be above the WTA of the supplier, as the differential will depend on the bidding rules and the number of buyers. For Levels 3–4, the ask price will be strategically set based on the expectations of market conditions, following Parker and Filatova (2008) and Filatova et al. (2009a, b).

26.3.2 Acquirers of Land

At each level, the *acquirers of land* (Table 26.3) will represent new buyers entering the region. Each will seek to acquire a single residential parcel (their *motivation for Acquisition/trigger for market participation*).

In all models, acquirers of land will base their decision to acquire land on a simple utility function, whose representation will stay fixed between experiments. They will gain utility from two factors: the *proximity influence* as a function of distance to a city/service center and the *neighborhood influences* of open-space amenities, which, for simplicity, will be generated by undeveloped open space in the local neighborhood of the parcel.[3] For each case, the *parcel they hope to acquire*

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[1] We debated whether or not to make parcel availability stochastic, with the probability of parcel supply being higher for parcels closer to the city center. We may explore the effects of these alternative algorithms in future work.

[2] In later versions of the Level 3 model, the WTA could also be a function of additional resource constraints (credit and debt constraints) and of expected sales price.

[3] Later versions of the models will have much more sophisticated definitions of open space amenities based on land management as well as land use.

will be the highest utility parcel based on this utility function. In some experiments, agents will have heterogeneous preferences, so their utility for the same parcel will potentially differ. For model tractability, it is possible that this highest utility parcel may be selected from a sub-sample of all available parcels, constrained by budget if applicable.

In the Level 0 model, acquirers of land will face no *resource constraints*; they will be able to acquire their highest utility parcel at no cost. They will also face no constraint on their transportation budget. In Level 1–4 models, acquirers of land (buyers) will have both housing and transportation budget constraints, following Filatova et al. (2009a, b). Total income and transport costs will be set parametrically and varied experimentally. It follows that in the Level 0 model, acquirers' willingness to pay will be set to zero to reflect the fact that they are assumed to be able to acquire any parcel at no cost. For Levels 1–4, the willingness to pay will be a function of the utility gained from the parcel and the budget constraint. To avoid the need to model price expectations in the Level 1–2 models, the functional transformation used in Filatova et al. (2009a, b) will be used to create a WTP function that has the behavioral properties of a standard economic demand function.

The *terms offered* (bid price, in economic terms) for Levels 0–2 will simply be the WTP, in parallel with the setting of ask = WTA for suppliers of land. Again, in cases where the acquirers' WTP is above the suppliers' WTA, the actual transaction price may lie below the WTP. Bid prices at Levels 3–4 will be strategically set, dependent on market conditions, and will follow the approaches outlined in Parker and Filatova (2008) and Filatova et al. (2009a, b).

Model initialization and exchange rules: Here we describe some key elements of the various levels in the form of both the *Exchange Rules* subclass of the *Land Exchange* and *Model Operation* classes in MR POTATOHEAD (Parker et al. 2008).

Initial agent numbers, types, and locations: As mentioned above, we will initialize our landscape with a single active seller located on each parcel. Our initial experiments will focus on comparison of the Level 0–2 models. One of the biggest challenges in model design was the decision of what macro-scale constraint would drive land development in the model. In the real world, land development is driven by a combination of such factors as migration and changes in employment and population structure. In land-use modeling, these influences are often represented by proxies that make assumptions regarding a quantity of cells/parcels that should change land in each time period. In an ABM, these influences could be represented through the assumption that a fixed number of agents enter (or leave) the market in each time period. In our longer-term modeling, we intend to have progressive in-migration of new buyers, at rates consistent with the land change dynamics of our study area, and we also intend to endogenously model relocation decisions of currently settled agents (see "extensions," below). However, in order to be able to draw a broad set of conclusions, relevant to the many other previously developed land-use change models that fall under our different model levels, the first version will fix some concept of "quantity of change" in order to facilitate comparison between models.

Executing experiments with comparable levels of change is difficult because one of the major differences between models with sequential allocation vs. land market exchange is whether they have a fixed vs. endogenous quantity of change. A first-come/first-served allocation method, such as in Level 0, requires that the quantity of change be limited, or the entire landscape will be converted. In contrast, a model with resource constraints (Level 1 and above) will limit conversion to only those parcels where the willingness to pay of the buyer is above the willingness to accept of the seller. With positive transport costs, these constraints will also lead to clustering of development around city/service centers. Once competitive bidding is introduced, the process of land-use change will be further constrained, because a buyer not only needs a higher level of resources than a seller, but also a higher bid than other potential buyers who strive to acquire the same parcel.

The implication of these differences in model mechanisms is that, for a fixed population of agents who differ only in their resource constraints, (i.e., moving from a Level 0 to a Level 1 model), less land-use conversion should occur in the Level 1 model than the Level 0 model. Furthermore, even less land conversion should occur in the Level 2 model than the Level 1 model. (Filatova et al. (2009a, b) demonstrate that more conversion may occur when strategic bidding is introduced). We will find appropriate parameter settings for the model (a homogeneous total population less than the number of cells on the landscape, and a combination of utility and budget parameters that imply that not all agents in the Level 2 model will seek to buy) in order to run a baseline model that verifies these results. If our model behaves as we anticipate, we will then fix the number of agents in at each level to an amount that produces the same number of land exchange events. This means that the number of participating agents may be different at each level, but that the total amount of land conversion will be the same. This will allow us to run experiments that examine the effects of the model runs on the extent and pattern of land conversion, holding the number of converted cells fixed.

Land allocation mechanisms, event sequencing, and scheduling: For the Level 0 model, acquirers of land will be allowed to sequentially select and acquire their most preferred parcel. For the Level 1 model, this acquisition will be limited to the parcels that are affordable under the buyer's budget constraint, accounting for both the purchase price (the WTA of the seller) and the transport costs to city/service center. In each case, for any model run in which there are positive open space amenities and/or any heterogeneity in agent characteristics or resources, multiple model runs with different stochastic draws need to be run to account for stochastic elements. For the Level 2 model and above, initially all buyers will put a bid on their highest valued parcel, and sellers will then review bids and accept the highest valued bid, if it lies above their WTA. Buyers who do not succeed in acquiring a parcel, and sellers who do not succeed in selling their parcel, will participate in a next round of trade. Rounds of trade will continue until no more trades occur. Again, multiple model runs will be needed in most cases, since different agents may have equal utility and WTP for a given parcel.

Experiments: Our initial experiments will compare the Level 0–2 models. Our first goal is to identify sets of parameter values that demonstrate the extremes of model outcomes. In other words, we will search for a set of parameter values that lead to the smallest effects of including market mechanisms as well as those that lead to the largest effects. Consistent with our previous work, we plan experiments that vary distributions of agent characteristics in terms of preferences for proximity and open space amenities and resource constraints.

Although we plan to run baseline models that set open space amenities to zero for verification purposes, we are essentially interested in land-use change models that explore the effects of open space amenities on the pattern and extent of land conversion in ex-urban settings. Given the wide variety of models that explore similar questions that have been developed using a variety of modeling methods (including those based on CA, spatial econometrics, neural nets, and agents), we believe that a set of experiments that incorporates open-space amenities will still be quite generally informative with respect to investigating the importance of land market mechanisms on land-use change models of this type. Therefore, the bulk of our experiments will include positive open space amenities.

Hypotheses: How do we expect inclusion of the land market mechanisms to affect patterns? We are still developing these hypotheses, and of course, one reason for building simple simulation models of complex systems is to help develop theoretical hypotheses for systems for which simple intuition and/or mathematics fail. However, an initial hypothesis is that a model that excludes market mechanisms (Level 0) may predict more expansion and sprawl than a model that includes them. Including representations of positive open space amenities, disamenities from commuting without transport costs, and some prior development, a parcel that is relatively distant from the city center will provide relatively higher utility than a closer in parcel, which will likely have more highly developed neighborhood density. If an acquirer of land is not constrained by a housing or transport budget, they will easily acquire that higher utility parcel. Having located there, they then decrease the utility of that location for another potential resident with a high preference for open-space amenities, leading to path dependence in which the next acquirer occupies a parcel even further out than they would have had they not been able to acquire that parcel.

This path-dependent, leapfrog-generating location incentive will be present in any of our model runs that have positive open-space amenities. However, our hypothesis is that the pull towards the city center – whether from transportation cost constraints or from the need to outbid other buyers – will be stronger for the model that include market mechanisms. Thus, the constrained development path may be progressively more compact for the Level 1 and 2 models. This result, however, could be dependent on relative parameter values.[4] It may also no longer hold, or may be dampened, in models that allow endogenous relocation by residents (see Sect. 26.4). Finally, based on our previous work with heterogeneous agents, we anticipate that differences between model outcomes will be magnified as the degree

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[4] Note that this hypothesis could break down if buyers had sophisticated expectations regarding future paths of development. However, in a complex environment, even the most intelligent boundedly rational agent would likely fail to anticipate exact future patterns of local development. Modeling of such expectations, in any case, will be an interesting topic for future work.

of agent heterogeneity – in terms of preferences for open space amenities and proximity and resource constraints – increases.

A second set of questions relate to the degree to which the modeled landscape produces an economically efficient allocation, where economic efficiency is measured by the sum of economic surplus (the difference between WTP and WTA) generated by the landscape. Economic efficiency is, in theory, characterized by Pareto optimality, under a very narrow set of conditions that include a "no externality" condition. When open-space amenities are present, every landscape pattern/quantity allocation outcome will be characterized by a potentially different pattern of external costs and benefits. Thus, for the majority of our experiments, we do not expect the land market allocation to be economically efficient.

Yet, given the limitations of models that omit market mechanisms that we discuss above, we are interested in the economic surplus generated in each of our experimental outcomes, since it should reflect the success of the competitive allocation algorithms. We plan to evaluate the economic efficiency of each landscape outcome for a baseline, no open space amenity model, relative to a baseline random allocation model. Since calculations of economic efficiency depend on WTP and WTA, economic efficiency for each outcome will be calculated using the WTP and WTA for the level 2 model. One hypothesis is that, in terms of relative orders of magnitude, the level 0 model (which bases allocation on utility-metric preferences) will lead to the highest relative increase in the economic efficiency of the generated landscapes, relative to the level 1 and 2 models. A counter hypothesis is that only the level 2 model, which most closely resembles the traditional market models on which economic efficiency theorems are based, will lead to a significantly more efficient landscape. From the perspective of economics, these comparisons will shed light on the question of whether land markets matter from a formal theoretical perspective.

26.4 Model Extensions

We have described a series of incremental steps to add market mechanisms (Levels 0–4) and evaluate the effects of including a market on spatial development patterns. A number of additional mechanisms could be added to (1) extend the levels of market complexity and (2) include additional mechanisms that may alter the effects of our current set of market mechanisms. In this section we focus on the second of these two types of extensions. We provide a brief discussion on endogenous price expectation in supply that could lead to relocation by residents and the incorporation of developers into the land-change system as mechanisms that could alter our model behavior and provide increased realism desired by policy and decision makers.

Endogenous relocation by residents: Spatial economics suggests that there are several main reasons for the migration and relocation of households (Clark and van Lierop 1986; van der Vlist et al. 2002; Clark et al. 2003). Employment opportunities elsewhere are a main driver of inter-urban migration. Intra-urban migration occurs when households become dissatisfied with the neighborhood or home they live in and they find more attractive housing options elsewhere (potentially due to a change in life-cycle stage). Housing bundle theory identifies three components that influence the attractiveness of a particular property for a buyer: (1) housing structure (2) neighborhood quality, which includes both social and environmental components and (3) accessibility to public and private services (influenced by transport costs and geographic/institutional restrictions) (Adams 1984). The relocation process is largely determined by the demand and supply of these components. Relocation creates two important feedbacks. In the short run, relocation can change neighborhood quality; and in the long run, it also changes the quality and cost of public services. Given the focus of our modeling work on open-space amenities, we are most interested in how these short-run feedbacks may trigger a subsequent cascade of endogenous relocation.

Although a lack of endogenous relocation has been put forward as a criticism of land change models that lack a land market (Polhill et al. 2005), endogenous relocation can be modeled even in the absence of resource constraints, competitive bidding, and strategic behavior. If new residents influence the quality and character of natural or neighborhood amenities, then the utility/value that an agent holds at a location may change. In a non-market context, an agent will have a utility-based incentive to move. In a market context, a parcel that was initially allocated to its highest valued use may no longer be.

In later work we will evaluate the influence of endogenous relocation on model output for each of the model levels described above. For Levels 0 and 1, agents will be able to relocate when the expected utility (constrained by budget where relevant) of relocation exceeds the expected utility of remaining on the current parcel. For Level 2 and beyond, this relocation would, under most circumstances, be contingent on the ability of the current agent to sell the current parcel and make a gain from trade. Endogenous relocation should facilitate evolution of a more dynamic landscape. For the market model variants, it will allow the highest valued use to evolve over time.

We hypothesize that the inclusion of endogenous relocation may increase residential sprawl. Preferences for natural amenities by households have been increasing over time as evidenced by the rate of exurban development, which has outpaced that of population growth in the conterminous USA between 1980 and 2000 (Theobald 2005). We anticipate that as neighborhood density increases, there will be increasing incentive for agents to relocate to locations with higher in natural amenities or to locations that have socio-economic characteristics that are more preferable but are constantly changing over time.

Modeling developers: Conventional urban economic models typically assume that agricultural land is transferred to households directly (Alonso 1964). In some cases, these models omit the direct modeling of agricultural land owners and focus instead on transactions between developers and households (Henderson and Thisse 1999). In others, the transactions occur between agricultural sellers and developers

(Asami and Teraki 1991). Rarely are all three actors, i.e. agricultural owners, developers and households explicitly represented in a spatially explicit model.[5] Perhaps the largest void exists with respect to research on developers. However, developers significantly influence land change. It is the developer who, in a free market, generally determines which agricultural lots to convert to residential land use, at what structural density (subject to government constraints) and at what price to offer parcels in the land market. These decisions and the market transactions between developers and farmers, and further between developers and residential households are important processes influencing land market dynamics (land patterns and land prices). As a next step of model development we plan to include developer agents in the land market. As with other agents we would like to consider three levels of economic behavior of a developer based on two criteria: resource constraints and land acquisition via competitive bidding. In future work we will evaluate the influence of developers on model output for each of the model levels (0–4) described above.

26.5 Discussion and Conclusions

Our focus has been on evaluating the incremental inclusion of land-market mechanisms, using a suite of ABMs, on spatial settlement patterns and market dynamics. ABMs of land-use use virtual agents to provide computational representation of the actions and decision-making strategies used by real-world actors. The forms of interaction among agents in the absence of a market are typically through substitution (i.e. the acquisition of one property alters the selection choices available to other agents), by constraint (i.e. a township invokes a land-use policy that excludes a specific type of development action from occurring), or through neighborhood effects (i.e. the evaluation of a settlement location by residential household agents involves comparing its location preferences with those of possible neighbors at the evaluated site). However, with the inclusion of market mechanisms, the degree of interaction is increased through competitive bidding, strategic behavior, and endogenous supply decision making. Anderson (1972) notes that 'more is different' with respect to the degree of interaction among agents. Therefore we speculate that through the increasing degrees of interaction brought about by market mechanisms, our results will illustrate that markets do influence settlement patterns.

Ultimately we are interested in the role of land development dynamics and patterns on ecosystem function(s) through land-use and land-cover change. Several market interactions are relevant to this question. First, land cover patterns intervene in the

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[5] Analytical non-spatial models that account for the behavior of all three categories in a land market exist (Kraus 2006). However, within each group (developers, agricultural land owners and households) all agents are assumed to be homogeneous, perfectly rational and, with constant returns to scale. Space is assumed to be homogeneous except for the distance to the center, and enters economic models as travel costs and amount of spatial good acquired (sq foot). Location specifics and neighborhood externalities remain unexplored.

choices of land for development and residence, through the individual preferences of residents for particular landscape characteristics and the perception of those preferences by developers. Second, to the degree that residents and developers are concerned about the market value of their land, residents' and developers' perceptions of the influence of landscape characteristics on the choices of other residents could influence their choices about landscape management activities, regardless of their own landscape preferences. In later stages of our modeling, we will explore such questions in detail.

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