Agent-Based Land Markets: Heterogeneous Agents, Land Prices and Urban Land Use Change

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Abstract. We construct a spatially explicit agent-based model of a bilateral land market. Heterogeneous agents form their bid and ask prices for land based on the utility that they obtain from a certain location (house/land) and based on the state of the market (an excess of demand or supply). We underline the distinction between bid /ask price and individual willingness to pay/to accept and show that variations between them that reflect market conditions can influence land prices. Agents sort among locations with respect to distance from the city center and environmental spatial externalities. Aggregated outcomes such as land patterns and land prices are produced by the model. The basic model of buyers and sellers trading land in the urban area produces results identical to the monocentric urban model. However, more complex dynamics appears when environmental amenities and market-adjustment variable influence the formation of land prices.

Keywords: urban land market, heterogeneous agents, division of gains from trade, open-space amenities.

1 Introduction

The benefits of applying agent-based modeling (ABM) to study economic and ecological-economic systems are widely discussed in the literature [1-4]. Parker et al. [4] suggest that ABMs are appropriate when agent heterogeneity and interactions and cross-scale dynamics drive land-use outcomes. Further, ABMs may be useful for modeling the path of land-use change, whether or not that path may lead to equilibrium. Starting from the classical books [5, 6] the society of economists who adopt ABM tools to model economic problems is growing. ABM has been successfully used to model economic markets from bottom-up since mid 1990s [7-9]. Recent progress in designing markets with ABM is discussed at length by R. Marks and B. LeBaron [10, 11]. However, there is relatively little research done on simulating land markets with ABM. This can be explained by the fact that land markets are a very specific kind of markets. In comparison to other types of markets designed with ABM, a land market has not only *heterogeneous agents* (e.g., fundamentalists and chartists in financial markets) but also *heterogeneous goods* (each parcel of land or house has very different characteristics, which determine agents' willingness to pay and consequently market prices).

Several models study effects of hypothetical land markets, but with primary emphasis on the demand side. The SOME and SLUCE models allow agent to choose the parcel that maximizes their utility without competition from other sellers and assuming that the locating agent will outbid the current use [12]. Other models of agricultural land markets model both the demand and supply decisions [13-16]. While these models are becoming increasingly more sophisticated, they do not model differences between the buyer's willingness to pay –WTP – (underlying utility or payoffs for the land) and her bid or offer price for the land; nor do they model differences between the seller's willingness to accept – WTA – (opportunity cost of the sale) and his ask price.

This paper presents an agent-based bilateral residential land market, with a particular focus on the formation of WTP/WTA versus bid/ask price for land as well as the division of gains from trade. Moreover, we explore how heterogeneous preferences for green amenities influence the emergence of land prices via an endogenous land market. We model both the demand and supply sides and their negotiation over the final transaction price explicitly. This negotiation might depend on previous trades in the neighborhood and on some aggregate market information (relative excess of buyers or sellers). Our model also differs from previous ABM land market models through its focus on urban markets, rather than rural markets and farmer decision making. A WTP for land of a farmer can be directly expressed in monetary terms (derived as potential agricultural gains net of costs). In contrast, it is less obvious how to derive a WTP/WTA of a household in monetary units, since it is influenced by both market and non-market values. A household obtains a certain level of utility when she buys a spatial good (land lot/house). Her preferences, such as preferences for green amenities, are expressed in non-monetary units, which must be monetized to express her WTP and bid price.

The paper proceeds as follows. First, we discuss the economic approach to modeling residential land market and the advantages of an ABM for this problem. The main section of the paper presents the bilateral agent-based model of residential land market. Here we discuss interactions between traders and differences between willingness to pay/accept for a spatial good and the actual bid/ask price. Next, the results of several simulation experiments are presented. We conclude with a discussion of future elaborations of the model and a potential application to the case study in the Netherlands.

2 The traditional Economic Approach to Modeling Urban Land Use and Value Added of ABM

We underline the importance of using existing theoretical and empirical work done in the fields of spatial, urban and environmental economics in constructing ABM of land use with an endogenous market mechanism. ABM should be viewed as a way to supplement traditional scientific methods and expand the boundaries of science to test hypothesis and undertake experiments, rather then as substitute for traditional methods [4]. Many traditional models of urban land markets find their roots in the model of W.Alonso [17]. According to his bid-rent theory, households choose locations a certain distance from the central business district (CBD) based on the utility they get from the joint consumption of a spatial good (land lot/house) and a composite good (all other goods) under their budget constraint. Both demand for two types of goods (spatial and composite) and prices households are ready to pay are derived as a solution of a constrained maximization problem. Microeconomic studies usually use standard mathematical tools for that, such as a Lagrange function [18]. However, in order to be able to obtain analytical solutions for all variables, economics makes several assumptions, which may not hold for land markets with interacting buyers and sellers and explicit modeling of land price negotiation. There are several reasons why analytical solutions only cannot be used and ABM needs to be applied:

1. A representative agent approach is usually used in spatial economics models. This means that a demand curve of one agent can be extrapolated to represent the demand for the particular good (e.g., land) in the whole economy. However, the preferences for location differ among different economic agents, such as firms or households, and within these groups. The limitations of a representative agent approach are widely discussed by A. Kirman [19].
2. In a land market context, the utility of an agent is often dependent on the behavior of others, especially when actions of immediate neighbors change the local environment. However, traditional analytical models do not account for interactions among agents. The decision to convert open space into developed use or provision of a public good such as good quality schools influences the utility of households living in the neighborhood. These spatial externalities/neighborhood effects are difficult or impossible to model analytically in a spatially explicit context.
3. In addition to agent heterogeneity and interactions, the spatial environment is also heterogeneous. Spatial goods differ in their availability of environmental and social (schools, theatres, etc.) amenities, soil quality, administrative affiliation (and consequently taxes), and zoning and spatial planning regulations. Analytical methods used in economic theories dealing with space usually treat these characteristics of spatial goods as being distributed *uniformly*, denying heterogeneity. However, different characteristics of land produce different land use patterns and land prices, which are usually not uniformly distributed.
4. In an analytical setting a market clears only at the equilibrium state. While finding analytical solution we have to assume that system comes into equilibrium in one shot, as if all agents make optimal decisions at one moment. In reality, decisions of different agents to buy/sell spatial goods are separated in time, meaning that in time step t situation on the market and spatial neighborhood will be different than in time step $t-1$ and agent in time step t will be willing to pay different price for the same land lot/house. Economic markets, including land markets, are dynamic adaptive systems rather than static models [20], and the temporal interdependency of agent decisions may produce path dependence [12]. Often real-world economic systems are out-of equilibrium

[21], and systems may move towards, but not reach, equilibrium (for instance, in a case where cyclical adjustments of changing neighborhoods, changing patterns of land use, and land price adaptations occur). The dynamic path towards equilibrium can be elucidated through agent-based market modeling.

Keeping some main axioms of economic theories dealing with space (such as the fact that people want to minimize travel cost and value green amenities) as a basis, ABM makes a step forward by allowing agents and spatial environment to be heterogeneous, modeling agents' interactions, and modeling dynamics in a 2D spatially explicit setup. At the same time, by modeling spatial and market interactions between buyers and sellers explicitly, ABM allows modelers to obtain patterns of land prices and total urban territory occupied, *endogenously* as economic theory does.

3 An Artificial Land Market

The ABM of an Artificial Land MArket (ALMA), which model explicitly interactions between buyers and sellers of spatial goods and feedbacks of the market transactions, is based on the following conceptual scheme (see Fig. 1).

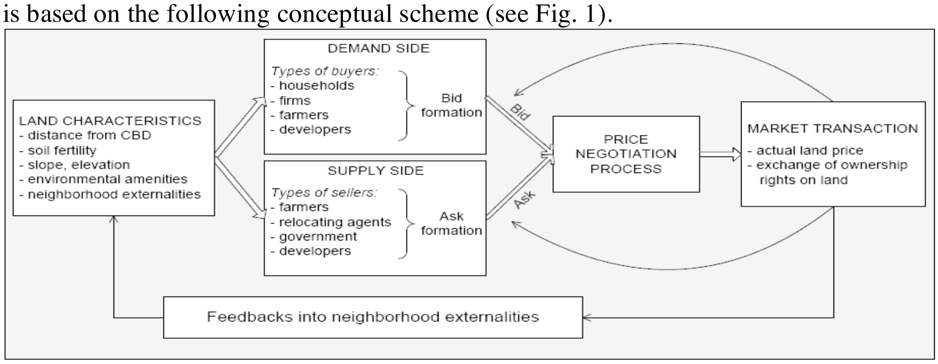

Fig. 1. Conceptual scheme of the land market

Depending on the characteristics of the spatial good, buyers and sellers form their "bid" and "ask" prices for land. Both supply and demand sides are represented by several types of agents. Buyers and sellers participating in land market may differ in nature, in their motivations to buy or to sell a land parcel or a house, and in their preferences for location. Each type of land market actor might appraise the same land parcel or house differently. When two trading partners are able to agree upon transaction price of a spatial good (decide how gains from trade will be divided), then the land is transferred to a new user or may be converted into another land use (e.g., developers buying land to convert it into the developed state). Thus, prices for spatial goods are formed endogenously via interactions of heterogeneous economic agents. If a spatial good changes its owner, then the structure of the neighborhood changes as well and feeds back into spatial externalities. At the same time, actual transaction prices affect the formation of ask and bid prices in the future. The ALMA model produces urban land patterns and land prices (rent gradients) as a result of market allocation of land between competitive users.

3.1 Types and Characteristics of Economic Agents

The main agents in ALMA model are land users operating in an urban area. The main good they exchange via market mechanisms is a spatial good, which can be viewed as a land lot or a house. The landscape is represented by a grid of equal cells. Each can be owned by one economic agent. The ALMA model was developed using the NetLogo 3.1.4 environment.

In this first implementation, households and developers are the main economic agents. Households are assumed to be buyers and sellers, and developers may convert open-space parcels. We do not aim to model all potential land market actors as presented in Figure 1 and leave it for future research. *In this paper we rather concentrate on explicit modeling of market mechanisms, bid and ask price formation of heterogeneous agents for heterogeneous goods, the effects of green amenities on the demand for land and its price, and the final allocation of the tradable spatial good.*

The land market in the ALMA model is presented as a two-side matching market. Sellers represent households who want to relocate. Buyers are households searching to buy a house/land lot. At the moment of model initialization, the number of buyers and sellers is defined, each seller holds one land lot, and each buyer has a certain budget. The location choices of agents are based on their preferences expressed in the form of utility function (Formula 1).

$$U = \alpha \cdot \ln E + \beta \cdot \ln \frac{k}{D+1} \cdot \qquad (1)$$

Here: α is agent's preference for green amenities, which can be heterogeneous (uniformly distributed in the range from 0 to 1) or homogeneous among agents;

β is an agent's preference for commuting; at this point βis equal to one for all agents;

k is a constant.

The utility of a spatial good (house/land) decreases with the distance (*D*) from the CBD and increases if environmental amenities (*E*) are available. Green areas, which could be considered as parks, forest areas or open space, are defined at the initialization stage. One can choose whether to have green areas only at the city fringe or to spread them over the whole city. Both the type of location of green areas and their amount can be defined by a user.

The choice of location is constrained by the budget (Formula 2), where *Y* is an agent's disposable budget for housing (it is assumed to be equal to some constant Y since we do not assume that market clears in one shot and, thus, cannot determine housing budget share via constrained maximization solution), *T(d)* equals transport costs, and *R* is price for land the person can afford.

$$Y = T(d) + R. \qquad (2)$$

Agents are assumed to maximize utility by choosing the optimal location under the budget constraint. However, there are two important distinctions from neoclassical utility-maximization problem. We assume that economic agents are boundedly rational (agents are not able to predict how the neighborhood will develop in the future) and do not possess perfect information about their environment (agents look for a local maximum among the sample of spatial goods they have randomly chosen). The algorithm, which artificial traders follow, is presented in Figure 2.

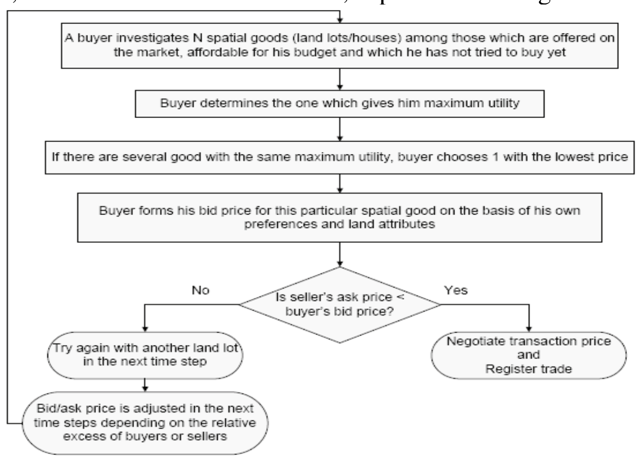

Fig. 2. Algorithm of trade

3.2 Ask and Bid Price Formation

An important question to be asked while modeling agent-based markets is the question of price formation. Economic theory suggests that buyers form their willingness to pay for land (WTP) based on their preferences for different land attributes under their budget constraint, and sellers form their willingness to accept (WTA) based on their profit expectations. WTP/WTA can be derived by monetizing utility (Formula 1). The difference between WTP and WTA defines the gains from trade—the economic surplus that can be captured from the market transaction. For homogeneous goods, the market-clearing price is assumed to be the price at which each trade will occur, and it is thus used to define the way in which gains from trade will be divided. However, residential land is generally sold through bilateral bidding and negotiation. A clear distinction should be made between WTP and a bid price, and WTA and an ask price. WTP/WTA is that threshold level (reservation price), above/below which a trader is not able to buy/sell. A bid/ask price is the price that the agent announces in the market when it comes on the stage of negotiation (see Figure 1). Since economic agents try to maximize the proportion of surplus that they capture from the transaction, they tend to form their final bid/ask prices for land lower/higher than WTP/WTA, as in Formula 3, where the WTP is adjusted by ε_b for buyers and ε_s for sellers.

$$P_{bid} = WTP - \varepsilon_b \ , \qquad P_{ask} = WTA + \varepsilon_s \ . \tag{3}$$

However, if a bid price will be too low or an ask price will be too high, the trade will not occur. Thus, the variable ε should not be random number but should reflect the situation on the market (for example, excess of demand or supply [10], or rate of land prices change). In perceived "seller's" markets (when sellers have an advantage), realized transaction prices are often higher than ask prices. In "buyer's" markets, prices are often lowered over time. In the current version of the ALMA model we define ε as in Formula 4.

$$\varepsilon = (NB - NS)/(NB + NS) \ . \tag{4}$$

Here: NB – number of buyers, NS – number of sellers. For sellers variable ε also accounts for the average price in the Moore neighborhood of the cell, which seller owns.

3.3 Price Negotiation and Market Transactions

Location choice and the price for the desirable site are determined jointly. However, the market transaction may not take place if two sides are not able to come to a price agreement (e.g. if the sellers ask price is higher than the bid price of a buyer). In the opposite case when a bid price of a buyer is higher than a seller's ask price, there are several possible ways to determine the actual transaction price for the spatial good. Price negotiation mechanisms in the existing ABM of markets vary from simple arithmetic/geometric average of bid and ask prices [14] to sophisticated algorithms, such as auctions [16, 22]. For simplicity at this stage of the ALMA model the price negotiation procedure is implemented as a calculation of the arithmetic average of the seller's price and a bid of a single buyer who finds the offered land lot attractive and can afford to buy it.

After the matching buyer and seller have agreed upon the actual price of the land, the market transaction takes place. At the moment when trade is registered in the ALMA model both buyer and seller update their status (the seller will not sell in the next period and the buyer will not search for a land lot to buy), the ownership rights on the spatial good are transferred from seller to buyer, and the transaction price is registered as the actual price for this specific land lot. The numbers of buyers and sellers left on the market after the transaction will influence the determination of bid and ask prices via the variable ε (see Formulae 4 and 3). The actual transaction price influences future ask price in the neighborhood. The state of the sold land (urban use or green area) feeds back in the spatial characteristics of the neighborhood and influence WTP/WTA for the surrounding cells in the future trades.

4 Simulation Experiments

We run the model with different assumptions and different numbers of agents.

Experiment 1-1: In the first set of experiment we tried to reproduce the traditional monocentric model proposed by Alonso. The model assumes that the city will grow until the moment when urban rent will be equal to the agricultural rent. We do not model the agricultural profit calculation directly, but as in the model by Alonso assume that agricultural rent is fixed and equal to some constant R_a=24). This potential agricultural profit serves as an ask price for sellers. It is assumed that buyers bid exactly their WTP, so that variable ε (see Formula 3) is equal to zero. In other words, the market situation is not taken into account, only the pure preferences of the economic agents. We run the model on a small cell grid (11x11 cells) and a number of traders equal to 265 (120 sellers and 145 buyers). Buyers' disposable budget Y is equal to 100. The result is that we always get the typical rent gradient for the monocentric city as in Alonso type of models (see Figure 3).

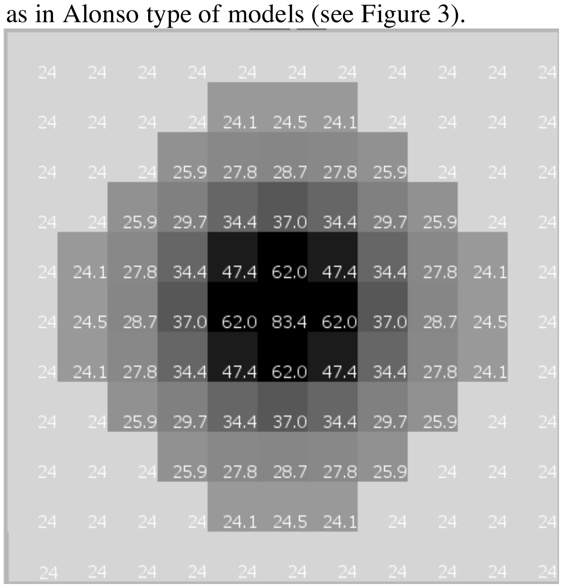

Fig. 3. Rent gradient (bid price is equal to WTP; no green amenities)

In Figure 3, the number in each cell shows the actual market price on which buyer and seller agreed. The intensity of grey color symbolizes the price of the land: the darker the color, the higher the land price. The rent is equal for all the cells that are situated an equal distance from the CBD (as in the Alonso model). The expansion stops expand when the bid price of a buyer is less than the agricultural rent R_a. The lightest-grey area shows the beginning of agricultural (non-sold area) and symbolizes the city border.

Thus, the model of a bilateral land market, with buyers and sellers negotiating over land price is able to produce the traditional spatial economics model. However, *we have made a step forward, since this spatial equilibrium is not obtained in one shot but rather is a result of dynamic trading*.

Experiment 1-2: Let us assume that buyers form their bid prices not only on the basis of utility but also taking into account market situation (variable ε Formula 3). All other conditions stay the same as the previous exercise. The new assumption implies that we make a distinction between buyer's WTP and her bid price. If bid price is higher or lower than in the Experiment 1-1 for the same property, then the final transaction price will be different as well. Whether land prices will be higher or lower depends on whether there is a "seller's" or a "buyer's" market. In our settings (where the amount of buyers is higher than the amount of sellers) land prices will grow. The result of the rent gradient and actual values of the rent is shown in the Figure 4 below.

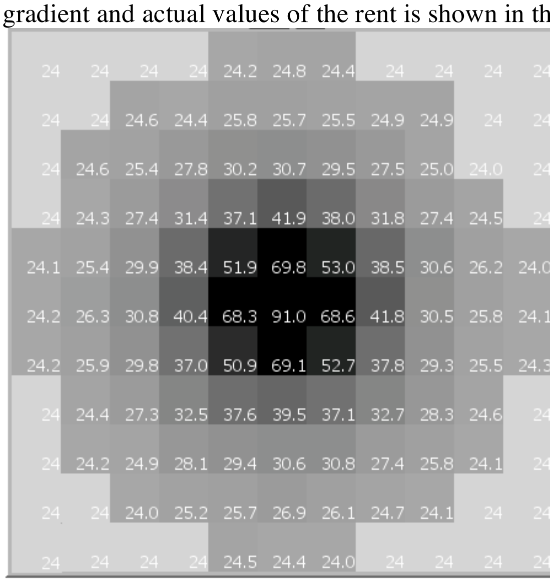

Fig. 4. Rent gradient (bid is a sum of WTP and ε, no green amenities)

As one can see, first of all the boundary of the city expands, as expected. It is caused by the fact that the market structure favors for sellers. So, buyers incrementally raise their bid prices and are able to buy the land further from the CBD even if they originally would have bid less than R_a. The rent gradient still follows the Alonso-von Thunen predictions, i.e. the rent decreases with the distance. However, the structure of the land prices is different than in the previous example: the *land at the same distance may not have the same price*, since buyers bid it at different time steps within different market structure (different value of ε). The bigger the gap between the number of buyers and sellers on the market, the larger the deviation of land prices from Figure 3 above (where bid price is equal to WTP and is not biased by the agent's perception of the market situation).

Land prices in general are higher in Figure 4 in comparison with Figure 3. However, sellers' WTA did not grow: it is still the same fixed R_a. Buyers bid higher prices and capture fewer gains from trade. Thus, *if not only WTP but also market variable ε is included in the determination of a buyer's bid price, then aggregated market outcomes changes qualitatively (the land price gradient shifts up and the city border shifts out).*

Experiment 2-1: Here we concentrate on investigating environmental externalities and their influence on land prices. Let us bring in 15 green areas spread over the city. The agents have uniformly distributed preferences for green amenities (variable αin

Formula 1). Both buyers and sellers take market information into account while forming their bid and ask prices. Figure 5 shows the rent gradients in the city with green amenities. The cells with letter "G" show where the green areas are. The white cells are the ones which nobody either can afford with the current disposable budget (defined by user) or wants to buy. Here we do not assume the existence of the agricultural land rent equal for the whole landscape as a reservation price of the seller. Each seller has individual ask price (a sum of her WTA, which is determined as a monetized utility, and market variable ε).

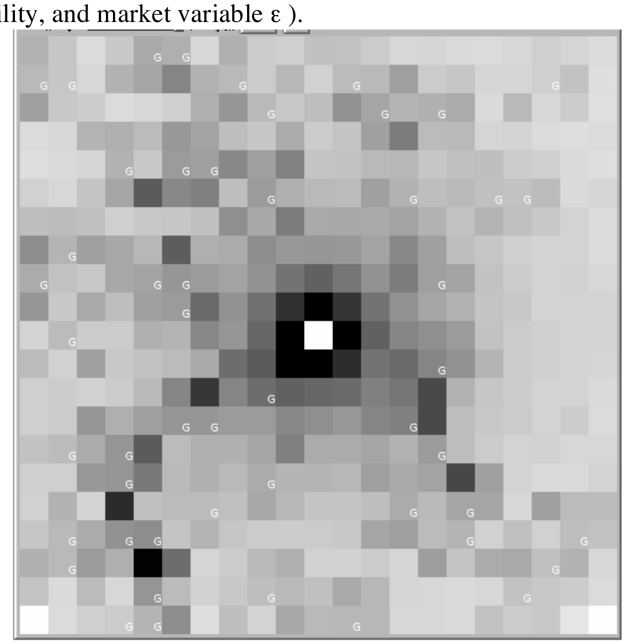

Fig. 5. Rent gradient (with green amenities and ε included in determination of bid and ask)

Prices are no longer strictly decreasing with distance from CBD. We can see some "islands" of higher land prices, clustered around the green areas in the city. Theoretical and empirical literature gives the evidence that people value green amenities and that this value is reflected in the prices for land or for houses. Our results show that *it is possible to obtain aggregated land market outcomes (e.g., prices) via endogenous markets even with interacting heterogeneous agents and heterogeneous spatial goods (different in distance and green amenities), with the possibility to explore spatial markets in dynamics rather than only in one static equilibrium state*. With the help of the ALMA ABM we can explore how prices evolve over time and how systems moves towards equilibrium.

5 Case Study and Future Work

This study was motivated by the case study of land use in the costal zone in the Netherlands. The coastal zone is a very densely populated area, and traditionally

Dutch government guarantees a certain safety level. The main two policy objectives in the coastal zone area are to provide safety from flooding and efficient spatial allocation. However, since 2002 parts of some coastal towns appeared to be in the area beyond the dikes and are considered legally unprotected [23]. According to the Commission of Poelmann decision (declared in 2005) future developments in these areas are at the risk of individuals. Nevertheless, some studies showed [24] that the perception of the risk of coastal flooding is very low. In this situation individual location choices bounded by low flood risk perception might produce outcomes that contradict policy objectives. Neither land prices nor patterns of land use will reflect the existing risk of flooding if risk perception bias is present at micro level. A better understanding of individual behaviour and aggregated outcomes of this behaviour is crucial to achieve policy objectives. Thus, a proposed ABM with endogenous land price and land pattern formation might serve to simulate emergence of land use patterns in coastal zone area caused by individual location preferences. The utility function of an agent can be easily extended to include the notion of risk of flooding (for example in a form of preferences for safety). Safety can be considered as a public good.

At the current moment we have included another attribute of the spatial good – so-called social amenity (S). By social amenities we mean the availability of public services (such as schools of a good quality, or higher standards of safety from flooding) in the neighborhood. Social amenities are implemented by local governments and are financed by the taxes the local government gathers from its citizens. The ABM land market model with social amenities presented elsewhere [25] is inspired by the logic of the Tiebout model [26]. The Tiebout model assumes that citizens choose where to locate according to their preferences for public services provided by local governments, which compete for citizens by offering different quality of public services. These settings very well represent the situation of our case-study in the Netherlands.

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References

1. Bousquet, F. and C. Le Page, *Multi-agent simulations and ecosystem management: a review*. Ecological Modelling, 2004(176): p. 313–332.
2. Grimm, V. and S.F. Railsback, *Individual-based Modeling and Ecology*. 2005: Princeton University Press.
3. Judd, K.L. and L. Tesfatsion, *Handbook of Computational Economics Volume II: Agent-Based Computational Economics* 2006: Elsevier B.V.
4. Parker, D.C., T. Berger, and S.M. Manson. *Agent-Based Models of Land-Use and Land-Cover Change*. . in *LUCC Report Series No. 6; Report and Review of an International Workshop, October 4-7, 2001*. 2002. USA: University of California.

5. Arthur, W.B., S.N. Durlauf, and D. Lane, *The economy as an evolving complex system II. Santa Fe Institute Studies in the Science of Complexity, Vol. XXVII.* 1997: Addison-Wesley.
6. Epstein, J.M. and R. Axtell, *Growing Articial Societies: Social Science from the Bottom Up*. 1996, Washington, DC, Brookings and Cambridge, MA: The MIT Press.
7. Arthur, W.B., et al., *Asset pricing under endogenous expectations in an artifcial stock market.*, in *The economy as an Evolving Complex System II, SFI Studies in the Science of Complexity, Vol. XXVII*, W.B. Arthur, S.N. Durlauf, and D.A. Lane, Editors. 1997, Westview Press. p. 15-44.
8. Gode, D. and S. Sunder, *Allocative Efficiency of Markets with Zero-Intellegence Traders: Market as a Partial Substitute for Individual Rationality*. The Journal of Polictical Economy, 1993. **101**(1): p. 119-137.
9. Lux, T., *The socio-economic dynamics of speculative markets: interacting agents, chaos, and the fat tails of return distributions*. Journal of Economic Behavior & Organization, 1998. **33**: p. 143-165.
10. LeBaron, B., *Agent-Based Computational Finance*, in *Handbook of Computational Economics Volume 2: Agent-Based Computational Economics* K.L. Judd and L. Tesfatsion, Editors. 2006, Elsevier B.V. p. 1187-1233.
11. Marks, R., *Market Design Using Agent-Based Models*, in *Handbook of Computational Economics Volume 2: Agent-Based Computational Economics* K.L. Judd and L. Tesfatsion, Editors. 2006, Elsevier B.V. p. 1339-1380.
12. Brown, D.G., et al., *Exurbia from the bottom-up: Modeling multiple actors and their landscape interactions*. Geoforum, 2007.
13. Balmann, A. and K. Happe. *Applying Parallel Genetic Algorithms to Economic Problems: The Case of Agricultural Land Markets*. in *"Microbehavior and Macroresults", IIFET 2000 Proceedings*. 2000. Corvallis, Oregon USA.
14. Berger, T., *Agent-based spatial models applied to agriculture: A simulation tool for technology diffusion, resource use changes, and policy analysis*. Agricultural Economics, 2001. **25**(2-3): p. 245-260.
15. Happe, K., K. Kellermann, and A. Balmann, *Agent-based Analysis of Agricultural Policies: an Illustration of the Agricultural Policy Simulator AgriPoliS, its Adaptation and Behavior*. Ecology and Society, 2006. **11**(1): p. 49.
16. Polhill, J.G., D.C. Parker, and N.M. Gotts, *Effects of Land Markets on Competition Between Innovators and Imitators in Land Use: Results from FEARLUS-ELMM*, in *Social Simulation Technologies: Advances and New Discoveries*, C. Hernandez, K. Troitzsch, and B. Edmonds, Editors. Forthcoming.
17. Alonso, W., *Location and Land Use*. 1964, Cambridge, MA: Harvard University Press.
18. Varian, H., *Microeconomic Analysis. Third Edition*. 1992, USA: W.W. Norton & Company, Inc.
19. Kirman, A.P., *Whom or what does the representative individual represent?* Journal of Economic Perspectives, 1992. **6**(2): p. 117-136.
20. Tesfatsion, L., *Agent-Based Computational Economics: A Constructive Approach To Economic Theory*, in *Handbook of Computational Economics Volume 2: Agent-Based Computational Economics* K.L. Judd and L. Tesfatsion, Editors. 2006, Elsevier B.V. p. 831-880.
21. Arthur, B., *Out-Of-Equilibrium Economics and Agent-Based Modeling*, in *Handbook of Computational Economics Volume 2: Agent-Based Computational Economics* K.L. Judd and L. Tesfatsion, Editors. 2006, Elsevier B.V. p. 1551-1564.
22. Miyake, M., *Precise Computation of a Competitive Equilibrium of the Discrete Land Market Model*. Regional Science and Urban Economics, 2003. **33**: p. 721-743.
23. Ministerie van Verkeer en Waterstaat Rijkswaterstaat, *Towards an Integrated Coastal Zone Policy – Policy agenda for the coast,*. 2002, The Hague: Direct Dutch Publications BV.

24. Kaiser, G. and D. Witzki, *Public perception of coastal flood defence and participation in coastal flood defence planning*. Geographie der Meere und Küsten. Coastline Reports, 2004(1): p. 101-108.
25. Filatova, T., *Public Services and Tiebout Hypothesis: Households' Location Sorting via Spatially Explicit Agent-Based Land Market Model (ALMA)*, in *Term paper for the course CSS-610*. 2007, George Mason University: Fairfax, VA, USA. p. 1-26.
26. Tiebout, C.M., *A Pure Theory of Local Expenditures*. The Journal of Political Economy, 1956. **64**(5): p. 416-424.