

# MODELING OF A RESIDENTIAL LAND MARKET WITH A SPATIALLY EXPLICIT AGENT-BASED LAND MARKET MODEL (ALMA)

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**Abstract:** We construct a spatially explicit agent-based model of land market. There are two main actors in the land market model: buyers and sellers of land. Heterogeneous agents sort among locations with respect to the distance from the city center and environmental spatial externalities. Land prices are formed endogenously via agents' interactions. The links between individual behaviors and macro-phenomena (land patterns and land prices in the case of land markets) emerging from their interactions are explored. 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 of land prices appears when environmental amenities are added.

Agent-based modeling (ABM) is coming into use to explore market dynamics. According to (Marks 2006) there are five examples of designed markets: financial markets, markets for pollution emissions, auctions for electro-magnetic spectrum, electricity markets and on-line e-markets. The use of agent-based modeling (ABM) technique implies heterogeneity among agents, implicit modeling of agents interactions and cross-scale dynamics. ABM has been successfully used to model economic markets from bottom-up since mid 1990s (Gode and Sunder 1993; Arthur, Holland et al. 1997; Lux 1998), mainly in the field of financial markets. The reasons why economists started to use ABM in their research are widely discussed in the agent-based computational economics (ACE) literature (Arthur, Durlauf et al. 1997; Judd and Tesfatsion 2006). In short, they can be summarized as an alternative solution to the idea of a representative agent in economics (which goes in contrast with the real-world economic agents who are heterogeneous (Kirman 1992)) and the problem of getting to the equilibrium in one shot (when the empirical evidence shows that economic systems are dynamic and adaptive). ACE considers economy as a system of many micro agents, who by interacting with each other give rise to global regularities (market institutions, employment rate or income distribution), which in turn influence local interactions. (Tsfatsion 2006). Conventional economic theory declares equilibrium, which is by definition a unique static state, as an essence. In contrast ACE considers economy as a dynamic system, which tends to come to equilibrium and in some cases reaches it, but also accounts for multiple equilibria or out-of-equilibria situations (Arthur 2006).

Land markets are specific markets. Land has a complicated history in economic theory (Randall and Castle 1985) and was not usually treated in a spatially explicit way. Researches in spatial economics admit that land differs from other goods in a number of ways because it is immobile, has unique and unalterable properties (e.g., slope, affiliation with a region/municipality, access to other locations), usually has a inelastic supply and use of land by one agent unavoidably affects the use and value of the surrounding land (generates externalities) (Buurman, Rietveld et al. 2001; Wu, Adams et al. 2004). In turn, modeling land markets involves two challenges:

1. In contrast to other designed markets designed land market should have 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). This fact complicates the formalisation of price formation procedure because different agents (consider a business firm and a farmer for example) might value the same piece of land in

a different way. At the same time, the same agent will have different willingness to pay for land with different characteristics (e.g., distance from the central business district, availability of green amenities, soil fertility and etc.)

2. Land markets need to be modeled in a *spatially explicit* setup. The desire to purchase a specific land lot or house depends not only on its own characteristics but also on the characteristics of its neighborhood. It is widely discussed in the literature that externalities related to the geographical location, i.e. *spatial externalities*, influence the attractiveness of an area (Fujita, Krugman et al. 2001; Irwin and Bockstael 2002; Wu, Adams et al. 2004). Firms might find it advantageous to locate in the proximity to each other because of the economies of scale. Households value the houses close to the green natural areas higher. Thus, land markets should be better modeled in a spatially explicit way in order to track the spatial externalities and changes in land prices with changes in the neighborhood.

There are few examples of land markets modeled within ABM for land use (Balmann and Happe 2000; Berger 2001; Polhill, Parker et al. in press). Based on this experience and keeping roots in the spatial economics literature, we are proposing an ABM of a land market. The aim of this paper is to present a spatially explicit market for land designed with the help of ABM – an Artificial Land Market (ALMA). We focus on the ownership land market and consider land/house as a good traded at the market. The following scheme represents the logic of the ALMA model:

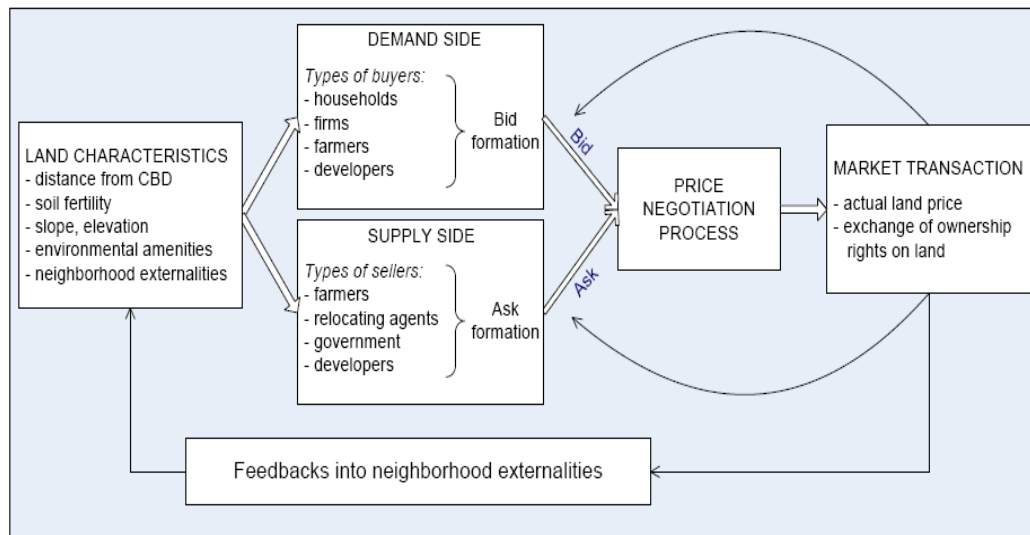


Figure 1: Conceptual scheme of the land market

Depending on the characteristics of a spatial good buyers and sellers form their “bid” and “ask” prices for land. Both supply and demand side are represented by several types of agents as it can be seen from Figure 4. Buyers and sellers participating in land market are different in nature, in their motivations to buy or to sell a land parcel or a house, and 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, 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 price affects 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.

At this point of the model elaboration we do not include all the actors of land market into the ABM. We just concentrate on the households which want to buy a house and supply of housing from other households, which want to move or from former agricultural use. The land market in ALMA is presented as a two-side matching market. There is a set of  $n$  buyers  $B = \{1, 2, \dots, n\}$  and a set of  $m$  sellers  $S = \{n+1, n+2, \dots, m\}$ . At the moment of model initialization 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  $U = U(Z, D, E)$ . Agent's utility depends on the consumption of a composite good  $Z$ , presented as a numeraire and equal for all agents, and on the consumption of a spatial good. Spatial good is characterized by the distance ( $D$ ) from the central business district (CBD) and availability of environmental amenities ( $E$ ). The choice of location is constraint by the available budget  $Y = Z + T(d) + R$ , where  $Y$  is an agent's income,  $Z$  proportion of his budget spent on the non-spatial consumption good (equal to numeraire) and  $R$  is price for land the person can afford. 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.

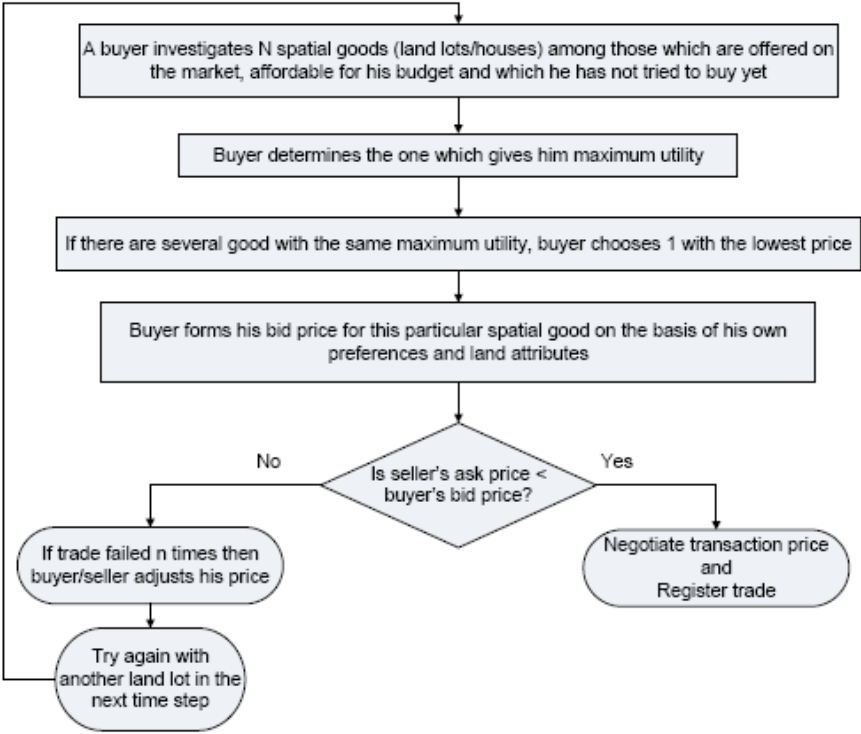


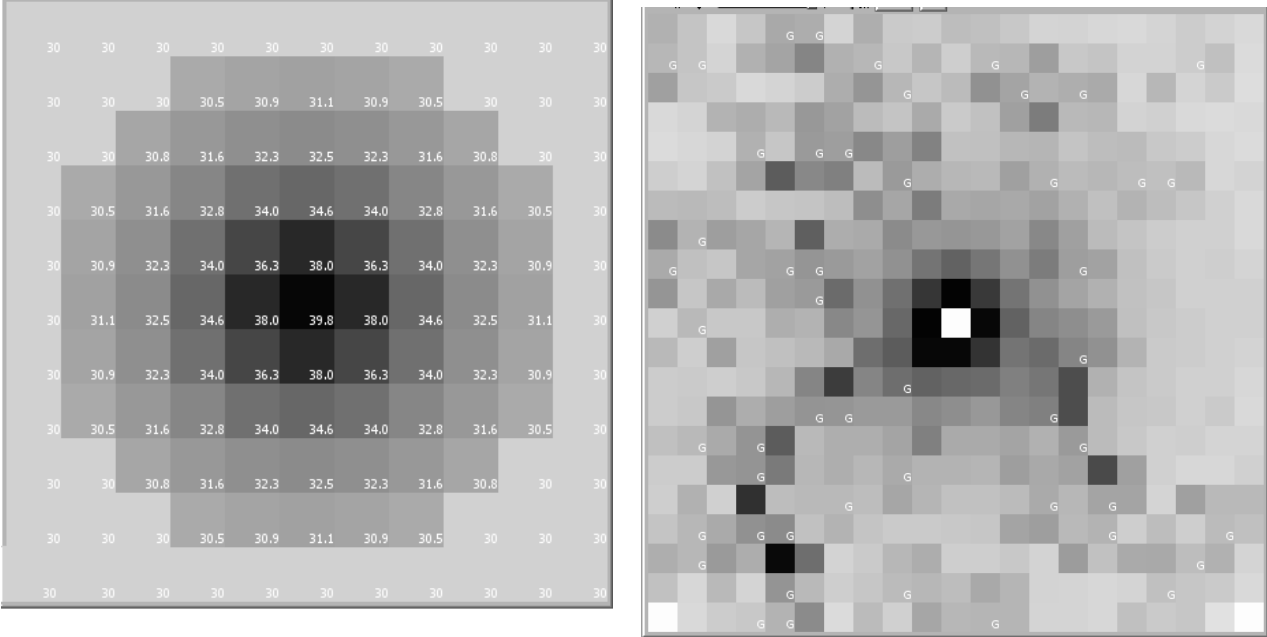
Figure 2: Algorithm of trade

We run the model with different assumptions and different number of agents. For the first experiment we assumed that former agricultural land is supplied at the market. Potential agricultural profit serves as an ask price for sellers. However, we do not model the agricultural profit calculation directly. For the case in Figure 3.a we just wanted to reproduce the standard

urban model. We run the model on a small cell grid (11x11 cells) and a number of traders equal to 265 (120 sellers and 145 buyers).

For the case in Figure 3.b the area of the simulated city was extended (21x21 cells) as well as an amount of traders (425 sellers and 520 buyers). Besides, we included green areas (50 units, they may be considered as parks) spread randomly over the city. The cells with letter “G” show where the green areas are. The white cells are the ones which nobody 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 an individual ask price. The prices are not just decreasing with distance from CBD. We can see some “islands” of higher land prices, which clustered around the green areas in the city.

Figure 3 shows the map of land prices for a simple monocentric model, the number in each cell show the actual market price on which buyer and seller agreed. The intensity of green color symbolizes the expensiveness of the land: the darker the color, the more higher the land price. The rent in Figure 3.a is equal for all the cells, which are situated at an equal distance from CBD (as in von Thunen and Alonso type of models). The city stops to expand at the moment when bid price of the buyer becomes less than the agricultural rent ( $R_a=30$ ). The most light-green area shows the beginning of agricultural (non-sold area) and symbolizes the city border.



a) no green amenities

b) with green amenities

Figure 3: Rent gradients as a result of the artificial land market allocation

In addition, we calculate the aggregate households’ utility in the city. Since the amount of actors and amount of spatial goods are different we present here the average utility/per capita. For the case in Figure 3.a average household’s utility in the city is 14.75 in comparison to 20.16 for the case in Figure 3.b.

The ALMA model is still a work in progress. The model can be extended and improved in many directions. However, the most fundamental question we will be willing to discuss is the formalization of the price formation for a spatial good. Since we are attempting to depart from the static equilibrium model the traditional solution for the optimization problem with the help of Lagrange function does not apply. So, finding some alternative to determine price for a good on

the market, which has not yet come to the equilibrium, is the most challenging and interesting issue.

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