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Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models

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ABSTRACT

This paper introduces an economic agent-based model of an urban housing market. The RHEA (Risks and Hedonics in Empirical Agent-based land market) model captures natural hazard risks and environmental amenities through hedonic analysis, facilitating empirical agent-based land market modeling. RHEA is well grounded in economic theory and uses rich spatial data and econometric analysis. It moves beyond the existing work by explicitly simulating the emergence of property prices and their spatial distribution under adaptive price expectations of heterogeneous agents, advancing toward empirical modeling of agent-based land markets. At the same time RHEA operates in a realistic GIS landscape where realtor and households agents form ask and bid prices using empirical hedonic price functions. The simulation results demonstrate that this combination of theoretically sound micro-foundations in agents' behavior and empirical data is feasible. This opens opportunities to explore various methodological and policy-relevant research questions including exploration of abrupt non-marginal changes in markets and regime shifts in coupled socio-environmental systems.

1. Introduction

Spatial patterns of land values in real estate markets emerge from complex interactions of market dynamics, heterogeneous trader preferences, and heterogeneous attributes of the property stock. Various modeling approaches aim to represent the feedbacks between micro-foundations of actors' behavior and macro dynamics of property markets measured in land prices and their spatial patterns. There is a long tradition of modeling these spatial processes from the bottom up using statistics (Geoghegan, Wainger, & Bockstael, 1997; Irwin & Bockstael, 2002; Plantinga & Lewis, 2014; Sheppard, 1999), cellular automata (van Delden, Luja, & Engelen, 2007; Verburg, de Koning, Kok, Veldkamp, & Bouma, 1999), micro-simulation (Ettema, Arentze, & Timmermans, 2011; Miller, Hunt, Abraham, & Salvini, 2004) or agent-based methods (Brown & Robinson, 2006; Parker, Berger, & Manson, 2002). It is essential that computational models are based on micro-foundations, which are not only theoretically sound but are also empirically justifiable, especially if effectiveness of policy interventions is to be assessed.

This paper presents an innovative agent-based model (ABM) of a spatially explicit empirical housing market – RHEA (*Risks* and *Hedonics* in *Empirical Agent*-based land market model) – and explores its behavior under various micro-foundations.[1] Several recent papers provide comprehensive reviews of ABM methodology applied to socio-economic processes in space (An, 2012; Filatova, Verburg, Parker, & Stannard, 2013; Heckbert, Baynes, & Reeson, 2010; Matthews, Gilbert, Roach, Polhill, & Gotts, 2007; Schreinemachers & Berger, 2011) and review the state-of-the art in agent-based land market models (LMMs) (Ettema, 2011; Huang, Parker, Filatova, & Sun, 2013; Magliocca, Safirova, McConnell, & Walls, 2011; Parker & Filatova, 2008). Spatial ABMs applied on an urban scale generally either tend to use a comprehensive empirical landscape setting and some data to lay foundations for agents' behavior omitting theoretical assumptions about economic processes (Benenson, 1998; Brown, 2006; Dawson, Peppe, & Wang, 2011; Yin & Muller, 2007), or use a stylized landscape and little empirical micro-foundations of agents' behavior with

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[1] By micro-foundations this paper means the basic principles that lay out the foundations of individual agents' behavior. These include a specific theoretical basis as well as empirical information that is used to parameterize and/or validate these behaviors. The ability to generate market level phenomena and patterns based on detailed empirical data and theoretically-sound micro behavior provides a novel advancement in ABM.

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theoretically-elegant economic solutions (Ettema, 2011; Filatova, van der Veen, & Parker, 2009; Magliocca et al., 2011). There is a gap in the field: the feasibility of combining empirics and theory when designing micro-foundations of agents' behavior in spatial markets is underexplored.

ABMs are particularly strong in integrating socio-economic and environmental modeling, often within a spatial landscape, across scales, as well as exploring various market phenomena by going beyond stylized assumptions of equilibrium economic models. Yet, ABMs are often weak in connecting to empirical data when parameterizing various attributes and validating decision-making processes of agents (Boero & Squazzoni, 2005; Poggio, Lo, LeBaron, & Chan, 1999). In fact validation and parameterization is one of the main research challenges in the field of ABM (Filatova et al., 2013; Heckbert, Baynes et al., 2010; Heckbert & Bishop, 2011; Robinson et al., 2007; Smajgl, Brown, Valbuena, & Huigen, 2011; Windrum, Fagiolo, & Moneta, 2007). The benefits of connecting ABMs to empirical data are obvious. Firstly, while purely theoretical ABMs have an important added value (Boero & Squazzoni, 2005), their application for policy analysis is contingent on the use of empirical data for parameterization and validation. A consistent use of empirical data increases trust of various stakeholders in any model, including ABMs (Janssen & Ostrom, 2006). Secondly, ABMs are extremely flexible on the choice of behavioral rules at individual agent level and on the structure and frequency of interactions. This forces a modeler to face a choice of numerous variability in a model instantiation (Polhill et al., 2014). The parameterization of an ABM with the actual data filters the nearly-unlimited collection of options for micro-foundations or parameter settings to an easier-to-handle parameter set that produces an ABM world resembling a realistic case. Thirdly, data on individual choices over time and on the structure of human interactions permits an examination of the theoretical consequences of more realistic assumptions (Janssen & Ostrom, 2006). Empirical data could be used to design and parameterize realistic micro-foundations of an ABM or to validate macro outcomes of a simulation but preferably both (Boero & Squazzoni, 2005). Empirical methods for building ABMs such as surveys, stylized facts, archival and census data, participatory modeling, expert knowledge elicitation, participant observation, field and laboratory experiments, and GIS data have been extensively reviewed (Boero & Squazzoni, 2005; Heckbert, Baynes et al., 2010; Janssen & Ostrom, 2006; Robinson et al., 2007; Smajgl et al., 2011).

Advantages of using empirical data for an ABM are vast. However, there are also challenges, which may include: (1) maintaining a link between empirical data and a theory, assumptions of which an ABM is supposed to relax, (2) scaling up observed behavioral data to large population of artificial agents, (3) capturing behavioral change through time when empirical data often provides only a snapshot, (4) a necessity to collect case-specific data to match the design of an ABM, (5) difficulty in replication and generalization of the results since some methods of collecting data that is suitable for ABMs are difficult to reproduce, (6) translation of qualitative data into formal rules when coding (Heckbert, Adamowicz, Boxall, & Hanneman, 2010; Janssen & Ostrom, 2006; Robinson et al., 2007; Smajgl et al., 2011; Valbuena, Verburg, & Bregt, 2008; Windrum et al., 2007).

An empirical ABM of an urban economic system, which is well grounded in economic theory and could use readily available spatial data and economic empirical analysis, is not available yet. The RHEA model aims to address this gap. Specifically, theoretical micro-foundations of residential household agents' behavior are framed within urban economics theory (Alonso, 1964; Frame, 1998; Wu, 2001) and use adaptive price expectations. At the same time RHEA operates in a realistic GIS landscape where realtor and households agents form ask and bid prices using empirical hedonic price functions, i.e. empirically-estimated willingness-to-pay functions based on detailed spatial attributes of the property stock. Moreover, empirical micro-foundations include real income distributions, and behavioral rules of traders in a housing market validated through an interview with a US realtor.[2] The interview shed light on the fact (i) that sellers set prices based on realtors predictions, (ii) that buyers anchor their bids on seller's ask prices, (iii) that an outcome of price negotiations depend on market power of traders and their opportunity costs, and (iv) that prices, at which realtors anticipate to sell a house, depend not only on spatial and structural attributes of a house but also change dynamically with market conditions. In addition, some quantitative parameters of the models, such as percent of differences between bid and ask prices, and a period of recent sales realtors take into account when forming prices expectations, were derived from the interview. RHEA is applied to a coastal town in North Carolina, USA where data on both coastal amenities and flood risks affect locations choices and price dynamics.

The innovativeness of the current model is threefold: (i) in comparison to economic studies of land use (Irwin & Bockstael, 2002) RHEA explicitly simulates the emergence of property prices under adaptive price expectations of heterogeneous agents, including the emergence of cardinally new trends in prices and their spatial distribution, (ii) in comparison to other agent-based LMMs, which are stylized abstract models (Ettema, 2011; Gilbert, Hawksworth, & Swinney, 2009; Magliocca et al., 2011; Parker & Filatova, 2008), the current model makes a step forward toward empirical modeling of ABM land markets by using actual hedonic studies and distribution of households incomes; (iii) in comparison to other empirical spatial ABMs of urban phenomena (Brown et al., 2008; Robinson et al., 2007) RHEA has a full LMM with adaptive price expectations, which allows for the emergence of prices and may lead to qualitatively different trends in spatial patterns (Parker et al., 2011).

The primary goal of this paper is to provide the first detailed description of the RHEA LMM with a special focus on micro-foundations and methodological aspects related to merging theoretical and empirical approaches (Section 2). In addition, a series of experiments is presented to explore how the model's micro-foundations impact aggregated spatial urban system dynamics (Section 3). Conclusions and future work are outlined in Section 4.

2. Model description (ODD + D)

The RHEA LMM is described below employing the standard ODD protocol for ABMs (Grimm et al., 2010), which was recently extended to account for human decision making – ODD + D (Mueller et al., 2013).

2.1. Overview

2.1.1. Purpose

RHEA aims to provide a methodological platform to integrate adaptive economic behavior into the spatial landscape using urban economics theory and traditional data sources. This article presents the base model but specific experiments could be designed to explore a range of research questions that are difficult to tackle with other economic or geographic tools, which rely exclusively on static agents' behavior and past data (Filatova & Bin, 2013). In particular, how do changes in preferences or risk perceptions

[2] An open question interview was conducted in 2012 with L. Vidgop-Barg a practicing realtor with extensive experience.

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