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Agent-based modelling of purchasing, renting and investing behaviour in dynamic housing markets

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ABSTRACT

Residential Location Choice (RLC) and Real Estate Price(REP) have been considered as highly correlated and therefore have been jointly studied. This paper develops an agent-based RLC-REP joint model as a key component of an integrated land use-transport model, SelfSim. RLC-REP is capable of simultaneously simulating purchasing, renting and investing behaviour, considering the interactions and competitions between different agent types in the housing market, including renter, landlord, purchaser, seller and investor agents, resulting in new residential locations and real estate prices. In addition, the demographic evolution model in SelfSim that is directly linked to the RLC-REP model is also introduced. Next, both global and local sensitivity analyses (SAs), which employ the Elementary Effect Method (EEM) and Once-At-A-Time (OAT) Method, respectively, are carried out to fully test RLC-REP in a numerical example set up based on a Chinese medium-sized city, Baoding. The EEM-based global SAs identify four influential parameters (among the thirty-four) that could significantly influence the outputs of interests. The OAT-based local SAs further explore how these four important parameters influence the outputs, suggesting that the interactions between parameters could heavily influence the model sensitivity. Finally, the potential applications of the SA results to calibrate the model and to set up "what-if" scenarios are discussed.

1. Introduction

Residential Location Choice(RLC) and Real Estate Price(REP) models have been developed as essential components for many urban models, such as UrbanSim [1] and ILUTE [2]. In general, the studies of RLC were focused on two research questions [3]: 1) whether a household decides to move; 2) and where to move. Two classical and most-cited studies for these two questions are Rossi [4] and Brown and Moore [5], respectively. A comprehensive review of the RLC studies can be found in the work of Dieleman [6]. Recently, agent-based modelling has gained popularity in the studies of urban micro-simulations and has also applied to model RLC. A comprehensive review of the agent-based modelling of RLC can be found in the work of Huang, et al. [7]. The studies of REP generally investigated the factors that might influence the price and then used the empirical findings to develop methods to predict the price. Among them, the hedonic model appears to one of the most-used approaches [8–13]. Since RLC and REP are highly correlated and interact with each other, they have been jointly studied. The economic bid-rent theory is a traditional approach to simultaneously modelling RCL and REP, in general with the assumption of a static demand-supply equilibrium [14,15]. Some attempts have been made to couple the bid-rent theory with agent-based modelling, in order to investigate disequilibrium housing markets [16–20].

In general, these agent-based RLC-REP models mainly differ from each other in two aspects: agent types included and the behavioural rules of agents used. Buyer and seller agents were two typical types in agent-based RLC-REP models [16,21]. Some of the models also considered developers and land owners, in order to simulate the land market as well [19,20]. However, the renters and landlords in the rental market, as well as investors in the housing market have received relatively scant attention

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in these RLC-REP models. In response to this limitation, the proposed RLC-REP model will simultaneously simulate purchasers, sellers, landlords, renters and investors, considering the interactions and competitions between them. In terms of behavioural rules of agents, the utility maximization theory has been widely applied to model the decision-making of different agent types, including buyers and sellers, with the assumption that agents always choose the alternatives with the highest utilities [16–18,20,22]. Further, it has been argued that the loss in utility due to choosing a new residential location might have heavier influence than an equivalent-sized gain in utility, according to the prospect theory [23–26]. Therefore, some attempts have been made to incorporate the prospect theory into utility functions, in order to consider the difference between gain and loss utilities [19,21,27]. Since many integrated urban models incorporated RLC and REP as key components, some agent-based RLC-REP models have been developed particularly for these integrated models: Ettema [16] proposed an agent-based micro-simulation model of housing market processes as a component of PUMA (Predicting Urbanisation with Multi-Agents) [28]; Habib [27] simulated both residential mobility and location choice processes within ILUTE (Integrated Land Use, Transportation, Environment) modelling system [2]. Zhuge, et al. [21] developed an agent-based RLC-REP model as a component of SelfSim, an agent-based land use and transport model. It is worth noting that the latter two RLC-REP models incorporated the prospect theory into their utility functions that were used to simulate the decision-making of agents.

This paper attempts to extend the agent-based RLC-REP model in SelfSim by incorporating the rental market and investing behaviour, aimed at fully capturing the interactions and competitions in the dynamic housing market. Specifically, the proposed RLC-REP model will define the behavioural rules of purchasers, sellers, landlords, renters and investors, and simulate the interactions and negotiations between these agents, resulting in new residential locations and real estate prices. As a component of SelfSim, the proposed RLC-REP model is directly and indirectly linked to several SelfSim sub-models. Among them, the demographic evolution model, which is used to simulate demographic transitions, is more closely associated with RLC-REP, as the life-cycle events (e.g., death and birth) of agents, which are the outputs of the demographic evolution model, are the key inputs of the RLC-REP model. Therefore, the demographic evolution model, as well as its relationship with the RLC-REP model will also be introduced. Another focus of this paper is to fully test the RLC-REP model using parameter Sensitivity Analysis (SA), in order to better understand how RLC-REP behaves, and also how the outputs of interest may be influenced by the model parameters. This kind of full SA has not been done for the previous version of RLC-REP in SelfSim and has also seldom carried out for the other land use and transport models or their components [16–18,20,22,29–31]. SA is of great importance to new proposed models [32], especially for agent-based urban models that are generally involved in many parameters, as the SA results are expected to be useful for model simplification and calibration, as well as scenario analysis.

2. Agent-based land use and transport model-SelfSim

As aforementioned, the RLC-REP model is developed as a key component of an agent-based land use and transport, SelfSim. Compared with other micro-simulation land use and transport models, such as UrbanSim [1], ILUTE [2], ILUMASS [33] and PUMA [28], SelfSim aims to be more theoretically advanced and much more easily applied. Specifically, SelfSim attempts to use agent-based models to implement each component as far as possible, thereby simulating the co-evolution of land use and transport systems at a more micro

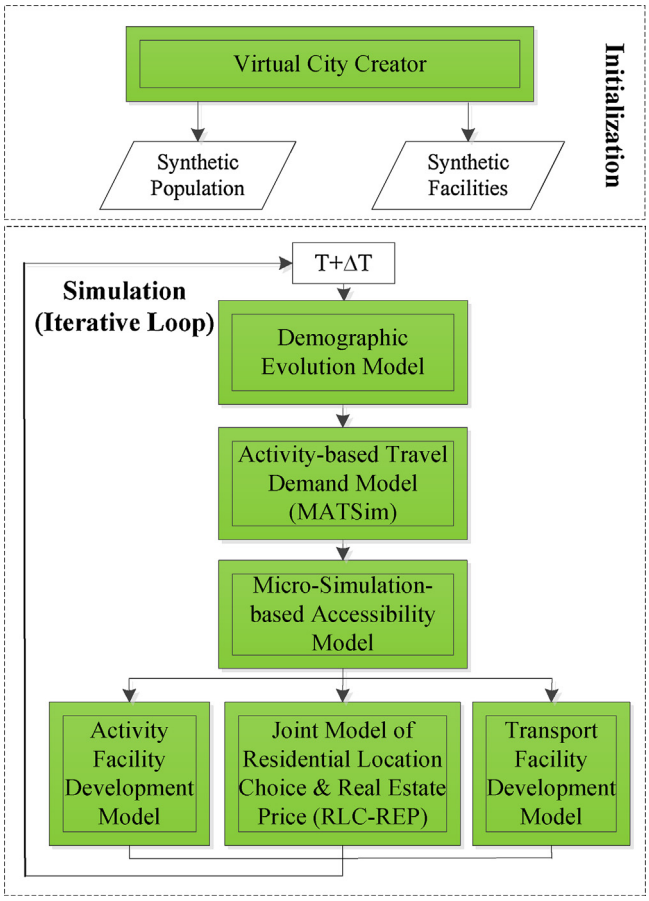

Fig. 1. Framework of SelfSim [21].

and disaggregate level. However, it is a concern that the agent-based simulation may further increase the demand for input data, which makes the integrated model more difficult to apply. In order to address this concern, an effort has been made to decrease the demand for the input data, which is the second aim of SelfSim [21].

SelfSim is composed of two modules, namely initialization and simulation modules (see Fig. 1). The initialization module is a virtual city creator that is a set of synthesis methods. The creator is used to generate a virtual city containing individuals, households and facilities. The virtual city creation can be viewed as a process of model initialization. The simulation module comprises several agent-based spatial models, including a demographic evolution model, an activity-based travel demand model, a micro-simulation based accessibility model, an activity facility development model, a RLC-REP model, and a transport facility development model, which make up an annual loop to simulate how the land use and transport systems co-evolve over time. Specifically, the demographic evolution model is used to simulate the demographic transitions, such as death and birth; the activity-based travel demand model, which is based on MATSim (Multi-Agent Transport Simulation), is used to simulate the daily plans of each agent in the population throughout a whole day at the micro level [34]; Based on the MATSim micro-simulation, the accessibility can be calculated with the micro-simulation based accessibility model for both activity and transport facilities at the disaggregate level. Finally, the accessibility is used as the main input for the transport facility development model, activity facility development model and RLC-REP model. The former two models are used to simulate the development of transport and activity facilities, respectively; the RLC-REP model is used to simulate the residential lactation choice and to predict real estate prices. Among the models, the demographic evolution