Chapter 12
Multi-scale Validation of an Agent-Based Housing Market Model

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Abstract Validation is a vital step in any model that aspires to have an impact. In agent-based computational economics in particular, it is essential because, unlike most neoclassical economic models, the models are vastly complex and often unique in their kind [1, 2]. Importantly, they often require disaggregated data to specify attributes, behavioural rules and interactions among agents. Therefore, agent-based models require more time and effort to validate. There are numerous ways of validation in agent-based modelling discussed in the literature, e.g [1, 3–7]. Reviewing them is beyond the scope of this paper. Here we will focus on two dimensions of validation: empirical versus theoretical validation and micro- versus macroscale validation. In our agent-based model of the housing market, we have applied both ends of the two spectra.

12.1 Introduction

Validation is a vital step in any model that aspires to have an impact. In agent-based computational economics in particular, it is essential because, unlike most neoclassical economic models, the models are vastly complex and often unique in their kind [1, 2]. Importantly, they often require disaggregated data to specify attributes, behavioural rules and interactions among agents. Therefore, agent-based models require more time and effort to validate. There are numerous ways of validation in agent-based modelling discussed in the literature, e.g [1, 3–7]. Reviewing them is beyond the scope of this paper. Here we will focus on two dimensions of validation: empirical versus theoretical validation and micro- versus macroscale validation. In our agent-based model of the housing market, we have applied both ends of the two spectra.

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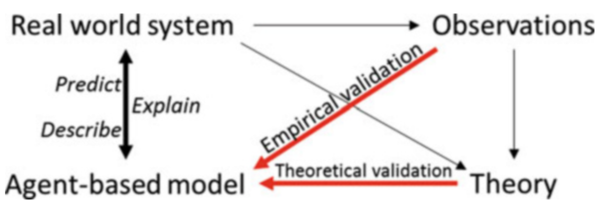

Fig. 12.1 Validation process for agent-based models. Empirical validation is directly based on observations of the real-world system, while theoretical validation – like the name suggests – is done by making use of theories, potentially derived from observations and our understanding of the real-world system or confirmed by them. Note that the arrows from observations to theory (induction) are also empirical validation but are beyond the focus of this paper

Empirical versus theoretical validation can be presented as a trade-off between making the model as detailed and realistic as possible – demanding empirical validation – and as simple and stylised as possible, which mostly demands theoretical validation. These two options of validating agent-based models are not mutually exclusive. Yet, the trade-off between detailed representation of a particular case study and generalisability governs where the modeller should put most of her effort. Moreover, she should realise that theoretical validation is often a lot less costly and time-consuming than empirical validation. Figure 12.1 summarises our conceptual overview of these two choices in an agent-based model where we try to describe, explain, explore as well as predict real-world phenomena. Processes in these real-world systems can be observed and studied. A modeller can choose to spend her time collecting data and formulating stylised facts based on these observations and use that as input for the agent-based model – empirical validation. When time is scarce, however, or when a modeller wants to build a model that is more stylised and generalisable, she will need to rely on theories – theoretical validation. Ideally, these behavioural theories should be passing an empirical test independently of a particular agent-based exercise, as many theories in psychology do [8, 9].

In this paper, we discuss our experience with an agent-based model of the housing market that is validated both empirically and theoretically across multiple scales. In our model, we attempt to seek a balance in scale and realism by combining empirical and theoretical validation methods and applying them on multiple scales (agent-level and market-level). We highlight what we learned from this example and how it is useful for other modellers, especially in environmental applications of agent-based computational economics where both spatial and behavioural data are to be combined.

12.2 Model Description

We built an agent-based model to explore how urban housing markets evolve in the presence of climate-driven floods and behavioural biases on the agent level. Climate change imposes severe consequences for urban development in hazard-prone coastal and delta areas. The issue is complicated by the fact that disaster risk is spatially correlated with rich environmental and urban amenities of those locations. They drive population clustering and growth of property values in hazard-prone areas, rapidly increasing exposure and vulnerability. Individual preferences for locations play a crucial role in the formation of spatial patterns in urban land markets. Yet, increasing climate-related risks may alter choices of individual economic agents, which enforces the potential for critical transitions from the bottom-up. In complex systems, changes in individual expectations driven by new information and emotions could lead to major abrupt shifts in the aggregated market dynamics.

We address the methodological challenge of studying non-marginal abrupt land use transitions by incorporating adaptive expectations about land market dynamics into a spatial agent-based model. It is a complete model of the property market in both a coastal and an inland city that experience regular floods. Extensive datasets of both GIS and housing transaction data are employed [10, 11] in addition to income and housing budget data from the USA [12–14]. Our current model is based on an existing model of a flood-prone housing market, the background and ODD+D description for which can be found elsewhere [15]. The current version makes significant improvements on the price expectations' procedure [16] and the structure of the utility function. In the model, we simulate household decisions in the flood-prone housing market, in particular, (1) households deciding on whether or not to sell their property, (2) a realtor agent advising sellers on their ask price, (3) buyers looking for properties within their budget, (4) buyers comparing properties based on expected utility calculations and deciding to bid on a property, (5) sellers entering negotiation with buyers that offer the highest bid and (6) buyers and sellers negotiating over prices. Flood risk enters the calculations in steps 2 and 4. The capitalised discount for properties at risk of flood is calculated in step 2, and individual risk perception enters the utility calculation in step 4. The utility calculation is based on buyers' housing budgets, preferences for neighbourhood quality, preferences for housing characteristics and subjective flood probabilities. Housing budgets are heterogeneous among agents. The capitalised discount for flood risk is calculated through analysis of sales during the simulations. Each time step, the realtor agent updates his price expectations through hedonic analysis and spatial interpolation (kriging) of sales in the previous time step.

12.3 Validation Techniques Used in Our Model

We can divide the validation techniques of our model into a theoretical part and an empirical part.

Theoretical:

- Economic theory: microeconomics, supply, demand and bidding, utility maximization

- Urban economics [15]: markets with spatial goods that are differentiated by distance to CBD, amenities and risks.
- Risk perception theory: risk negligence, prospect theory, expected utility

Empirical:

(a) For parameters on spatial and economic attributes:

- Two datasets in Eastern North Carolina – one coastal city with coastal flooding and one inland city with river flooding – with 4799 [11] and 3106 [10] property transactions, respectively
- Two datasets of actual housing properties and their structural characteristics in the same cities: 9793 properties in the Greenville dataset and 3481 properties in the Beaufort dataset.
- Empirical data on household income and budget spent on housing in the USA

(b) For parameters on behavioural attributes:

- Surveys among 600 current buyers and 600 current sellers

(c) For the structure of behavioural rules and interactions on the market:

- 2 × 2 hour in-depth interviews with real estate agents to specify the main architecture of the market (how ask and bid prices are formed, how agents negotiate prices, how they adjust prices, how learning on price expectations is happening) in 2013 and 2015
- 19 × half hour to 1-hour interviews with real estate agents in 2017

The model was initially validated against a set of stylised facts based on empirical observations on macroscale and interviews with two realtors to get an understanding on how the market should be modelled. Additionally we used microeconomic theories to engineer buyer and seller behaviour. After a few simulation studies, our demand for empirically informed behaviour on the microscale increased. We needed more data on the perceptions and considerations of individual households in order to better understand the underlying behaviour of agents in the market and to better link and understand it in the context of market responses to flood risk. Therefore we added the surveys (part b of empirical validation) at the last stage. These surveys allowed us to ask individuals specifically about their risk perception, their behavioural responses (e.g. would they actively avoid properties located in the flood zone?) and their willingness to pay for properties inside versus outside the flood zone.

12.4 Why Multiple Scales?

Our agent-based model was validated theoretically as well as empirically on multiple scales, from aggregated market-level responses to flooding events to individual responses to natural hazards. We applied a variety of approaches on multiple scales for a number of reasons. Firstly, we found that our theoretical models of risk perception in this agent-based land market model were insufficient to capture the price dynamics that were observed in empirical studies [17]. Secondly, empirical studies of market transactions that consist past flooding events were insufficient to extrapolate the behaviour of individual agents in a world where the climate is changing and severe flooding events become more common. Thirdly, we needed more data on the risk perceptions and choices made by individuals in order to understand the underlying behaviour of individuals that govern the observed market behaviour since neither of the stylised theoretical models can explain it well [ref to EE paper]. Hence, there seem to be additional factors that play a role in the actual decision-making.

The micro-macro validation approach allows for a better understanding of the system. ABMs allow us to study systemic behaviour by looking at how individual elements behave and interact. Any mismatch that we find between validated micro- and macro-level behaviour forces us to rethink the underlying mechanisms and relationships of the system's functioning. This iterative process is the core of the good modelling practice [18].

12.5 Contribution and Further Study

This paper contributes to our knowledge of validation in ABM in the following ways:

- It provides examples of ways to validate agent-based models: in particular, why it is useful to validate the model empirically on system level as well as on individual level.
- It provides some insights that help as a guide to other agent-based modellers.

We discussed our improvements in terms of empirical validation of micro-level validation. In the next stage of this research, the survey results will be analysed and implemented in the model. We assess the differences in outcomes when the model is based on validated system behaviour versus agent behaviour. Moreover, we will explore under which circumstance non-marginal shifts in property values may emerge when individuals experience a major flooding. It is of most interest to understand how social amplification of risk impacts this process and to what extent changes in probability and severity of floods matter.

Validation can be a continuous iterative process, and there is no definite answer as to how much empirical validation is enough in order to make a model useful for its purpose. Moreover, our experience in validating our model does not necessarily apply to other models as well, and the balance between theoretical and empirical validation may shift depending on the modelling purpose (e.g. predicting, explaining and understanding of real-world system dynamics). Most importantly, as with any model, the model design should make sense. It is up to expert judgement whether it does. It is not so much about how much the model itself needs to be validated but about how much information a person needs in order to be comfortable making well-reasoned modelling decisions.

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