ipea Instituto de Pesquisa Econômica Aplicada

Título do capítulo	CHAPTER 1 – LITERATURE
Autores(as)	Bernardo Alves Furtado
DOI	http://dx.doi.org/10.38116/978-65-5635-041-7/chapter1

Título do livro	*POLICYSPACE2*: MODELING THE REAL ESTATE MARKET AND PUBLIC POLICIES
Organizadores(as)	Bernardo Alves Furtado
Volume	-
Série	-
Cidade	Brasília
Editora	Instituto de Pesquisa Econômica Aplicada (Ipea)
Ano	2022
Edição	1
ISBN	978-65-5635-041-7
DOI	http://dx.doi.org/10.38116/978-65-5635-041-7

CHAPTER 1

LITERATURE

The literature review is divided into two parts. The first presents a basic description of the real estate market and its contributions to the construction of the *PolicySpace2*; the second defines agent-based modeling (ABM) and presents the research carried out and the possibilities of the methodology for the theme.

1 REAL ESTATE MARKET

Households are the largest component of the fixed capital stock. For the Brazilian case, Souza Júnior and Cornélio (2020) estimated that family properties represent 33.5% of total fixed capital for 2017.[1] Using a similar methodology, Morandi (2016) estimated the share of construction at approximately one and a half times the gross domestic product (GDP), which was equivalent to almost BRL 8 trillion in 2014 (2010 reais).

Additionally, for families, the purchase of property is also possibly their most relevant expense (Dipasquale and Wheaton, 1996), generating financial commitments for long periods of time. Since the acquisition of their own property is a goal for many families – given the program name Minha Casa Minha Vida – or that the cost of paying rent does not exceed 30% of income (FJP, 2018), the ability of families to bear housing costs makes the issue relevant to public policies.

In this sense, lower volatility and the absence of sudden cycles of highs and lows in prices are also of interest. Nijskens et al. (2019) suggest that controlling localized demand peaks would contribute to the management of this volatility.

However, this is not just a local problem. Additional demand may arise from changes in real estate financing rates with cheaper credit, for example – or even from the presence of foreign investors, or from changes in the rental market (Ozel et al., 2019). In other words, the volatility of real estate prices does not come only from the cost of financing, but also from exogenous factors.

In addition to its significant weight in household budgets and in the country's wealth, "[the] housing market is a dynamic system of intricately woven interdependent processes" (Jordan, Birkin and Evans, 2012, p. 511).

1. Followed by 28.1% for infrastructure and 18.1% for machinery and equipment.

The discussion of the complexities of the real estate market begins with the description of the property and its characteristics. To this first effect are added: i) users' perceptions and the impact of these valuations on price; ii) the property's relationship with the city and its spatial context; and iii) the dynamics of changing these factors over time for a structure that is durable.

Whitehead (1999) summarizes the characteristics of property as a durable good with a significant transaction cost, which leads to time-consuming and expensive adjustment processes. Properties are heterogeneous and rigid in their location, usually indivisible and, simultaneously, consumption and investment items (Arnott, 1987). Finally, a large part of the stock is fixed, with a slow and small percentage of replenishment, depending on the civil construction market, characterizing what is usually called a thin market (Dipasquale and Wheaton, 1992).

Location is a central factor in the identification, valuation and usability of properties. In addition to an objective location, such as distance from the center (Alonso, 1964; Brueckner, 1987), relative location – that is, the positioning in relation to other properties – also contributes to different valuations. Changes in the environment near a property directly impact the perception of its value, in addition to its accessibility, visibility and functionality. A property is both the building itself and its spatial insertion.

Thus, the property's surroundings, urban amenities, open spaces (parks, green areas), factories, shopping malls, bus stations and university campuses are considered in the formation of real estate prices (Brueckner, Thisse and Zenou, 1999; Wheaton, 2004).

In the perception of urban space, these amenities that influence real estate can be condensed in the idea of neighborhood or district, as defined by Galster (2001) or Lynch (1960). The neighborhood of the property – or, more generally, its urban insertion – reflects the identification of the local scale of the cities. Access to the city and the construction of the city itself, with all its benefits and drawbacks (Bettencourt, 2013), are given by the immediate surroundings of the property.

It is the environment that links it to the possibilities of interacting with innovation (Jacobs, 1970), or to the original notion of agglomeration economies (Marshall, 1890), to the buzz concept (Storper and Venables, 2005) and the quantification of these values specifically for the real estate market (Furtado, 2009).

The influence of the property location on the formation of prices goes beyond the location of that property in relation to other properties, but also to employment centers (Fujita, Krugman and Venables, 1999; Mills and Nijkamp, 1987; Steinnes, 1982) and to transportation systems (Waddell, 2002), which modifies the relative distances.

Decision making about the property (and its location) depends on the family, as a collective unit that brings together financial resources and preferences. Arentze, Ettema and Timmermans (2010) conducted a seminal examination of management of individual mobility, given the needs and preferences of family members. Afterwards, other studies deepened the analysis detailing individual activities and the integrated management of their mobility (Moeckel, 2017; Zhuge et al., 2016).

In practice, the current economic proposition assumes that real estate prices follow a spatial equilibrium – resulting from the construction of the model by Dipasquale and Wheaton (1996) – in which the following conditions are all equalized: i) supply of real estate and demand by buyers on the sales and rental market; ii) remuneration of the property and its equivalent in the financial assets market; and iii) salaries and amenities compared to other locations.

However, as Glaeser and Nathanson (2017) themselves suggest, empirical data do not reflect this theoretical construction, mainly due to three factors: i) significant moment: that is, rapid price changes (up and down), which, as an inertial process, intensify high and low processes; ii) mean reversion; and iii) "excess variance relative to fundamentals" (Glaeser and Nathanson, 2017, p. 1).

These factors originate in the difficulty of market participants to acquire a complete picture when observing prices and also in the tendency to use historical data, with dated beliefs, so to speak, to predict future prices.

This discussion refers to understanding the market as a whole, the behavior of average prices and their correlation with financial assets. However, the real estate market is operated by "non-professionals" (Glaeser and Nathanson, 2017), in a market without advertised prices (such as asset prices on the stock exchange, for example), with high operating costs, making it impossible to buy and sell assets quickly (again, as on the stock market).

Taken together, these characteristics and specific dynamics of the real estate market make price estimates idiosyncratic and dependent on information about past and future demand; pace of inventory replenishment; future behavior of interest rates and availability of credit; detailed local information about the property itself and its surroundings; temporally accurate. All these needs appear in a market of ordinary citizens (urban residential real estate), who only occasionally participate in the market.

Regardless of the difficulty of valuing a property correctly, however, the legal apparatus of guarantees, rights and payment of taxes requires precise, decimal information. In Brazil, standard 14653-2:2011 of the Brazilian Association of Technical Standards (ABNT) defines procedures and methods for this assessment (ABNT, 2011). First, the rule suggests the classification of the property according to its use (residential, commercial, among others), the type (land, apartment, house, office, vacancy, store, warehouse etc.) and its insertion among other properties (condominium, building, set). Subsequently, the standard suggests that the appraiser characterize the region (vague concept, which would be the equivalent of a neighborhood or district), as well as the land itself and the property.

The standard preferably recommends the so-called "direct comparative method of market data" (ABNT, 2011, p. 7, our translation).[2] In practice, this methodology implies the use of a hedonic price regression (Rosen, 1974), in which the dependent variable is the total or unit price (in square meters of floor area) and the independent variables include physical characteristics, conditions of payment (cash or term, for example), the "common sense and other attributes that prove to be important" (ABNT, 2011, p. 13, our translation).

In any case, the standard recognizes that there is a gradation in the time spent in the evaluation process and in the provision of available data, as specified in this excerpt: "the specification of an assessment is related both to the *assessment engineer's commitment* as well as to the market and the information that can be extracted from it" (ABNT, 2011, p. 21, our translation, emphasis added).

The literature review, although quick, confirms on the one hand, the inherent complexity of the real estate market, especially due to the combination of several facets of influence far from each other (financial market, future expectations, intrinsic characteristics of the property itself and its location, temporal nature of use and dynamics of relevant changes in influence); and on the other hand, the absence of theoretical elements that can simultaneously encompass all these factors.

After all, "one unique price of housing does not exist, and knowing, exactly, the current market price of any particular house is usually impossible" (Glaeser and Nathanson, 2017, p. 7). In any case, these authors suggest that even so, without knowledge of the processes and at the cost of a large amount of historical data, it is possible to make predictions.

PolicySpace2, however, aims to incorporate all these factors influencing the real estate market in a single platform, with the vast majority of endogenous effects, in a data-generating process with feedback and dynamics processes. These elements are intuitively listed in the sequence (the details of formulas and processes are described in chapter 3).

1) The uncertainty of evaluating the correct price of the property is given by the local and limited knowledge of each buyer. However, as observed in the real market, the construction of the initial price is based on the

2. Additionally, other methods based on the income generation of the property are also suggested by the standard.

intrinsic characteristics of the property (size and quality) and its location. The transaction price also considers the buyers' endogenous savings, which are relevant in determining the purchase proposal.

2) The intention to participate in the real estate market is exogenous, however, the participation only occurs when the family has savings or loans, both endogenous, to pay the prices. Families are always linked to an address (owned or rented home).
3) The variation in the dynamism of the neighborhood, depending on the number of firms and their endogenous results, influences property prices, as well as the average income of resident families, also an endogenous factor. The resources are collected within the municipality and applied linearly to each neighborhood, in proportion to its population.
4) The construction market is also endogenous, with firms planning new homes according to earnings possibilities, the availability of vacant lots (weak constraint), employees and the size of the current supply.
5) Aspects of the financial market include the availability of credit, and the configuration of the family and its endogenous financial capacity to obtain credit.
6) Finally, the dynamics of the family life cycle, involving deaths, aging and marriages, is also endogenously incorporated into the model.

2 ABM

ABM refers to the construction of models in a computational environment in which agents follow explicit, formal rules and interact with other agents and with the environment (Epstein and Axtell, 1996).

The seminal model applied to urban segregation is that of Schelling (1969). In economics, the model called El Farol (Arthur, 1994) can be considered the pioneer. The relevant innovation point of both models is the explanation of the difficulty of rationalizing the problem through traditional equations, methodologies and formalization.

Schelling's segregation problem refers to new family behaviors when the neighborhood context changes. The existence of a tolerance limit that generates the trigger for change, on the whole, leads to continuous dynamics that are sometimes stationary, sometimes not.

Likewise, the El Farol model demonstrates how the rationality of the individual – preferring to go to the bar when it is neither too full nor too empty – is dependent on the decision-making of other individuals. Again, given the dynamics of the problem and the agents' search for adaptation, no decision-making possibility (for example, going to the bar always on Tuesdays, or on the third Thursday of the month, or every eight days) provides satisfactory results over time.

A more current definition suggests that a model in the ABM concept must contain, at least, a "sufficient" number of individual, heterogeneous entities, with attributes that are unique to each of them and that participate in some dynamics that influence the attributes of other entities (Polhill et al., 2019).

Since these initial models, and from the theoretical construction of Epstein, Axtell and others (Epstein, 1999; 2006; Epstein and Axtell, 1996; Tesfatsion, 2006), there has been a profusion of studies and analyses in several areas of knowledge, using ABM.

Manuals are widely available that describe the process, relevance, steps, care, limitations and applications of ABM (Hamill and Gilbert, 2016; Helbing, 2012; Wilensky and Rand, 2015). Other publications bring compendia for specific areas of analysis: public policies (Colander and Kupers, 2014; Furtado, Sakowski and Tóvolli, 2015), international relations (Geyer and Cairney, 2015), social sciences and politics (Edmonds and Meyer, 2017; Johnson et al., 2017), economics (Boero et al., 2015; Dawid and Gatti, 2018; Hamill and Gilbert, 2016) and geography (Heppenstall et al., 2012).

Several other applications have also used ABM successfully. Veen, Kisjes and Nikolic (2017) developed a generic ABM – called Spree – that investigates the provision of new services. The authors define services as market transactions, which emphasize selling the use of the service rather than the product itself. The decision-making process for the generic model includes the companies and consumers, preferences, and willingness to pay. The Spree model is then applied in three case studies: i) bicycle and car rental programs; ii) protection of agriculture; and iii) domestic water saving systems.

Vooren and Brouillat (2015), in turn, create a car purchase and production market to test four alternative policies to reduce carbon dioxide emissions. The model includes endogenous investment by firms in innovation, consumer preferences and choices for the new cars offered and changes in public policies associated with the financial costs of each of them.

ABM was used in some real estate market analysis models (Axtell et al., 2014; Baptista et al., 2016; Carstensen, 2015; Ge, 2017; Geanakoplos et al., 2012; Gilbert, Hawksworth and Swinney, 2009; Goldstein, 2017; Guerrero, 2020; Jordan, Birkin and Evans, 2012; Prunetti et al., 2014; Yun and Moon, 2020). Additionally, Huang et al. (2014) make a related review of land use models for residential decision making that use ABM.

One of the first specific models for the real estate market was designed by Gilbert, Hawksworth and Swinney (2009). The model is stylized and abstract, not representing a particular geographic region, but based on UK data. The authors seek, in particular, to replicate market characteristics, including the role of the real estate broker. Given supply constraints, prices are fixed in the short run and demand is set by new buyers in the market. Sensitivity analysis conducted shows the dynamism of the market . The model suggests that lower limits of loan-to-value (LTV), the ratio of the value to be financed in relation to the total value of the good, reduce real estate prices, while exogenous increases in demand increase prices.

Geanakoplos et al. (2012) present an initial agent-based model that uses all units in the Washington, DC region, seeking to investigate whether the crash of the 2007 US housing bubble was due to interest rate fluctuations or to leverage and collateral volatility. Massive in data, the model seeks to replicate the financing process of each buyer, replicates several observed empirical indicators and can be considered the most applied. The authors claim, through their counterfactual analysis, that when they kept the leverage (LTV) fixed, the boom softened sharply, which did not occur when interest rates were kept unchanged. The model is developed and presented in more detail in Axtell et al. (2014).

Baptista et al. (2016) advance the model proposed by Geanakoplos et al. (2012) and Axtell et al. (2014) and make an application for the case of the United Kingdom. The initial interest of Baptista et al. (2016) is to investigate the influence of the behavior of investors – who buy to rent, in addition to analyzing limitations to leverage. The study suggests that both an increase in the presence of investors interested in rent or higher borrowing limits for income increase the volatility of the housing market.

Goldstein (2017) builds on previous models of Axtell et al. (2014) and Geanakoplos et al. (2012), and advances in the application of ABM for the case of the real estate market in Washington, DC. In addition to confirming the relevance of leverage and expectations as causes of the housing bubble, the author also demonstrates the influence of the percentage of income that goes to the market and interest in the causal process.

Yun and Moon (2020) follow the tradition of these earlier models and apply them to South Korea with three experimental policy designs. Their findings suggest that LTV is relevant as a macroprudential policy, while the debt-to-income (DTI) ratio is inconsistent and may vary by market.

Ge (2017) also studies the effects of volatility and speculation in the real estate market with a focus on the 2000s. The contribution of the study in relation to the previous ones is the more detailed inclusion of the bank as a lending agent in the model. The calculation of the bank financing rate is endogenous and fluctuates according to the prices of properties given as collateral and the probability of default of the bank agent. Model shocks include the variation in the number of investors in the market who act speculatively. The author concludes that leniency in the provision of loans and speculation are sufficient conditions to generate bubbles in the real estate market.

Carstensen (2015) has developed a model for the case of Denmark in order to investigate interest and wage shocks. In line with other macroprudential analysis models, in the post-bubble period of the 2000s, the author identifies an abrupt collapse behavior when increasing the DTI limits.

Jordan, Birkin and Evans (2012) have developed a model based in Leeds, UK, whose main purpose is to identify patterns of urban regeneration. The authors use anonymized data that contain the probability of intention to relocate and prepared a series of seven rules based on the literature that suggest the destination of families who move. The model also makes it possible to identify possibilities for creating more diverse communities.

Still in the tradition of spatial relocation models, Moeckel (2017) has developed a model of land use associated with the transport system that seeks to simultaneously contemplate several restrictions on families. As a result, it includes vehicle ownership, family cycle, financial access to the real estate market and travel time. The author emphasizes that the space of constraints – in contrast to the full space of opportunities – will be more relevant in a future with high transport costs, especially those of fossil origin.

In turn, Prunetti et al. (2014) present a model that uses the calculation of partial utilities for several agents, associated with the tradition of models with cellular automata that represent the dynamics of land use and cover. The model agents represent typical land uses, such as: industrial, commercial, and residential. Through calibration and sensitivity analysis, the authors seek to parameterize the agents' heterogeneous decision process. The emphasis is on the land market and its spatial configuration.

Poledna, Miess and Hommes (2020) focus on the economic forecast of macroeconomic indicators with a model that contains the accounting details of each sector, including real estate, for the Austrian economy. After validating the model, the authors use it to estimate the effects of social distancing measures imposed in the fight against covid-19.

Guerrero (2020) uses ABM to investigate the real estate market's contribution to economic inequality. The author proposes three policy experiments for the UK case: an expansion of the housing stock, sales taxes and inheritance taxes. Their results suggest that the effects of policies are different among themselves and among different regions. His model is an attempt to unite microeconomic foundations with explicit interaction protocols available in ABM as a way of endogenously analyzing the construction of inequality.

2.1 Advantages of ABM

ABM has some advantages and some disadvantages in relation to other methodologies available for dynamic analysis. The first advantage, of an epistemological and ethical nature, is that ABM makes it possible to carry out population experiments, with artificial societies, in silico. While some experiments would not be possible with real populations, they would also be expensive to implement. Performing them in the computational environment, in turn, constraints costs for planning, executing and testing the code.

Additionally, given that the code is made available – as an explicit recommendation from the community (Grimm et al., 2020) –, the model can be verified. There is, in this case, the complete absence of a black box.

Still, understanding the code can be costly. It is up to the authors to proceed with the correct and detailed communication of processes, sequence, decision making, preferably following the Overview, Design Concepts and Details (ODD) protocol (Grimm et al., 2020), in order to allow adequate comparability and reproducibility.

Another central advantage of ABM is that the rules that determine the behavior of agents are formal and can be expressed through equations or procedures. These procedures, called pseudocodes, have a standardized description in the computer science community and are implementable in different programming languages.

Another advantage of ABM is its modularity (Boero et al., 2015). *PolicySpace2*, for example, is an adapted expansion of the initial model *PolicySpace* (Furtado, 2018b; 2018c).

The emphasis of *PolicySpace2* is on the real estate market. In any case, the banking sector is relatively simple, containing only one bank, and the transport sector is also marginally relevant. Nothing prevents new versions from using the existing framework and detailing, for example, the banking and transport sectors; or implementing the dynamic endogenous evolution of agent qualification. These expansions, such as modules, would overlay the existing platform.

Another advantage emphasized by Boero et al. (2015) is the scalability of ABM. Once the model is established, verified, and validated, the cost of running it 1 billion times and achieving pseudo-significance is relatively small, if computational resources are available. Axtell (2013), for example, replicates stylized facts from the labor market of American firms using the total number of employees in the economy.

Despite all these advantages listed, the greater relevance of using ABM derives from its inherently heterogeneous nature, when considering agents, and from its explicit and dynamic use of space. Overall, the heterogeneity and consideration of time and space allow the construction of bottom-up (Epstein and Axtell, 1996) and micro-based simulations. Thus, interaction, feedback and emergence effects[3] become component parts of the built model.

Finally, it is worth mentioning the main function of ABM as a simulator of "what if" questions. If the model mimics the main phenomenon of interest – that is, it is formally executed, has achieved its purpose and has been verified and validated, new questions can be asked.

This ability to replicate patterns and stylized facts allows the simulation of alternatives that are still only planned. In other words, this is equivalent to looking at policy scenarios not yet implemented. Let us assume that a certain phenomenon occurs as modeled. If alternatives A, B and C were implemented, what would be the effects on the results? Which alternative is more viable?

Compared to models based on equations, ABM seems to be advantageous for analyzing phenomena in which there is no clear equilibrium (such as the real estate market) – or when the option is not to impose equilibrium as a construction that allows deduction, through equations, of the theoretical answer of the phenomenon.

This is not the same as saying that the results are not similar. Sasaki and Box (2003) replicated the result of Johann Heinrich von Thünen's elegant theoretical construction through ABM, just as Axtell (2013) modeled the standard neoclassical behavior of American firms.

In turn, Fagiolo and Roventini (2012), discuss what they call the theoretical, methodological and political inadequacies of the use of the dynamic stochastic general equilibrium methodology (DSGE) for economic analysis, followed by the presentation of the advantages of ABM.

The main theoretical criticism refers precisely to the impossibility of obtaining a single general and stable equilibrium, even using unrealistic assumptions about the capacity and knowledge of agents and complete information. From an empirical point of view, Fagiolo and Roventini (2012) claim that there are numerous identification problems derived from the number of nonlinearities present in the structural parameters. This leads to the difficulty for models to simulate historical patterns, especially in times of crisis and depression.

The criticism of economic policy refers to the expectation that the agents have "olympic rationality and have free access to the whole information set"

3. The presence of these concepts and others is detailed in chapter 3.

(Fagiolo and Roventini, 2012, p. 83). The authors believe that this may be valid in the scope of the economy as a whole, but not at the agent level, as is assumed in the case of DSGE.

ABM also seems to be interesting in the analysis of self-organizing systems, such as natural systems (swarms or flocks) or biochemical systems (Turing, 1952); in systems where there are measurable inflection points, such as the shift from fluid traffic to congested traffic; or those that generate a cascade effect, or the so-called critically self-organized systems, the best example of which are avalanches (Furtado, Sakowski and Tóvolli, 2015).

Finally, ABM also appears to be useful in the analysis of reinforced learning (Sert, Bar-Yam and Morales, 2020).

Despite this list of advantages and possible uses of ABM, this does not mean that the methodology implies exclusivity or supremacy. To the contrary, Scott Page's approach to diversity suggests that multiple models (and multiple methodologies), together, contribute to a more comprehensive and complete view of the phenomenon under analysis than any single approach:

> complex systems do not represent a silver bullet, but another arrow in the policy maker's quiver. More accurately, all of these tools put together can be thought of as multiple imperfect arrows that provide insight into what is likely to happen, what could happen, and how what happens might spill into other domains (Furtado, Sakowski e Tóvolli, 2015, p. 11).

2.2 Disadvantages of ABM

Obviously, there are several disadvantages of ABM. Perhaps the most eloquent of these is its flexibility. It is so simple and cheap to create new models, at any level of detail, that the resulting output is too varied to allow classification, competition, community building of consensus and standards.

It was precisely this flexibility, together with the lack of comparability, that led to the proposition and continuous search for improvements in the ODD protocol (Grimm et al., 2006; 2010; 2014; 2020; Grimm and Railsback, 2012). At the same time, Dawid and Gatti (2018) created a list of the "big families" of macroeconomic ABMs, highlighting similarities and common practices of the specificities and emphases of each group, in order to create a list of benchmark, or good practices.

Buchanan (2009) adds the criticism that there is no way to identify whether a plausible result of a model is just a fortuitous combination of parameters or if it is, in fact, the result of the correct description of the phenomenon. Soon after, however, the author himself recalls that traditional models also contain a series of adjustable parameters that would be subject to the same criticism. Additionally, he notes that a good ABM should base its rules and procedures on available theory and literature, or on experiments or estimates – although these precautions do not eliminate the presence of ad hoc decisions not substantiated or not explained correctly.

Another criticism of ABM refers to the complexity and obscurity of the models, which would reinforce this plausibility of fortuitous results similar to those empirically observed, however from incorrect or artificial mechanisms. In fact, a model like the *PolicySpace2* will require reasonable effort to understand all the mechanisms and connections between the parties.

However, given that both the algorithm and the data used and the guiding rationality are available, it is possible to make an association between certain rules, behaviors and parameters and seek to identify their implementation in the code. An example of this is the rule used in the job market that determines that the distance from the candidate's residence to the firm influences the search for a job. This detail can be identified in the program code and investigated individually.

Another practice that is frequently seen in *PolicySpace2*, in response to such criticism is the possibility of simply testing the presence or absence of certain rules. If the user does not agree with the rationale used, it is possible to make the effect of some rules null. Non-exhaustively, this is done in chapter 5.

Additionally, note that, as proposed by the ODD protocol, each model is evaluated to verify if it fulfilled the initial purpose. There are purposes that aim to contribute to the theoretical discussion and there are others that seek to predict events. Each one should be evaluated according to what is intended (Edmonds et al., 2019).

In fact, in disciplines with different emphases, different validation routines may be necessary. In the social sciences, it is common practice to use models that use ABM in order to contribute to reasoning, as methodological tools related to argumentation (Moss, 2008). On the other hand, there are economic models that aim to replicate and predict time series (Dosi et al., 2015). In this case, it is necessary to validate that the model was able to do so in historical data not used in its original design (Guerini and Moneta, 2017).

In addition to these criticisms, Polhill et al. (2019) review the difficulties faced by the ABM community. Specifically, the authors identify the transition from abstract representations of systems to models that are more grounded in empirical analysis and that can make more applied contributions. Completing this passage will require access to detailed and organized databases, as well as an understanding of behaviors, contexts and rules also at the agent level.

In fact, when the scientist uses ABM and proposes to model agent actions, coding them in rule systems, it is necessary to know exactly which those rules are. Note that there is a relevant difference between estimating the rate of spread of rumors, on the one hand, and understanding the mechanisms (the rules) that determine how rumors spread, on the other hand.

From the point of economic markets, the theory informs that firms have perfect knowledge, they know the future demand, and the price is given by the market, as are wages. In reality, the process of setting wages, or anticipating future demand, is based on imperfect, dated information, experience, and trial and error (Blinder, 1994). Therefore, more and more neoclassical economists use experiments from behavioral economics studies (Glaeser and Nathanson, 2017), in order to better understand the mechanisms that agents use to act.

This process of building more empirical models also leads to increasingly complex models (Sun et al., 2016). Indeed, *PolicySpace2* is an evolution of a model that was born simple – focused on general behaviors and understanding the phenomenon in an abstract way (Furtado and Eberhardt, 2016) – and advanced to empirical detail (Furtado, 2018b), then seeking greater specification of rules and behaviors, even though it has not reached the level of predictions.

Finally, and in line with suggestions made by Polhill et al. (2019), public managers, managers and decision makers expect deterministic rules that fit into goals and planning. The public policy evaluation system itself provides indicators and monitoring to assess the effectiveness of policies. The existence of goals and the attempt to achieve them, however, are not contradictory to the possibility that complex systems – of public policies to combat inequality or improve urban mobility, for example (Furtado, Sakowski and Tóvolli, 2015) – are difficult to predict. Thus, there can be numerous endogenous and exogenous effects that affect outcomes, regardless of the implementation of a given policy or action. The understanding that some systems can be classified as complex suggests that their trajectories are less deterministic and more probabilistic and dependent on continuous actions and reactions in time (Mueller, 2015). In other words, there are systems whose forecasts must be limited to shorter periods, so that their development is monitored, and actions and forecasts are changed discreetly, instead of setting goals for distant moments over which it is simply not possible to determine the target space reliably.