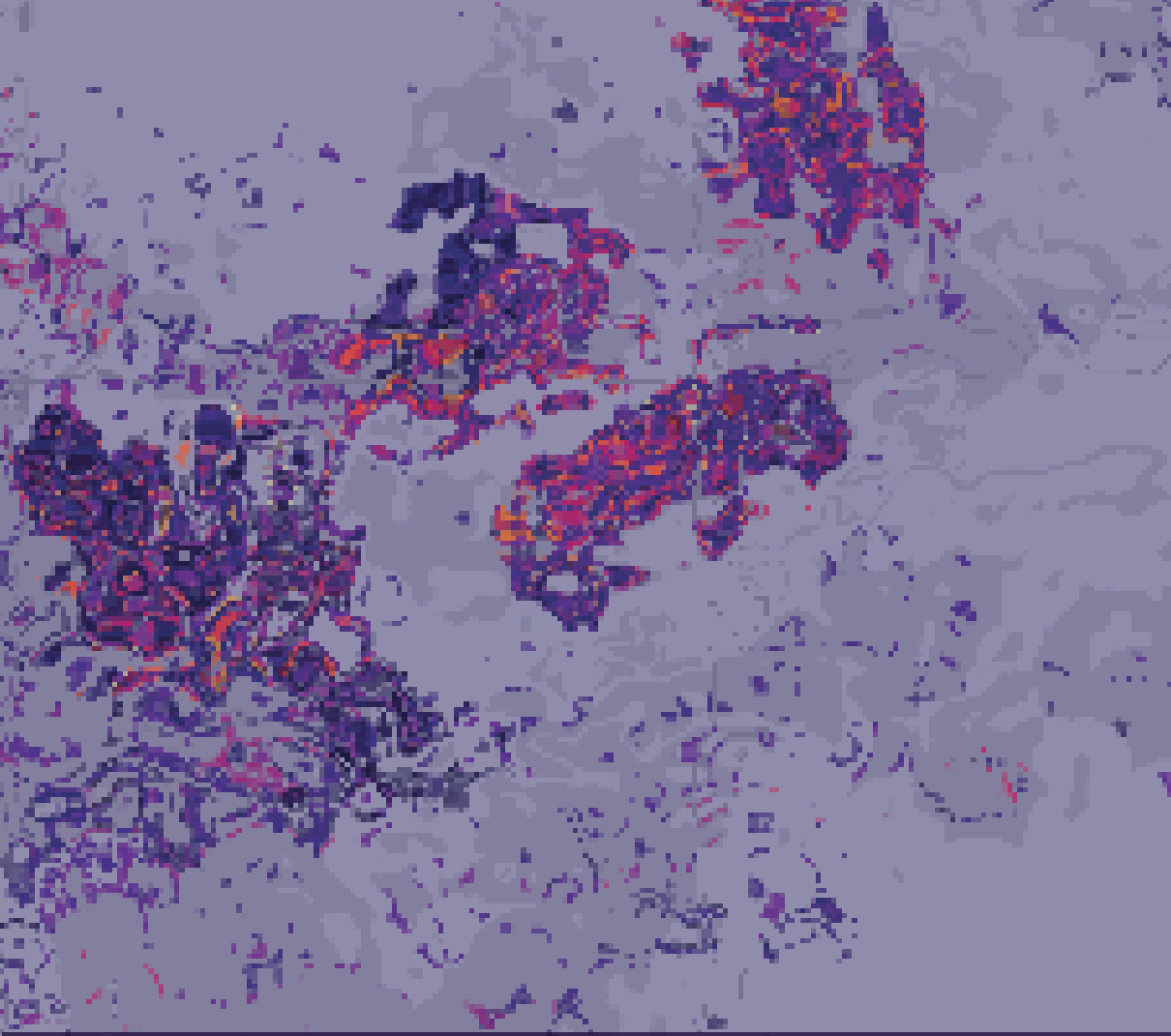


PolicySpace2

Modeling the real estate market and public policies

Bernardo Alves Furtado

ipea

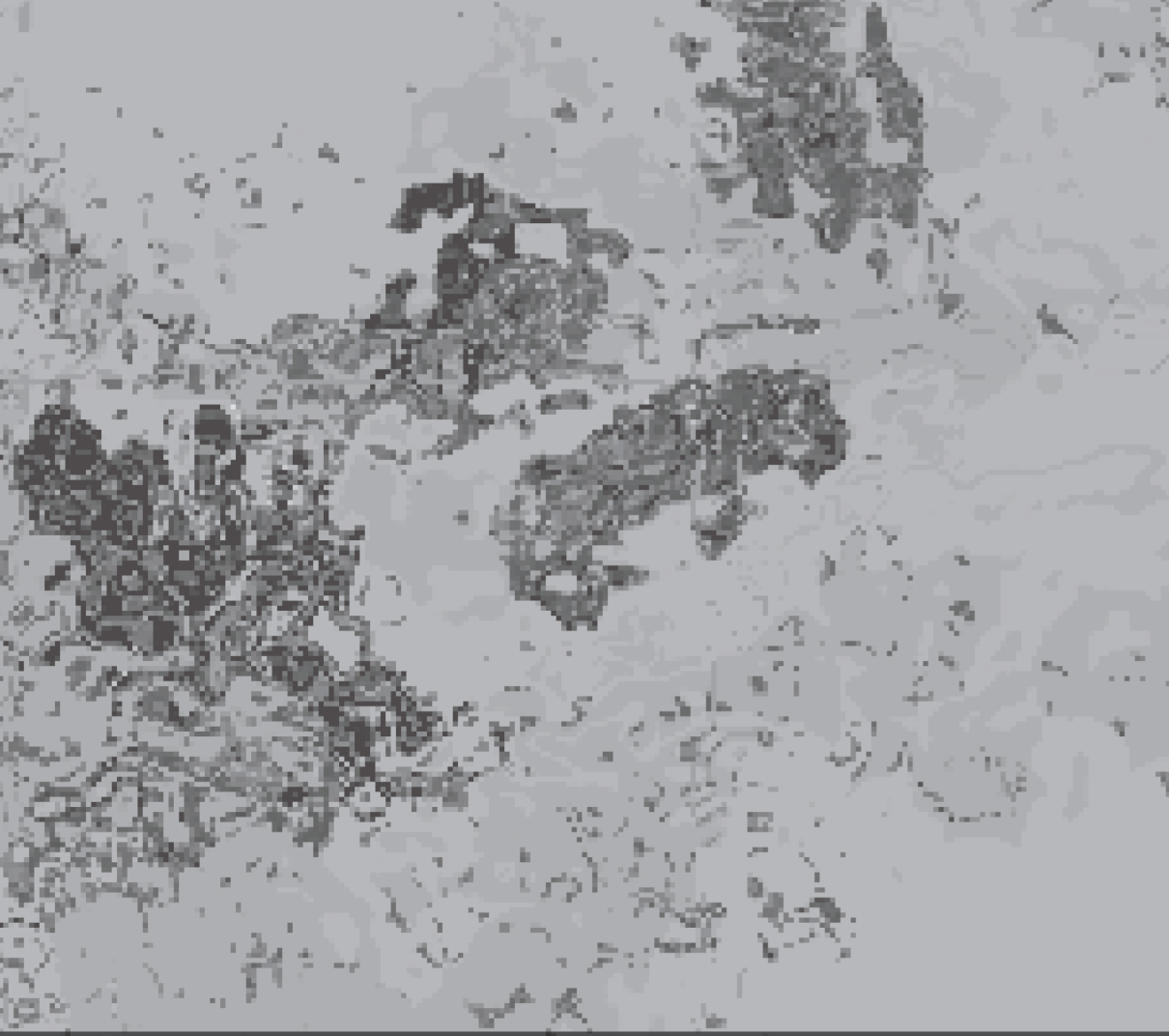
This book describes the evolution of *PolicySpace2*, a computer simulation and platform of public policy evaluation. The text brings details of the underlying methodology – agent-based modeling (ABM) – from the theory that supports the analysis of policies and the real estate market to the construction of the computational model. It also presents the analyses performed and the policies tested.

ABM is complementary and additive to other public policy assessment methods. In particular, it is useful for ex-ante policy analysis, anticipating possible effects and relational advantages of different policies. Additionally, the empirical analysis, as presented in this work, allows the heterogeneous identification of policies' effects, with results spatially and socioeconomically detailed.

PolicySpace2 is a computational model, primarily endogenous, empirical, dynamic and spatial, which includes real estate financing, civil construction, collection and distribution of taxes, labor markets, goods and services and real estate for regions Brazilian metropolitan areas. The platform allows the understanding of market mechanisms, so that changes in a certain behavior generate effects on the model indicators.

PolicySpace2 is cumulatively validated, so that: i) the processes and rules are in accordance with previous literature, made explicit and openly available; ii) the sensitivity analysis of parameters and rules ensures robustness; iii) macroeconomic indicator trends remain at expected levels; and iv) there is similarity in the distribution of simulated real estate market data, in relation to real data collected.

PolicySpace2 allows testing of investment of endogenous resources in public policy alternatives that contain relative strength of comparison. Specifically, transfer of real estate, rent payments or monetary aid to families are compared with the no-policy model.



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Federal Government of Brazil

Ministry of Economy
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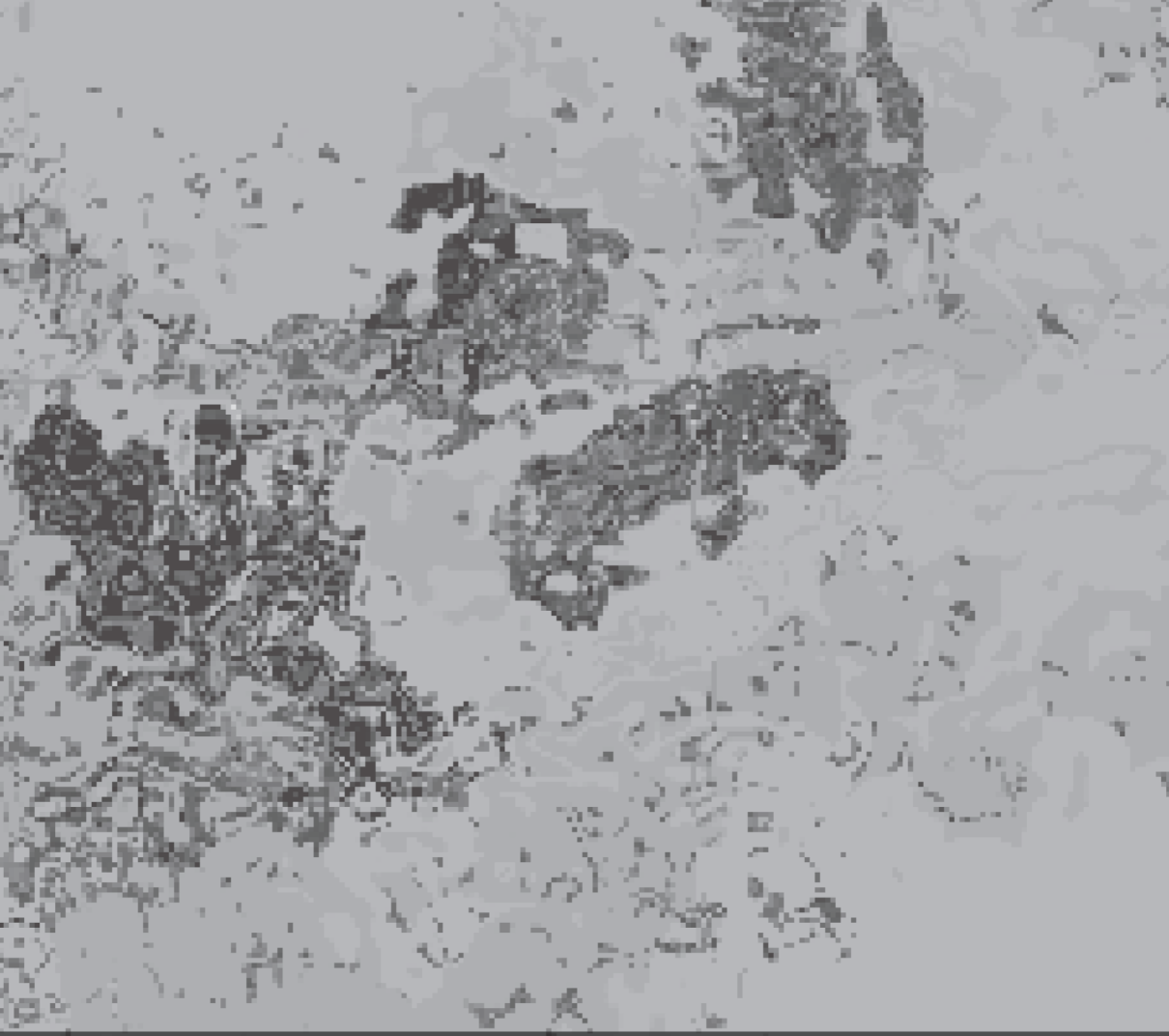

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CONTENTS

INTRODUCTION

The real estate market is intrinsically convoluted, just as in botany – it is tangled, with leaves rolling together in cylinders. This analogy seems to make sense. The real estate market involves different elements with asynchronous adjustments: economic cycles, changes in interest rates and levels of financial liquidity; intertemporal decisions made by families; investor choices; urban regulation and zoning; construction; and location of jobs, amenities, neighborhoods, perceptions, and preferences. In addition, real estate consists of durable goods, with high transaction costs, which are relatively expensive, usually indivisible, with a unique (monopolistic) and heterogeneous location.

There is vast literature that analyzes real estate markets. The seminal text and reference of urban economics consolidates the model of rational economic choice (Dipasquale and Wheaton, 1992). Abstractly and diagrammatically, the authors propose a spatial balance model that combines financial asset market and real estate market, mediated by the civil construction market's ability to adjust inventory.

Empirical work, however, suggests that current interest rates in the financial market are not fully reflected in real estate prices, which would suggest inefficient markets (Case and Shiller, 1989). Otherwise, it can be said that there is excessive variance of prices in relation to fundamentals (Glaeser et al., 2014). In this sense, there is some consensus that the available models do not capture the volatile and heterogeneous aspects that are intrinsic to this market (Davis and Nieuwerburgh, 2015; Glaeser and Nathanson, 2015).

This understanding was reinforced after the housing credit crisis of the 2000s. The unexpected volatility prompted a series of literature reviews in order to identify what is known and what is not known about the general behavior of real estate markets. Regarding the influence of the credit market and real estate financing, Chan, Haughwout and Tracy (2015) note that the user cost structure points to the direction of demand in times of growth. However, the size and location of the change are not reflected in current models. The analysis suggests that spatial equilibrium models based on rational choices would be limited in scope (Glaeser and Nathanson, 2017).

This difficulty of traditional urban economic models dealing with multiple, simultaneous impacting factors supported the expansion of the epistemological field and the search for contributions from other disciplines and analytical methods.

Among these search initiatives for integration and methodological alternatives to understand the real estate market, we must highlight three aspects: one based on traditional economics, which intends to expand the understanding of finance and encompass liquidity and credit with a more empirical bias (Davis and Nieuwerburgh, 2015; Leamer, 2015; Saiz, 2019); a second one focused on the spatial and urban issue, on the dynamic transformation of uses, by addressing land use, integration with transport, its potential to generate new uses and change the occupational pattern and urban planning (Waddell et al., 2018a; 2018b); and a third one that analyzes macroeconomics from a computational point of view with an essential change in methodology (Dawid et al., 2012; Dawid and Gatti, 2018).

In addition to these integration efforts, other authors have proposed initial computational models that replicate the fundamentals and empirical data observed in the real estate market (Baptista et al., 2016; Geanakoplos et al., 2012). These papers emphasized financial volatility, the relevance of asset markets, and the possibilities of macroeconomic prudential action for the financial manager in charge of public accounts.

Within the scope of spatial dynamic analysis, computational modeling, called Land Use Change and Transport Model (LUT), has a more consolidated tradition and history of applications (Engelen, White and Uljee, 1997; Filatova, Parker and Veen, 2009; Parker et al., 2003). Traditionally, it models the evolution of the conversion of agricultural to urban uses, industrialization and de-industrialization, as well as changes in the composition of green areas in general. More recently, these models have incorporated real estate dynamics associated with transport structure planning (Waddell, 2011; Waddell, Wang and Liu, 2008).

In this context, *PolicySpace2* is a primarily endogenous, empirical, dynamic, spatial computational model, which includes real estate financing, civil construction, tax collection and distribution; labor, goods and services, and real estate markets for Brazilian metropolitan regions. The platform makes it possible to understand real estate market mechanisms, so that changes in a certain behavior can generate effects on the model's indicators. Additionally, *PolicySpace2* allows tests of investment of endogenous resources in alternative public policies for housing: transfer of properties, payment of rent or money aid for families.

In short, from the empirical description of the status quo in 2010, individuals, families and properties are probabilistically generated and spatially allocated. Subsequently, each month, families and firms interact in the goods, labor and real estate markets, mediated by: loans, bank deposits, and investment remuneration; location; and mobility of workers between these firms and families and their places of residence. In this way, they generate transactions in the markets, whose taxes are collected and reinvested in the municipalities, characterizing the remarkably

endogenous and dynamic aspect of the process and providing a scenario for public policy experiments, with relative comparability of results.

PolicySpace2 brings together three types of modeling – economic, land use and transport – in a joint and integrated fashion. We do not know of any other computational platform for the real estate market:

- that is open (open source);
- that contains official data, organized at the intra-urban level of weighting areas of the Brazilian Institute of Geography and Statistics (IBGE) or equivalent;
- that adopts spatial rules associated with all markets (goods and services, labor and real estate markets);
- that includes a system of tax approximation at the municipal level;
- whose decision-making agents are primarily firms and families; and
- whose policy tests are based on the endogenous development of demand and supply of resources and families.

Thereby, *PolicySpace2* positions itself as a model that is capable of correlating real estate price formation mechanisms based on several of its own influences:

- composition and location of families;
- productivity and location of firms in the goods and services market;
- migration, formation of new families and demographics;
- credit system and financial liquidity;
- labor market and recruitment processes that consider distance and qualification; and
- the dynamics of the entry of families in the real estate market and construction firms.

Additionally, *PolicySpace2* is described according to the most recent and transparent practices in the Agent-Based Modeling (ABM) literature, following the protocol Overview, Design Concepts and Details (ODD) (Grimm et al., 2020) and the TRACE suggestion (Grimm et al., 2014).

The performance of the *PolicySpace2* model is evaluated successively and cumulatively as described in the following.

1) The processes and rules are inspired and justified according to the preexisting literature, which is explained throughout the model description.

2) Extensive and exhaustive sensitivity analysis is performed to test the inclusion or absence of rules and mechanisms (structural sensitivity) and how robust the results are after changing the parameters. Simulations are run numerous times and the results are expressed as the average of the results of each simulation.

3) Internally, graphs depicting 66 indicators are produced and guarantee the observation of the simultaneous behavior of various processes, states and mechanisms.

4) The code itself is not error-free. However, several tests, checks, simulations and verifications have been repeated throughout the process in order to guarantee the accuracy of the presented results.

5) Macroeconomic behavior indicators, such as gross domestic product (GDP), inflation, unemployment and the Gini coefficient, remain at levels similar to those observed empirically.

6) Specifically in relation to the real estate market, we carried out a comparison of data from real properties, collected in 2020, with simulated data. Considering that no real estate market information is included and that only official data from firms and families are entered at the beginning of the simulation in 2010, the model behaves reasonably well and manages to replicate the first half of the real estate price distribution for the tested case in the Brazilian Federal District.

7) The public policy implementation test carried out presents results whose logic can provide some understanding and explanation based on the comprehension of how the model works.

The mechanisms and configuration of *PolicySpace2* suggest that, in the real estate market, the negotiation process, supply and real estate financing are less relevant to price dynamics, when compared to the relevance of household demand and their availability of resources. In addition, the location of firms and families, in conjunction with the increase of family income in the neighborhood, does not seem to be a sufficient element to exactly replicate the spatial design and distribution of real estate prices. Other factors not present in the model – such as the stock of properties and their characteristics observed at the beginning of the simulation or the regulation of land use – would need to be included so that the results could be more spatially reliable in relation to those observed.

The *PolicySpace2* model simulation, in particular, seems to confirm the absence of a perfect spatial equilibrium in the real estate market. Indeed, the rental market, given the design of the model, works as a receptacle for families that do not have a permanent and sufficient income. The concept also establishes that the initial

negotiation price, with low possibility of discounts, is the reference price in which the rent is a proportion of the sale price. As the design of the model also requires that all families have a residential property, families enter into the contract, but spend more than 30% of their income on rent, in a higher proportion than expected. Eventually, it is still possible that the family cannot pay the rent to the landlord.

The analysis of changes and interventions subject to public policies to be tested based on the model suggests that, in fact, the real estate market has the ability to boost the economy as a whole and does so when there are greater savings available to families, when there is greater participation of families in the market, when there is an influx of families or the creation of new families, when the productivity of workers increases and taxes on wages or consumption are reduced, or when the efficiency of municipal management increases.

Another factor that emerges from the analysis is the marked influence of productivity as a model mechanism capable of changing the levels of the economy as a whole. As such, the research joins several others that identify productivity as the core of the process of improving economic well-being.

The policy tests carried out reflect the investment of part of the municipal collection alternatively in: i) buying and transferring properties to registered families, in order to favor those with less resources; ii) paying the rent of these families for a period of two years; or iii) simply make transfers in the form of money aid to all families registered in the municipal system.

Considering the GDP of metropolitan regions and the Gini coefficient, the best policy is undoubtedly the (more equitable) distribution of resources among all families, vis-à-vis the payment of rent or purchase and the transfer of real estate.

Lastly, *PolicySpace2* reinforces the results obtained in the previous version (Furtado, 2018a). The model confirms the benefit in terms of quality of life for citizens by equitably, and not locally, redistributing tax funds raised among metropolitan municipalities.

In addition to this brief general introduction, chapter 1 provides a review of recent literature on the real estate market and defines ABM. ABM is the methodology on which the *PolicySpace2* is built, a computational modeling platform. Chapter 2 provides an intuitive description of *PolicySpace2* that will allow the reader to understand the features and limitations of the platform. Chapter 3 is methodological, details the purpose of the model, according to the suggestions of the ODD protocol (Grimm et al., 2020), and contains steps 2 to 7, also provided for in the protocol. Together, these steps provide an overview, detailing the processes and explaining all the rules, operations and functioning of the model. However, since the ODD process is built from the general to the specific, the reader interested in the formulas

and details of the model will find the information in section 7. Chapter 4 presents both some stylized facts replicated by the model and the data used to validate the model, its comparison with the simulated data, and other general results. Chapter 5 expands the sensitivity analysis to broaden the understanding of the possibilities of *PolicySpace2* and its applications. Finally, chapter 6 tests housing and social assistance policies and analyzes the performance of the metropolitan region in a comparative way. The final remarks conclude the book.

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.

CHAPTER 2

MECHANISMS AND INTUITION OF *POLICYSPACE2*

The Overview, Design Concepts and Details (ODD) protocol recommends: "describe what the program does, not what you think the model does" (Grimm and Railsback, 2012, p. 6). This description and the step-by-step detailing of the model execution are carried out in chapter 3. In this chapter we chose to discuss the general mechanisms and intuition behind the model.

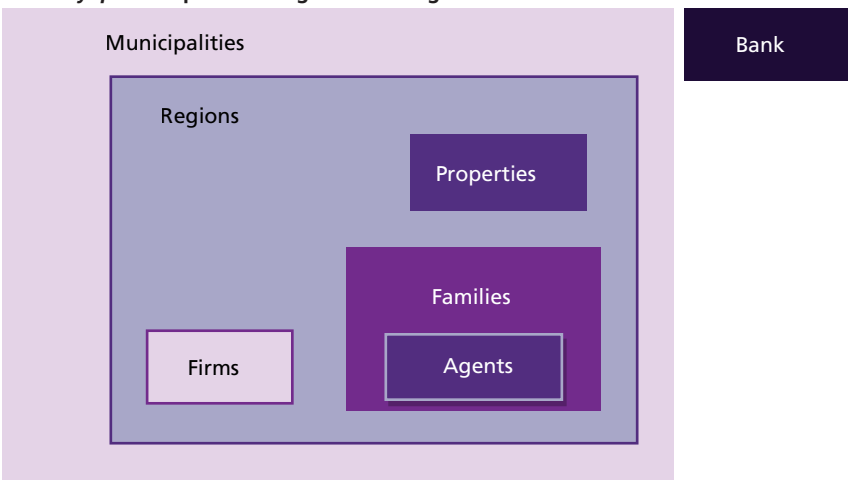
The *PolicySpace2* is essentially an economic model that emphasizes spatial elements – regional, municipal and intra-urban – of a complex market, real estate, whose dynamic influences are relatively poorly understood, although they produce perennial effects on families, municipalities and society as a whole.

The model starts from a reliable empirical description to build the main markets and their mechanisms endogenously. With this, it aims to have a platform that sufficiently replicates observable patterns, in order to allow a comparative analysis of the magnitude of effects generated in various dimensions of the economy from changes in the behavior of agents and the effects of possible changes in public policies and behaviors.

The *PolicySpace2* gathers numerous official and spatial data on the main metropolitan regions of Brazil. Included in the model are: municipal and intra-municipal boundaries; number of inhabitants by gender, age, color and qualification of individuals; average family size; and number of firms at the level of weighted areas (APs) – equivalent to large neighborhoods or districts. At the level of Federation Units (FUs), there is detailed information on migration, mortality and fertility. There are also details of tax distribution at the municipal level.

The agents are spatially represented as shown in figure 1. Agents (workers, individuals) are grouped into families and allocated within regions that represent the APs of the Brazilian Institute of Geography and Statistics (IBGE), according to the 2010 census. Real estate and firms are also allocated in the APs. Families, in the context of the model, are always linked to an address, whose property can be owned or rented. Families can have none, one or more properties. The APs always constitute municipalities for the IBGE's population concentration areas (ACPs). The bank – which provides real estate financing and remunerates household savings – is unique and not spatially allocated.

FIGURE 1
***PolicySpace2*: spatial configuration of agents**



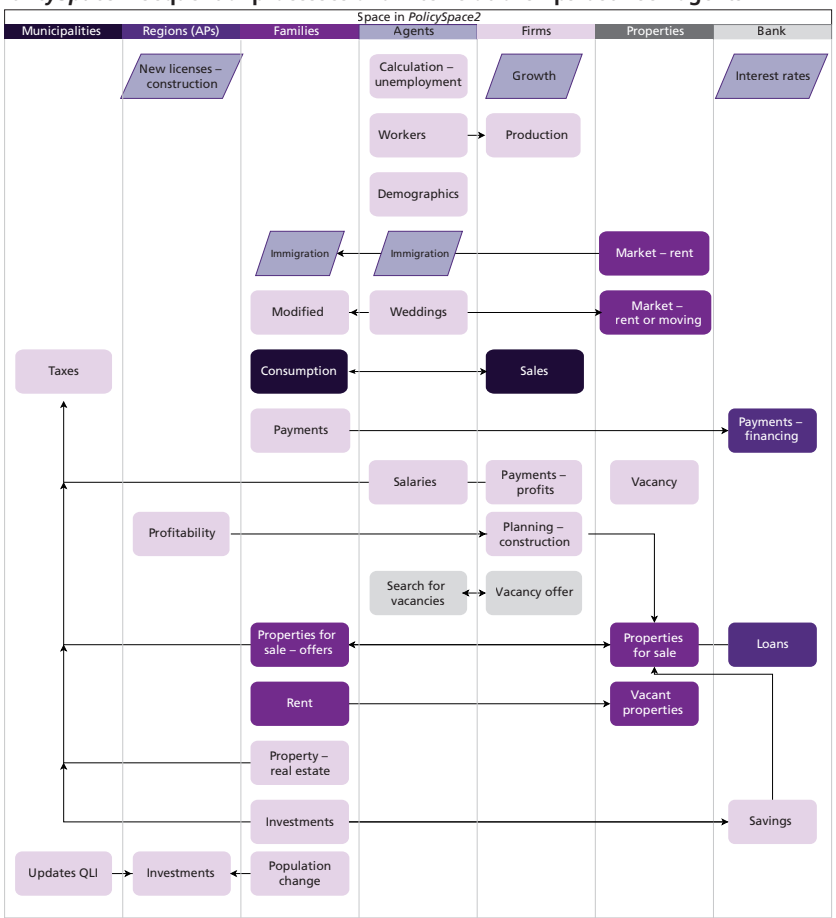
Author's elaboration.

The sequence of processes is illustrated in figure 2. The details of the sequence and steps are detailed in subsection 4.2 of chapter 3. The diamond-shaped processes occur according to a frequency determined exogenously through parameters. At the beginning of the month, new firms are created, interest rates on household investments and real estate financing are updated, and current unemployment is calculated. Subsequently, the workers move to the firms, with the distance being computed, and carry out the production.

The demand for goods is endogenous and varies according to the purchasing power of families and the prices offered by firms. The demand effectively created generates effects on inventories and leads firms to the need to hire or terminate workers. In turn, the salary received and the accumulated savings determine the possibilities of insertion of families in the real estate market of purchase and sale or rent.

The collection capacity of municipalities, or the real dynamism of municipal firms together with the size of the current population, is reflected in the magnitude of local investments. Municipal investments influence the prices of local real estate. Property prices are also influenced by the average income of the neighborhood and the intrinsic characteristics of the property.

FIGURE 2
***PolicySpace2*: sequential processes and interrelationships between agents**



Author's elaboration.
Obs.: QLI – Quality of Life Index.

Part of the economy's firms produce homes, instead of consumer goods. Portions of wages not spent on consumption or proceeds from sales of real estate feed deposits at the Central Bank, which generate interest and allow loans for real estate financing to other families.

The chaining of these effects, together with endogenous demographic transformations of families, is illustrated and communicated with the generation of graphs and monthly, individual, family, and neighborhood data, by municipalities and in general. This entire process can be examined for each action of each agent. Next, the demographic processes of aging, mortality and fertility, as well as the migratory process with the arrival of new families, occur. New families can be formed by marriage between adults of existing families.

Families then participate in the consumer market, choosing firms according to the closest proximity to their residence or the best price, among a sample of firms chosen at random. Real estate financing payments are processed, and the firm carries out its decision-making processes in relation to readjusting sales prices, hiring or firing the workforce and planning the construction of new properties in the case of construction firms.

Finally, the labor and real estate markets are processed, and families deposit their investments in the bank. During the processes, taxes are collected on consumption, on wages, on profits, on housing property, and on transfer of property. These resources are redistributed among the municipalities, considering the Municipalities Participation Fund (FPM) and the state (also among the municipalities) and local portions (according to generation). The investments result in an improvement in the QLI quality of life indicator, which is weighted by population changes.

The description of the processes, in detail, is given in section 7 of chapter 3.

1 ENDOGENEITY AND SPACE IN THE *POLICYSPACE2*

The most striking difference from *PolicySpace2* in relation to other models and theoretical proposals for understanding the mechanisms of the real estate market may be the incorporation of endogenous and spatial processes.

Traditional real estate market models usually completely abstract the spatial notion (Dipasquale and Wheaton, 1992). Agent-based models, in turn, model real estate processes from exogenous wages (Baptista et al., 2016), even though the shock process is endogenous (Ge, 2017).

At the *PolicySpace2* wages are endogenous and generated from the labor market. The dynamics of the labor market, in turn, evolves according to the population's purchasing capacity, which depends on wages received and income from rentals, property sales and interest on savings. Property prices also vary endogenously, based on the strength of municipal firms and the average income of families in each neighborhood. These variations are partly determined by the productivity of workers, given by the years of study and by the location of firms and their access to consumer markets, both of which follow the empirical data observed in 2010.

Spatiality is reflected in the labor market through the decision criteria to hire and be hired, for the firm and for the worker. For the firm, it is possible that the monthly selection system is based on qualification – employees with more years of education receive offers first – or by distance.

Employees residing closer are preferred. This criterion was introduced to reflect the fact that, among workers with low education, proximity to the firm may be relevant, as well as the probability of knowledge about the firm's needs. In addition,

this reflects the rationality of spending on the payment of transportation vouchers by companies. This criterion is one of the examples in which the parameter can be chosen so that this rule has no effect. When ranking the companies' offers, the employee deducts from the salary offered the cost of transport – private or public, according to the income decile.

In the real estate market, intrinsic spatiality reflects the intention of citizens to buy the "best" properties in the city, defined as the most expensive (Goldstein, 2017), conditioned by prices and their ability to pay. Prices, in turn, follow the intrinsic characteristics, but also the income of families in the neighborhood and the prosperity of the municipality, vis-à-vis the other municipalities in the same metropolitan region. Construction firms plan to offer real estate in regions where the estimated profit is the highest.

Finally, in the goods market, consumers can choose to pay the lowest price or buy from the nearest firm, reflecting the behavior of wholesale and retail trade.

Still from a spatial and administrative point of view, note that municipalities, as entities that collect and distribute resources in space, are present in the model. They collect taxes on the payment of wages, on corporate profits, on real estate transactions, on real estate and on consumption. These funds collected as *proxy* for real taxes are distributed according to the general rules in force for sharing between the Union, states of the Federation and municipalities.

2 INTEGRATION AND HETEROGENEITY

With this quick description of the processes, detailed in the methods chapter, it is possible to see that one of the aspects present in *PolicySpace2* is the integration between the parts of the different markets. It is easy to see these relationships and ties between the various processes when performing sensitivity analysis and investigating the mechanisms of the model and register the variation of the effects on the gross domestic product (GDP), on the Gini coefficient or on unemployment when workers' productivity or the initial spatial configuration of families are changed from different metropolitan regions.

Furthermore, the heterogeneity of *PolicySpace2* goes beyond what is observed in the characteristics of the agents themselves, including variations in relation to their location, family constitution and employment ties. The model results contain, for example, municipal unemployment. This type of information is difficult to validate, since the IBGE only publishes aggregated information on unemployment through the Continuous National Household Sample Survey (PNAD Continuous) for the metropolitan region as a whole.

3 CONTRIBUTIONS

The literature review, presented in chapter 1, points out the complexity of the real estate market and the theoretical and empirical difficulty of dealing with all the influencing factors simultaneously. The *PolicySpace2* responds to this review and manages to integrate immediate household consumption and long-term purchase decisions, together with changes in household composition and migrant arrivals. It also includes the construction market and the process of real estate financing and remuneration of household savings; the relevance of the location of the property, its intra-urban location, through the influence of the neighborhood and its access to jobs; and, mainly, dynamic effects with feedback from all processes over time.

Additionally, the *PolicySpace2* constitutes a platform for the analysis of public policy interventions with a level of integration between causal elements and mechanisms, with the inclusion of empirical data. We did not find similar works of this magnitude and scope. There are empirically and methodologically detailed analyses in relation to the economy exclusively or to transport or land use conversion. However, not these three aspects together.

The simulations carried out also provided interesting indications about the factors that make up prices in the real estate market and the role of supply and the intensity of household demand. In addition to the real estate market, the *PolicySpace2* highlights the importance of worker productivity and the efficiency of municipal management.

4 PRICE FORMATION ON THE REAL ESTATE MARKET

In addition to this panorama of the behavior of the agents in the model, the general processes of price formation are worth mentioning.

In the real estate market, the supply side is designed as a deterministic product of the property's characteristics (fixed) and its location (variable). The price also comprises the average income of families residing in the neighborhood. On the demand side, the family uses its cash resources, its emergency reserve (referring to six months of permanent income) and savings. Additionally, it checks the maximum amount it could raise from a potential loan.

The rationality of the transaction and price formation can be interpreted as follows: the first option occurs when the family anticipates the real value (calculated using hedonic regression elements) of the property and the seller estimates the maximum savings of the family (limited to up to 130% of the value of the property).[1] In this case, the sales price is the average of the two estimates. If there is no consensus, because the value of the family's savings is insufficient, the family

1. These values are tested in the sensitivity analysis performed.

checks if it can make the promised bank loan. If the loan is denied by the bank, the family leaves the market.

A second option occurs when the family's savings are insufficient to pay the calculated price of the property. In this case, the family can make an offer with a value lower than the price (up to a limit of 20%). The seller will accept it on a probabilistic basis conditional on the size of the vacancy of properties on the market. When there is a large percentage of properties for sale, the chances of accepting the proposal at a discount are greater.

With these behaviors, the trading prices are a combination of the actual purchasing power of households, the calculated price of properties and their neighborhood, and the size of the offer.

5 POSSIBILITY OF DEFAULT

In *PolicySpace2* there are three moments in which we could understand as default. When the landlord collects the rent, the family sequentially seeks out its immediately available financial resources, its reserves and its savings. When there are no resources, the landlord does not receive the payment due.

Likewise, when the bank collects mortgage payments, the family looks for alternatives. However, in case of delay, the bank records the information and tries to recover the funds over the following months, before issuing the certificate of completion of the loan.

Finally, it is also possible that, when there are no resources, the family consumes zero goods in a given month. The global indicators of model indicate that average consumption is constant and increasing. However, this does not mean that some families do not consume in a few months. This may also occasionally occur when none of the chosen firms has any product available for sale at any given time.

6 LIMITATIONS, MAIN CAVEATS AND FUTURE ANALYSIS

The analysis of a platform like the *PolicySpace2* will always be incomplete. There are numerous, possibly central, mechanisms that are not included in existing processes. Although the assessment of which processes are central or not is subjective, the reader's interest and field of investigation are usually decisive in this note.

In any case, what can be said is that the *PolicySpace2* was built with two main objectives: at the same time incorporating the spatial core to market analysis and integrating the real estate market into the scope of the wider economy. Additionally, the result is a continuous process of improvements and incorporations, whose scale and speed also depend on the interest and engagement of others interested

in expanding the platform, given that it is available in open and public source.[2] Since the *PolicySpace2* is modular, new details, expansions and process changes can be built from existing development. That said, it is worth emphasizing the aspects of the real estate market and the economy as a whole that are not yet included in the *PolicySpace2*.

From the economic point of view, politics, in a generic way, or the relevant facts of legislation and market institutionality, which influence perceptions and, therefore, prices, are not present in the model. Thus, topics such as strikes, corruption scandals, impeachment, pandemics, and supply shocks are not built into the model. Although general and difficult to implement, all these factors influence the time series, so validating the model's inflation path with an observed path is not feasible, nor is it a present or future objective.

Other mechanisms, however, could be implemented. To give examples, we note the sophistication of the asset market that also incorporates banking services to companies, in addition to real estate financing for families, or includes the differentiation of companies between the various sectors of the economy, with their respective heterogeneity of size, consumer market, size and qualification need.

In detailing workers' productivity, a relevant aspect of building the model would be to incorporate an endogenous financing system for improving workers' qualifications.

From the specific point of view of the real estate market, in our view, only three aspects are not covered by the *PolicySpace2*. Firstly, there is no vertical density, which is relevant to unlocking the supply of homes and thus keeping property prices in line with demand. However, given that the location of the residences is punctual, with an address in the form of latitude and longitude, as long as the municipality has (endogenous) building permits available, firms can buy the permits (*proxy* for bare land plots) and naturally densify profitable neighborhoods. Although this process does not simulate multi-story residential buildings, the density of real estate points can be densified, depending on the number of permits available.

Another aspect of the real estate market not included in the model is the investment of foreign assets in the real estate market. This point seems especially crucial for global cities in which there is interest from large external investors. The *PolicySpace2* only includes migrant families with resources equivalent to those of initial families, but does not include investors with high investment capacity.

2. Available at: <https://bit.ly/3yOuz3l>.

Finally, the scale of intra-urban analysis of the real estate market does not yet include urbanistic regulation and zoning, in terms of construction potential and restrictions, nor the location of physical urban amenities. Only the amenity of living close to families with similar income is included in the model.

7 CHANGES REGARDING THE ORIGINAL *POLICYSPACE*

The *PolicySpace2* is an extension of the original model *PolicySpace* launched in 2018 by Ipea (Furtado, 2018c). Below we explain the advances made in relation to the previous version. In addition to the change log, the listing also serves as an example of the modularity of the platform's proposal.

1) The process of endogenous remuneration of household deposits was included.
2) The rental market was introduced into the model.
3) An endogenous civil construction sector that provides new properties to the market was also included.
4) The effect of affluence of neighborhood families was explicitly included in the calculation of property prices.
5) The negotiation process was made more sophisticated with the inclusion of the possibility of access to real estate financing and the buyer's attempt to bargain. Information on the global real estate supply has also become part of the price formation process in the real estate market.
6) The price construction process now also includes the possibility that the property's permanence on sale for longer periods will influence prices.
7) The new version allows the generation of data on the origin and destination of workers and firms in a format directly applicable to the model, still unpublished, of traffic analysis, carried out by Ipea consultant Francis Tseng.[3] The model generates public and private transport routes, visualization and congestion times from the heterogeneities of the families. Note that this makes it possible to evaluate the traffic jam time caused by alterations to taxes or worker productivity, for example.
8) The consumption process was sophisticated, and families can use any resources, including savings, if they do not have resources for monthly consumption.
9) The initial generation of model families has been changed to ensure that every family has at least one adult.

3. Available at: <https://bit.ly/3Noec24>.

10) Firms are incorporated monthly, according to an exogenous monthly rate. The internal allocation to the municipality probabilistically favors the most endogenously dynamic regions of the municipality in terms of number of employees and profit.
11) Real estate began to be accounted for in the families' budget and used to build the permanent income and consequent endogenization of the decision process between immediate consumption and long-term consumption.
12) Migration processes were added starting with this release.
13) It also included processes of constitution of new families from marriage (single or married citizens).
14) An inheritance process was incorporated in which relatives of family members who will die inherit real estate assets. However, there is no inheritance tax implemented.
15) The version *PolicySpace2* transformed the census source of information from the municipal level to the intra-urban level by reading the information by IBGE APs.
16) Empirical data were updated from the year 2000 to 2010.
17) The real estate financing system follows the Constant Amortization System (SAC), more common in the Brazilian case.
18) The size of the vacancies influences the behavior of construction firms.
19) Interest rates follow real, nominal or exogenous values.
20) Some visualization changes have been improved and new graphics added.

CHAPTER 3

METHODS: *POLICYSPACE2*

The description of the method follows the consolidation of the literature through the Overview, Design Concepts and Details (ODD) protocol (Grimm et al., 2020).[1] It assumes an understanding of the progressive and increasingly detailed model. The first step is the description of the purposes and objectives of the model. This purpose will serve to illustrate the adequacy of the model, regarding whether it effectively served the purpose or not. Next, the agents, their attributes and scales are described. Once the agents are known, the modeler describes the process execution program; that is, in what order events occur within the model. At this point the reader already has a good understanding of the model's specifications, and the ODD protocol recommends discussing the concepts underlying the proposed modeling: the design concepts. In this section, the basic principles of modeling and the conceptual aspects of complex systems are discussed. Finally, the details of the initialization of the model, the necessary data, the description, the rationality and the justification of the sub-processes, for example, the markets present in *PolicySpace2*, are described in sections 5, 6 and 7. The formulas and parameters for each core process are available in section 7.

1 ODD: PURPOSE

In this book, it was decided to use the ODD protocol in its entirety for the description and analysis of the model. Originating in the epidemiological literature, the ODD was adopted, adapted and extended by the community of scientists who use agent-based modeling (Grimm et al., 2006; 2020; Grimm and Railsback, 2012). The protocol embodies the most accurate description of the built model, its fundamental principles, purpose and details. The rigor of the protocol requires, for example, that when starting the description, the following passage is included: "the model description follows the ODD (Overview, Design Concepts and Details) protocol for describing individual and agent-based models" (Grimm et al., 2010, p. 2763).

The first item established in the protocol is the description of the purpose of the model. Given the comprehensive feature of the *PolicySpace2* and its intention to constitute itself as a platform, we established two central purposes, each one with its associated result, following Edmonds et al. (2019). As suggested, the first

1. This description is compatible with version number 1.1. Available at: <https://bit.ly/3LqCsir>.

purpose is linked to the public policy test carried out in chapter 6. The second is linked to the results of chapter 5.

The first purpose of *PolicySpace2* is to illustrate a potential explanation as to how different alternatives for investing municipal public resources in housing policies and income distribution among citizens can result in comparatively different behavior in local economic indicators. In the simulated case, the generation of families selected to receive the aid, as well as the amount of resources distributed and the way in which the benefits are offered are endogenous to the process. It is possible to understand the advantages of each of the alternatives: provision of housing, payment of rent or distribution of pecuniary assistance. With this, relevant comparative indications are obtained for better investment of public resources. The results are robust for a wide range of parameters, processes and different metropolitan regions (RMs).

Additionally, the *PolicySpace2* is a model whose purpose is descriptive and useful for making analogies (Edmonds and Meyer, 2017, p. 45; Grimm et al., 2020, p. 30).[2] In particular, *PolicySpace2* shows itself capable of articulating distant facets of analysis. For example, by what order of magnitude would improvements in labor market productivity affect house prices or corporate profits? Or, how does the presence of a larger stock of unoccupied properties affect household savings?

The *PolicySpace2* is descriptive in the sense that it makes it possible to analyze how different policy configurations affect the dynamics observed. The model allows the quantitative and formal representation of parameters and rules, as well as their associated results. Questions that could be included in this item are: i) how the percentage increase in construction firms affects macroeconomic indicators and income concentration; and ii) how the socioeconomic composition of families, given by the 2010 census, affects the intrinsic dynamics of inflation and unemployment.

The *PolicySpace2* also makes it possible to assess the compatibility of the results with the hypotheses raised. In this way, it serves to illustrate general principles.

Finally, it also serves as a methodological instrument for making analogies. It is easy to use the model to reason about the housing market in an endogenously integrated way with the rest of the economic system. In particular, this purpose is verifiable through the flexibility of the proposal and its relatively simple amendment process. For example, if a given rule for real estate trading is not satisfactory or adequate for a specific hypothesis, or for a set of evidence, other alternatives, such as auctioning, can be implemented.

2. Also, as recommended by the ODD protocol, the *PolicySpace2* is licensed under the MIT License. The complete code of the model is available at: <https://bit.ly/3wnnDZI>.

The explicit indication of the model's purpose is relevant because it indicates the patterns to be replicated that will serve as the model's evaluation criteria (Grimm and Railsback, 2012). As our purpose includes the possibility of "articulating distant aspects of analysis" with a view to understanding real estate market mechanisms, the patterns to be replicated will involve different aspects of the economic environment. With this, the intention is to verify if the behavior of the economic indicators of the model remains within reasonable margins, at the same time that the real estate market also presents a similar performance to the observed real market.

In this sense, the model would not serve its purpose if some meaningful change – for example, an increase in the influx of migrants, or growth of construction firms, or even a reasonable change in interest rates – resulted in unemployment of 90% or a Gini coefficient of 0.01, for example. Or, still, if the characterization of the real estate market resulting from the model was not in line with real data of the real estate market.

In general, the *PolicySpace2* replicates expected trajectories of stylized effects or facts in the behavior of markets. For example:

- the increase in dynamism in the real estate market, when a greater number of families participate in the market on a monthly basis, leads to an increase in economic performance, with greater price volatility and increased inequality;
- the increase in worker productivity leads to lower prices in the economy;
- the reduction in the number of firms consulted when making purchase decisions in the goods and services market – less competition – generates more inflation; and
- when there is an increase in population, there is an effect of scale and efficiency with greater inequality and greater production and consumption.

Other effects – for example, on household wealth or on the behavior of gross domestic product (GDP) and unemployment – are not so obvious and may suggest interesting connections:

- the fact that companies choose more workers with the criterion of distance, to the detriment of qualification, suggests an increase in prices; and
- the increase in taxes on firms leads to a reduction in their profits, but it also leads to an increase in government investments, with an increase in real estate prices and, therefore, greater savings for families.

As a result, the specific patterns that the *PolicySpace2* hopes to replicate are:

- for economic behavior in general, reasonable behavior of the indicators for GDP, inflation, unemployment and the Gini coefficient; and
- for the real estate market, similarity in the distribution of real property prices.

2 TRACE – PROBLEM FORMULATION

According to the modeling follow-up procedure suggested by the Transparent and Comprehensive Model Evaludation (TRACE) methodology (Grimm et al., 2014), we specify here the formulation of the problem. The model must specify the customers, the specification of the question to be answered, and the products needed to do so. Additionally, the applicability of the model and its extension possibilities must be explained.

The target audience of *PolicySpace2* is formed by scientists and public managers interested in understanding the broader mechanisms of the real estate market. As described, the model's intention is to provide a means of reasoning and making analogies about the real estate market, allowing the observation of the scale and comparative analysis of the effects of implementing changes in public policies and behaviors. This reasoning is possible because the model produces adequate macroeconomic indicators and is similar to real estate market prices. Additionally, the *PolicySpace2* tests alternative public housing policies. In terms of extension and extrapolation, some possibilities are listed by way of conclusion in the final considerations.

We do not exclude the possibility of using *PolicySpace2* for specific forecasting of the housing market, provided that more building data from the initial housing base is introduced. We also understand that it would be possible to include additional mechanisms or analyses that contribute to a broader understanding of phenomena already represented here, such as the municipal fiscal issue; the qualification of workers; inequality and social mobility; urban mobility and its CO emission effects; and the analysis of intersectoriality or innovation in firms. Any of these additional analyses should maintain adequate results overall and be validated for each case specifically.

3 ODD: ENTITIES, STATUS VARIABLES (ATTRIBUTES) AND SCALES

The *PolicySpace2* contains six entities that interact throughout the simulation: *individuals*, who are always organized into *families* and that inhabit *households*, with fixed locations; firms, which hire individuals, participate in the labor market and offer goods on the property and real estate markets; banks, which collect deposits and offer loans; and the spatial entities, the *municipalities*, which can be subdivided into weighted areas (APs) or not. A lot of information is collected monthly, so variable attributes are also recorded each month.

3.1 Individuals, workers

Individuals in *PolicySpace2* have their own identification (character, size: 36); gender (character: male, masculine; female, feminine); years of study (integer: 1, 2, 4, 6, 8, 9 to 15); and birthday month (integer: 1 to 12), which are invariable.

Additionally, individuals register the family to which they belong (*family_id, character*) and, perhaps the company at which they work, when employed (character). When not used, the variable assumes the null value (*none*). Belonging to the family can be updated through marriage, as can the link with the employing firm.

The age of individuals is obtained in proportion to official data, according to the smallest spatial area (municipality or AP) at the time of creation (integer: from 0 to 100) and is updated annually, according to the anniversary demographic processes.

Individuals also record a numeric variable (*float*) *money*, which represents the individual's current portfolio of financial resources. Note that the worker individually receives resources from the firm, but purchase decisions are made within the family, with the sum of resources from other family members. Employed individuals also record monthly, in the variable *distance* the distance traveled between home and work. When not used, the numeric variable returns to zero.

3.2 Families (collective)

Families are formed by one or more individuals and are, in practice, the environment for decision-making and financial sharing. Only the family identification variable remains the same throughout the simulation. All others are updated throughout each process.

The variable *members* registers the family member agents. As used in Object-Oriented Programming (OOP) modeling, the variable contains the individual that is a member of the family. Thus, the individual's variables, such as his financial portfolio, for example, remain accessible from within the family, as long as the individual remains a member.

The composition of family members can change through marriage or death; and by birth of the child of a female member of the family.

Another object that is accessed as a family variable is *house*. This variable refers to the household in which the family currently resides and may be the owner or tenant. At the same time, the identification of the region in which the current residence is located is recorded (*region_id*). There is also a list of possible properties of real estate, called *owned_houses*, which changes when there is a sale or purchase of a property by the family.

Other numerical variables, updated monthly and recorded within the family include: balance sheet (*balance*); savings (*savings*); wealth – in which financial assets and real estate are accounted for (*wealth*); payment of any loan installments; and calculation of permanent income (*last_permanent_income*).

3.3 Firms

Firms have a fixed location (*address*), which consists of a geographic object of the type *point* from class *shapely*, referring to their coordinates. All other variables are updated monthly and include the available account balance (*total_balance*), quantity produced (*amount_produced*), current price of the product[3] (*prices*), wages paid (*wages_paid*), profits earned and taxes paid (*taxes_paid*). The quantity sold (amount_sold), in number of units of the good (*float*) and billing (*revenue*) are reset to zero at the beginning of each month. Finally, firms also record the price assigned to the product.

Additionally, construction firms specifically contain information on whether or not they are building (Boolean, *building*), the inventory of properties built and not yet sold (*houses_inventory*), the cost, size, quality and region of the home under construction (*building_region*, *building_size*, *building_cost*, *building_quality*). Finally, there is an organization of the firm's cash flow, so that the sale of the property is not accounted for in cash, but in installments. To allow the payment flow of employees, the data is recorded in the variable (*cash_flow*), which is a dictionary containing the payment month and installment.

3.4 Households

Households also maintain a unique identification, address, quality and region of location, all of which are invariable attributes. The price (*float*, *price*) is adjusted based on changing regional prices and other factors.[4] The household, specifically, contains the identification of the family (*family_id*) referring to the occupant (owner or tenant) and the owning family (*owner_id*). When in lease, the residence maintains information regarding the payment of rent (*rent_data*); and, when vacant, records the number of months on sale (*on_market*).

3.5 Bank

A bank concentrates customer deposits - identified separately, records available cash resources (*float*, *balance*), referring to income from loans and expenditures and total assets (*outstanding_loans*). It also maintains a portfolio with identified

3. The *PolicySpace2* only has one homogeneous product per firm – differentiated by the location of the sale – and by the price. However, the program has an inventory that could include new products, also endogenously generated, but which remain with only one product.

4. See details in subsection 7.7.

deposits and maturities. For each loan granted, an instance, called loan, is created and records the age of the contract, the principal amount, the outstanding balance (principal plus interest), the payments made and the number of arrears, as well as two pieces of information regarding the loan settlement (*paid_off*) or the existence of late payments (*delinquent*).

3.6 RMs, municipalities and APs

Central in the spacing of the *PolicySpace2*, the regions are APs constructed by the Brazilian Institute of Geography and Statistics (IBGE). In some cases, the municipality has only one AP, which spatially coincides with the municipalities. From the point of view of location and generation of spatial data, APs are used as a spatial element whenever there is information available at that level (gender, age, population). Also in relation to the real estate market, each AP has its Quality of Life Index (QLI) updated individually. That is, the value is the same for all APs in the municipality at the beginning, but they are updated according to proportional population gains (or losses) throughout the simulation. From the point of view of tax collection and recording of macroeconomic statistical information (GDP, inflation, budget), the municipality is the reference unit. It works as a collection center, receiving the budget and distributing it proportionally to the populations of each AP. With this, the QLI maintains as attributes (*index*), the GDP, the population (pop), in addition to dictionaries that record taxes with monthly and accumulated values (*treasure*, *cumulative_treasure*, *applied_treasure*). Finally, each region contains an exogenous number of permits to build new homes (licenses).

3.7 Scales

In terms of time, the scale of operation of the *PolicySpace2* is monthly. The processes described, according to the sequence of subsection 4.2, take place every month. By default, the simulation runs from January 2010 to December 2020, so for 120 cycles. However, the model can also be configured to start in 2000, from the 2000 census data and the 2000 APs, and last for as many months as the modeler chooses, up to a maximum of 2030. From 2030 onwards, the IBGE mortality data are not configured, so it is not possible to continue to later years.

In spatial terms, as described in the previous subsection, the *PolicySpace2* operates at the intra-urban level, with the official limits of the IBGE APs, which are aggregations of census sectors and maintain statistically weighted sampled data. The APs aggregate in municipalities that are entities of the model and collect and distribute taxes. Finally, each simulation is independent for an IBGE (2016) Population Concentration Area (ACP), which is equivalent to the most dynamic and central part of the 46 RMs used.

Therefore, there is no migration or travel between RMs. For the case of São Paulo, for example, which has several RMs that are very integrated and close together, it is possible to simulate those of Campinas, Santos and São Paulo together. However, in this case, there will be daily trips between any point of the RMs as a whole, although mediated by the cost of transport.

4 ODD: OVERVIEW OF PROCESSES AND SEQUENCE OF EXECUTED STEPS

The general intuition of the model and the overview of the processes are presented initially in chapter 2. Formulas and rationality based on literature are made for each process in the description of the sub-models (section 7 of chapter 3). The relevant thing at this point, according to the prescription of the ODD protocol, is the order of execution of each step and each phase and the rationale for each ordering. At the same time, the variables that are updated at each step are detailed.

The *PolicySpace2* is a simulation with monthly periodicity which, in the default configuration, occurs 120 times (2010-2020). The central call of the model occurs through the program main.py, executed by the Python interpreter (version 3.7). This module determines the number of simulations that will be executed and makes the parameters compatible for each simulation. In default mode (*python main.py run*),[5] the simulation is performed only once, according to the parameters established in the file params.py and information on start and end dates, RM name, percentage of population to be considered, rescue location, among other details of each execution.

When the call is made in sensitivity mode, which involves simulation with parameter variation and production of comparative graphs, the module *main.py* organizes each individual run for each parameter group.

4.1 Agent generation

Three processes run sequentially. First, the agents are generated, determined by the chosen parameters. As this process is time consuming, it is possible to save the agents already created and just read the corresponding files in the next simulation. It is also possible to adjust so that new agents are created at each simulation.

The saved files are specific to a given combination of parameters that influence the generation of agents. So any change in any of these parameters necessarily leads to the generation of a new set of agents. The parameters that influence the generation of agents are described next.

5. See section 8, which describes the operationalization of the simulation.

1) *Members_per_family*: used only when the simulation start date is the year 2000. For 2010, the number of family members is read directly from the AP data.

2) *House_vacancy*: determines the vacancy in the number of output properties of the model in the first month.

3) *Simplify_pop_evolution*: is a parameter to simplify the process of generating agents by age. If determined to be false, this parameter probabilistically generates the population for each year of age. When true, which is the default choice, agent ages are drawn into six aggregated age groups.

4) *Percentage_current_pop*: is the percentage of the RM population to be considered. By default, we use 1% of the population. It is possible to run with 100% of the population, but the computational demand is relatively large and we only simulate in this case for the RM of Ipatinga, in Minas Gerais.

5) *T_licenses_per_region*: refers to the number of new building permits per AP each month. The default value is random, which, in practice, leads to the generation of one or no licenses per AP per month, which seems more than enough to supply the simulated civil construction market, since there are many licenses left over at the end of the process.

6) *Percent_construction_firms*: determines the percentage among the firms in the model that will be civil construction firms. The number of firms itself is proportional to the percentage of the simulated population and is based on real data on the number of firms per APs (in the standard year of 2010).

7) *Starting_day*: can be set to January 2000 or January 2010, the latter being the default parameter.

For details on the agent generation process, see subsection 4.1. Here, the important thing is to specify the generation order of the agents. The first agents to be created are the regions; that is, the smallest spatial units of analysis from the IBGE's APs. An iteration is made over the regions, in no specific order, since they are independent of each other, and the generation depends only on the data. From then on, agents, families and properties for that region are successively created for each region.

The number of agents created for each region is given by the percentage of the real population in that particular region (AP), according to the number of agents of each gender and of each age. Once the agents and families for each region are created, the agents are allocated as members of each family separately for adults (over 21 years old) and children. Agents are randomly shuffled before being allocated to families.

Allocation of adults is done as equitably as possible so that households have similar proportions of adults. The allocation of children is done for all children with the choice of families at random, so that there can be families with more children and families with no children.

Next, the properties are shuffled and distributed to a percentage of the families, according to the exogenous factor. In this first part of the process, the intention is that each family of this percentage has its own property. The remaining properties are randomly allocated to families and can be rented by families that do not own properties. This is repeated for each region of the current simulation. In practice, some families receive more than one property and others no property.

At the end of the process, each agent belongs to a family that has a residence address, which can be owned or rented and all properties have a family that owns it, although not all properties are occupied.

A second general process just controls the passing of days and each month processes all the steps described below. Although no process runs daily, quarterly or annually, this possibility exists in the model's programming.

4.2 Monthly processes

After the initialization of the agents – through generation or reading –, the simulation runs through the same activities, month by month, until the end of the established period. Commands are invoked in the following order.

1) Monthly interest and mortgage interest are read from exogenous data.
2) Each region (AP) provides new licenses for civil construction (exogenous). As the process is independent, the order does not change the execution.
3) New firms are incorporated into the model. While the absolute number of firms follows the empirically observed exogenous pattern, its allocation in each AP is probabilistically according to the number of employees and average profit.
4) Firms update their production. This process is also independent for each company and depends only on the number of employees and on their qualifications.
5) *PolicySpace*'s processes also include stochastic decisions for mortality and fertility, drawn from official data. The demographic processes of mortality, fertility and aging, with exogenous probability parameters and official data, are performed. The process takes place annually, in the month of each agent's birthday. The cohorts are operated by Federation Unit (UF), which is the origin of the probabilities, and in ascending order of age.

The first process that occurs is age advancement, and then the probability of marriage (for those over 21) and the probability of death are updated. For women, additionally for those between 14 and 50, the probability of giving birth is checked. If so, a new agent is created and incorporated into the mother's family.

6) Then the immigration and marriage processes take place. By municipality, the annual number of migrants is calculated from exogenous data and linear estimation for the years without information, allocating it equally to each month of the year. The same procedure described in the generation process is performed. First there is the generation of agents, then the families and then the allocation of agents in the new families. However, when the property is allocated, the family is directed to the rental market. Families that are unable to rent a property are not included in the model.

7) In the marriage process, all agents – with their remarriage probability updated annually in the anniversary month – are probabilistically included in a list. The list is shuffled and pairs are randomly formed. The marriage and the formation of the new family only take effect if the new family manages to find a property to rent.

8) The goods market begins with the consumption of families. Families select a sample of firms at random that are exogenously fixed in size by a parameter.

9) The bank collects the mortgage payments due, according to the order in the portfolio, family by family.

10) Firms assess revenue, pay taxes and calculate profit or loss. They pay their employees and decide whether to update prices.

11) Prior to construction planning, the monthly global real estate vacancy is calculated. For each construction firm, the process of planning new properties takes place; next is verification of whether previously planned properties have been completed. If so, they enter the firm's sales portfolio.

12) Labor market: the first event of the labor market process occurs with the construction of a list of citizens who are of working age [16, 70] and unemployed. Subsequently, in a probabilistic way, according to an exogenous parameter, the firms assess whether they participate in the labor market in that month. If they choose to participate, they can fire an employee or open a new job.

13) Candidates and firms are shuffled. According to the last existing salary of the candidate and the corresponding income decile, it is verified whether there is car ownership for individual transport or not. The vacancies available are divided according to the exogenous parameter between those whose criterion is by proximity and those by qualification. Each of the lists is ordered so that the firms that pay the highest salaries choose first. The qualification process occurs first and is followed by the proximity process. For each firm that initiates the hiring process, a sample of candidates is selected.

14) After the selection process, however, firms and candidates are organized according to the value of the general indicator of offers; that is, each candidate who participated in each selection process ranks the firm according to salary and transportation cost. Additionally, the qualification is also included in the calculation of the indicator for firms that used this criterion. Thus, the final order is the score of the sum of the candidate's qualification (firm side), plus the salary deducted from the actual cost of transportation (candidate side). The firm of the candidate-firm pair with the highest score does the hiring and both exit the market. The next pair does the hiring, and so on, as long as the pair is still in the market.

15) Soon after, the real estate market transactions take place. A sample of families determined by exogenous parameter is chosen. All properties have their prices updated, and those that are vacant are included in the list of properties for sale and update the information regarding how long they are available on the market. Families are sorted by purchasing power, including potential mortgage loans. Properties are divided between the rental and sales market according to the proportion in the exogenous parameter.

16) The rental market comes first. In this case, families are ordered according to their permanent income variable. The rental properties make up a random sample. If there is a property whose rent is less than the family's permanent income, it chooses a random property. However, when the family is already settled – it is not a migrant family or one resulting from a new marriage – it will make the move only when the move is to a better (more expensive) residence. When the rent is not compatible with the family's income, it proposes a discount, proportional to the size of the vacant property supply, for the cheapest rental property.

17) In the buying and selling market, the family chooses a sample of properties available on the market and tries to buy the most expensive property in the sample. If the property chosen is within the limits of their savings,

they negotiate the price and make the purchase. If the property is within the limits of their savings plus financing, the family applies for housing finance. If financing is denied, the family exits the market. If the property is above the family's savings limits plus potential financing, the next cheapest property is looked at.

18) Families make investments when appropriate.

19) Municipalities invest the collected taxes in public improvements.

20) Monthly model statistics and information are collected.

5 ODD: MODEL DRAWING CONCEPTS

The design of the model sought to represent the processes from the point of view of families and firms, supported by the literature, when available. Following the proposal to build the description of the ODD model, the details of each submodel are shown in section 7.

5.1 ODD: basic principles – agents' decision process

The basic guiding principle of the *PolicySpace2* was the intention to describe the processes of the complex real estate market in an initially simple and intuitive way. From this basic model, constituent empirical data and a set of reasonable parameters were incorporated in order to observe the behavior of the economy after changes in processes and parameters. This was done to better understand the mechanisms of interaction and connection between the economy as a whole and the real estate market in particular, while including several dimensions of analysis of the problem. The *PolicySpace2* brings together in the same model the idiosyncrasies and location of the real estate, the asynchronous construction market, the relevance of production processes, the labor market and endogenous wages, real estate financing and changes in families in a specific empirical environment for each Brazilian RM.

Among the modeling traditions, the *PolicySpace2* manages to unite purely economic and non-spatial traditions, such as those reviewed by Dawid and Gatti (2018), with models originating from mobility analyses (Waddell, 2011), including endogenous wages, absent in typical real estate market analyses (Baptista et al., 2016; Guerrero, 2020; Hamill and Gilbert, 2016) and labor markets, as in the seminal model by Neugart and Richiardi (2012). In addition to including aspects of all these approaches, it is spatially more detailed than models of the traditional land use change stream (Parker et al., 2003), with spatial processes present in all markets.

In terms of design and modeling design, note that in the economic literature processes are traditionally instantaneous with equation solving and price adjustment in order to balance the market. In practice, however, the firm only knows demand after household consumption has taken place and does not have enough information to accurately determine prices and wages. Some central points of the simulation are based on modeling approaches present in the literature; others were included from our own concepts. Notably, we highlight below – as a complement to the description of the sub-models – processes that are difficult to design and how they were implemented.

1) Firm price decisions: Blinder (1994) reviews firms' practices based on a survey and identifies several distinct patterns in pricing decision making. We incorporated some of the behavior suggestions of firms as proposed by Blinder by including exogenous parameters that control the frequency with which firms update their prices. Firms also do not assess the labor market every month, but usually at intervals of three or four months. Additionally, the behavior was chosen in which the firm observes its own inventory to establish prices (Seppecher, Salle and Lavoie, 2017).

2) Salary decision: salaries are determined based on the firm's revenues, after discounting taxes and the size of overall unemployment. The higher the unemployment, the lower the volume of income to be distributed among workers. Distribution is made proportionately to the productivity of each.

3) Household consumption decision: the household consumption decision is based on the calculation of their permanent income (Dawid and Gatti, 2018), so that it is proportional to the monetary resources available, the family's savings and its assets. In practice, all amounts that exceed the calculation of permanent income are directed to savings, while values up to permanent income are directed to consumption. In some cases, when there are no immediate resources to pay loans, rents or consumption, resources are subtracted from savings.

4) Labor market and contracting decisions: the processes used generally follow those described in the literature (Neugart and Richiardi, 2012). They include, for example, the negative relationship between the supply of workers (unemployment) and the definition of wages. The searching by firms for more qualified workers is also followed. Additionally, *PolicySpace2* uses the proximity factor, more specifically the cost of transport conditioned on access to public and private transport services, as a criterion for the worker when choosing a firm. No interaction process or social networks are included in the sample that the firm uses for the selection processes.

5) Real estate negotiation process in the real estate market: the traditional price setting process follows a more abstract framework (Dipasquale and Wheaton, 1996) that is difficult to apply in practice or in ABM, as it is not micro-based and does not describe the path to equilibrium. Even so, the calculation of real estate prices from hedonic regressions is well established in the literature, according to Rosen's (1974) seminal text. The trading price, however, is difficult to measure (Glaeser and Nathanson, 2017). In the *PolicySpace2* we have designed a relatively ingenious process that allows for above and below market prices. Described in detail in subsection 7.7, the negotiation process itself involves two phases. On the demand side, the buyer makes a hedonic evaluation of the price, incorporating the intrinsic characteristics of the property, the municipal quality of life, which evolves according to the dynamism of its companies and is weighted by the weight of the population of each AP and the average income of the families in the neighborhood as a proxy for aspects of perception (Galster, 2001; Furtado, 2011). On the supply side, the seller correctly estimates the family's actual savings, including potential bank loans. The price adjustment, in turn, is made as an average of the two estimates, when savings are sufficient. Otherwise, the seller checks the size of the global property supply on the market (vacancies) and can probabilistically accept a certain level of discount.

6) Municipal management efficiency: an exogenous parameter linearly transforms the resources collected and transferred to the municipal treasury into changes to the municipality's QLI. This indicator is used in the formation of prices in the real estate market. However, note that this factor is only a referential component of the estimated price, and the actual transaction price will depend on the family's savings capacity.

7) Decision to participate in the real estate market and decision between renting or buying: we did not find enough elements to characterize when families decide to participate in the real estate market (Furtado and Souza, 2020), and we only have empirical indications of the frequency with which they do so. We also did not obtain any evidence of the decision process between living in own property or renting; the analysis of empirical data suggests that both families with greater and lesser economic power choose to rent or buy (Furtado and Galindo, 2010). Thus, these two processes are operated through exogenous parameters.

8) Decision to grant real estate financing: the process of the decision to grant a loan begins with the evaluation of three standard criteria: i) whether the bank has resources to lend; ii) if the requesting family no longer has

a loan; and iii) if the set of loans already offered does not exceed the exogenously fixed percentage of the bank's exposure; that is, if it has not exceeded the amount of deposits that must be compulsorily withheld.

9) Productivity of the firms: the productivity of firms varies in accordance with the qualification of their employees (Gaffeo et al., 2008). Two parameters make an overall adjustment of the productivity and consequential quantity of products that each firm produces.

5.2 ODD: emergency

Given the level of complexity to which the *PolicySpace2* evolved, with the number of mechanisms, parameters and empirical data, it is difficult to say which result is specifically emergent. However, sensitivity analysis – performed numerous times in the process of building and developing the model and analyzed in chapter 5 – suggests that worker productivity is the single mechanism with the greatest influence on the overall behavior of the economy. Regarding the real estate market, the efficiency of transforming funds raised into QLI improvement also seems to be especially influential on final prices transacted in the real estate market.

A third factor of relevance in the model is the initial empirical composition of the neighborhoods. Simulations that involve exactly the same set of initial parameters, but that use data for different RMs, result in behavior with a different trajectory for some central indicators, such as the evolution of unemployment, GDP or company profits, for example.

In any case, for a large set of analyzed variations, there is growth or maintenance of GDP and jobs, with relatively low inflation, with few combinations in which it exceeds 20%. The Gini coefficient is also stable for all configurations with most final values between 0.4 and 0.55. Tax payments and general household consumption are also preserved for the vast majority of parameter and mechanism configurations.

5.3 ODD: adaptation

Several mechanisms include decision-making based on the situation observed locally and its consequent adaptation.

1) Families decide to apply for real estate financing if the most expensive property in their sample is above their available savings.

2) Candidates choose the firm according to a ranking criterion, which includes their own transport cost, with their characteristic of being a public or individual transport user.

3) New couples abandon plans to create new families if they are not successful in the rental market. The same is true of new immigrant families.
4) Firms hire or fire employees according to their performance sales made in the consumer market.
5) Construction firms weigh projected profitability and the size of the current housing supply when planning to build new properties.

5.4 ODD: objectives

The *PolicySpace2* does not contain explicit utility functions. In any event, we can list some objectives pursued by the agents throughout the simulation:

- candidates of working age are always looking for jobs;
- unoccupied properties are always available for rent or sale;
- families always seek to buy the most expensive property in their sample, although they only move to the most expensive (better) when at least one family member is employed;
- firms seek to hire workers with the highest possible qualifications or who live closer, in order to reduce their own cost of subsidized transport;
- sellers seek to extract the greatest savings from purchasing families;
- banks seek to make loans to families that have proportionally enough equity to make the payments; and
- families seek to keep their consumption in line with their calculated permanent income.

5.5 ODD: learning

The *PolicySpace2* does not contain endogenous methods of altering behavior from past experience. We anticipate the possibility of implementing an endogenous change in the worker's qualifications.

5.6 ODD: forecast

There is also no explicit provision in the *PolicySpace2*. At three moments, agents consider future implications of present actions.

1) In civil construction, planning for the construction of new properties involves present profitability, as well as the size of the present offer to decide whether to start the construction process of properties that will be ready in the future.

2) Families, when carrying out the calculation of permanent income, consider current interest in the economy and the impact on their future wealth to decide on the share of present consumption.

3) Firms look at past demand and its consequent effect on their finances to decide in the present on whether to increase or decrease the size of the workforce and their future production capacity.

5.7 ODD: perception

Globally, only the indicators referring to unemployment and the general vacancy of properties are known to all agents. The rest of the information is restricted to agents at the time of their interaction, as follows.

1) The dynamics of the entry of families in the real estate market and construction firms. In the case of real estate market negotiations, families know the calculated prices of properties for a small sample. Sellers estimate (correctly) household savings when joint pricing takes place. Additionally, families are able to estimate the average income component of neighborhood families by calculating the real estate prices on offer in their sample.

2) Firms look only at their revenue, the skills of their workers, and overall unemployment to determine wages. Prices are assigned using the firm's own information.

3) Civil construction firms are able to calculate the expected profitability in the planning of new properties from the average size, quality and price of some properties for the intended regions.

4) Workers know the salary offered by the firm when they participate in a selection process and also calculate the distance and cost of transport from their current residence to the firm.

5) Banks know the assets of their clients, as well as their presence or absence in the portfolio when deciding whether to grant real estate financing.

6) Families know the prices and distances of a sample of firms at the time of the consumption decision.

7) Municipalities know the amount of their population on a monthly basis. They are also effective in collecting all taxes; therefore, they know the owners and tenants of real estate, those who have transacted real estate, family consumption, payment of workers and the profit of firms.

5.8 ODD: interaction

Agents interact with each other in the three markets; and with the bank, when they need financing or wish to make investments, as described below.

1) In the real estate market, interaction is mediated by competition, and the family seeks to buy the most expensive, best-quality property from its sample and rent the cheapest of the sample that its budget allows.
2) In the goods market, interaction is also mediated by the prices and location of the firms, among those contained in the sample – which varies every month – of the family.
3) Also on the labor market, hiring depends on the competition among agents, considering the criteria of greatest qualification and cost of proximity to the firm.

There are two other implicit interaction processes. The first refers to the influence of the income of the set of families in a given neighborhood on the prices of real estate in that location. The second refers to the influence of the collection dynamics of firms in a given municipality and its impact, via tax collection, on the municipal QLI.

5.9 ODD: stochasticity

Random processes are used numerous times throughout a simulation as in *PolicySpace2*. In general, every process described as probabilistic – such as participation in the process of marriage, fertility or mortality – involves drawing a number between zero and one, for example, and verifying whether the number is greater or smaller than the probability being tested. They are also random processes every time there is a sample selection among the agents in the model. By way of example, the input data suggest that a 79-year-old male residing in the Federal District in 2020 has a 0.0438 probability of dying over the next year. In the birthday month, the model processes a random number. If the value drawn is greater than the probability, the agent remains in the simulation.

The seed that determines the random number generating process in the simulation is controlled so that it is possible to replicate exactly the same simulation, using the same seed, regardless of the numerous existing random processes. Randomness is counterbalanced by simulating the model over and over again, with different seeds, and the result is presented as the average of the various simulations.

The following processes involve stochasticity.[6]

6. The list is not guaranteed to be exhaustive. Search the referenced code available on GitHub for an even more detailed analysis. Available at: <https://bit.ly/3wHq8Fs>.

1) Agent generation:
   a) in the pairing between qualification and years of study;
   b) in age attribution, within the age group;
   c) in the allocation of initial financial resources;
   d) in the birthday month;
   e) in the entry of immigrants, from the choice of an existing agent to replicate the characteristics – except for financial resources;
   f) at the time of shuffling and allocating the agents in the families;
   g) in choosing the specific address of the property within the AP;
   h) the size and quality of the property;
   i) in the allocation of urban or rural to municipalities with only one AP;
   j) in the process of allocating properties to families; and
   k) in the initial balance sheet of the firms.

2) In the real estate market:
   a) in the composition of the sample of properties that each family verifies;
   b) in the probability of granting real estate financing by the bank, to transpose the criterion of the amount of borrowed resources in proportion to the family's assets;
   c) in the seller's evaluation, if a discount proposal on the calculated price is accepted, in proportion to the vacancy of overall properties;
   d) in choosing the property to be leased, among those that fit the budget in the selected sample;
   e) in the evaluation of the construction company, if it decides to start building a new property;
   f) in productivity, in addition to markup of the construction firm; and
   g) in the monthly increment of licenses for the construction of the APs.

3) On the labor market:
   a) when verifying whether the firm participates in the market in a given month;
   b) in choosing which worker to fire, once the decision is made;
   c) in building the sample of candidates that the firm evaluates;
   d) in the shuffling of available jobs; and
   e) in the probability, according to the income decile of the worker's last salary, for owning a private car.

4) On the market for goods:
   a) in the composition of the sample of firms to be evaluated by the family;
   b) in choosing the decision criterion based on prices or proximity; and
   c) in the firm's decision, prices are updated.

5) Demographics:
   a) in the mortality decision, linked to the input data;
   b) in the fertility decision and consequent process of generating a new agent;
   c) in the distribution of assets and debts of agents who die and are the last in a given family, but who have generated descendants in other families; and
   d) in the composition of the agents that participate in the marriage process, in the shuffling of the list.

5.10 ODD: collectives

The great collective of *PolicySpace2* is the family. The family behaves as a decision-making unit in the consumption and real estate processes, but it is composed of its members who act individually in the labor market.

5.11 ODD: observation – collected data

The data collection and storage process can be configured in the module *run.py*. Data can be recorded monthly, quarterly or annually. Data from firms, banks, construction companies, by municipalities and general are always saved. Optionally, data on individual agents, on agents who died during the simulation, on properties and on families can also be saved.

The call to save the data is made as the last monthly process. The module *output.py* then calculates and saves the series of statistics about each chosen agent group. The file with general data, for example, calculates and saves the following information for the RM set:

- the current month;
- price index;
- GDP index;
- GDP growth;
- unemployment;
- average number of workers per firm;
- household wealth;
- household savings;
- total balance sheet of firms;
- profits of firms;
- Gini coefficient;
- accumulated household consumption;
- inflation;
- QLI of municipalities;
- real estate vacancy;
- average real estate prices;
- families who are renting properties;
- proportion of families whose rent is less than 30% of their monthly budget;
- investment by municipalities from equitably divided resources;
- locally, Property Tax (IPTU), Tax on Real Estate Transactions (ITBI) and segment on consumption;
- or through the Municipal Participation Fund (FPM), portions of the Tax on Industrialized Products (IPI), Income Tax (IR); and
- taxes paid by the bank.

All these statistics are reported in the form of evolution graphs over the simulation period.

In the default simulation (*run*), the graphs only show the evolution of the indicators for the standard configuration of the parameters and the chosen RM – the Federal District and surroundings.

The model results contribute to the purpose of the simulation, especially when performing simulation analysis of the *sensitivity* type, in which you can compare results for ranges of parameter changes.

6 ODD: TEMPLATE INITIALIZATION AND REQUIRED INPUT DATA

The model can be initialized for each of the RMs under analysis.[7] Model initialization can occur with the same seed; that is, with the same random number generator process, so as to repeat exactly the same results, or with a different *seed*, in order to produce different results for each simulation.

In addition to the chosen RM, it is necessary to identify the elements below.

1) The percentage of the population to be used as a sample. We usually run the simulations with approximately 1% to 2% of the population. The model saves the initial generation of agents, so that another simulation, with the same chosen RM and the same percentage of population, only needs to read the agents saved previously. Other factors should remain the same for reading agents.
2) Average number of members per family – for 2000.
3) Percentage of vacancy of residences.
4) Decision to simplify the population by age groups.[8]
5) The start year of the simulation (2000 or 2010). Housing vacancy is estimated from the analysis of the 2000 census (Nadalin, Furtado and Rabetti, 2018).

The data needed to run the *PolicySpace2* include the ones described next.[9]

1) Proportion of urban population per municipality.[10]

7. Manaus, Belém, Macapá, São Luís, Teresina, Fortaleza, Crajubar (current RM of Cariri: urban area of Juazeiro do Norte, Crato and Barbalha), Natal, João Pessoa, Campina Grande, Recife, Maceió, Aracaju, Salvador, Feira de Santana, Ilhéus-Itabuna, Petrolina-Juazeiro, Belo Horizonte, Juiz de Fora, Ipatinga, Uberlândia, Vitória, Volta Redonda-Barra Mansa, Rio de Janeiro, Campos dos Goytacazes, São Paulo, Campinas, Sorocaba, São José do Rio Preto, Santos, Jundiaí, São José dos Campos, Ribeirão Preto, Curitiba, Londrina, Maringá, Joinville, Florianópolis, Porto Alegre, Novo Hamburgo-São Leopoldo, Caxias do Sul, Pelotas-Rio Grande, Campo Grande, Cuiabá, Goiânia, Brasília.

8. Named parameters: *members_per_family*, *house_vacancy*, *simplify_pop_evolution* in the model.

9. Since the data used is required at the time of model initialization, we chose to describe it here, although the ODD protocol recommends doing so in the section immediately following.

10. Resident population, by sex and household status. Available at: <https://bit.ly/3MyTk81>.

2) The Municipal Human Development Index (IDHM), calculated by Fundação João Pinheiro (FJP) and by Ipea.[11]

3) The shapefiles (geo-referenced files) of the minimum statistical units considered, and in the case of the *PolicySpace2*, these are the IBGE's APs, for municipalities with more than one PA, and the municipality itself for those without statistical subdivisions. Additionally, urban areas are also used, as defined by the IBGE, according to the standard of census sectors.[12]

When starting the model in 2000, the weighting areas designed for the 2000 census are used. When the model start is specified for 2010, then the APs from the 2010 census are used. Note that the APs have a different design, geographic spatialization, quantity and code between the two censuses. Both APs used were built from the shapefiles of IBGE census sectors and the list of sectors that make up each AP.

The number of firms per IBGE APs, in fact the number of establishments, is the result of the effort of researcher Vanessa Nadalin, who processed the original bases of the Annual Social Information List (Rais) of the former Ministry of Labor and georeferenced, in the proprietary environment of the ESRI/Galileo system, the geographic coordinates of each company's location through its address and Postal Address Code (CEP).

From the georeferenced Rais processed, we calculated the number of establishments per AP, for each set of APs (2000 and 2010). The simulation, when it starts in 2000, uses data from the 2002 and 2012 Rais. When it starts in 2010, it uses data from the 2010 and 2017 Rais. Note that for 2010 all municipalities were incorporated and not just those belonging to the ACPs of interest. For reasons of confidentiality, the APs with fewer than three establishments were all updated with information from three establishments.[13]

Data by gender and age for 2010 were extracted directly from table 1,378 of the IBGE Automatic Recovery System (Sidra).

The population estimates come from data prepared by the IBGE for the Federal Audit Court (TCU) and published annually.[14] The model uses the estimates to infer population growth, in addition to the endogenous process of fertility and mortality existing in the model.

11. Available at: <https://bit.ly/3lspLJB>.

12. Available at: <https://bit.ly/39CcP10>; <https://bit.ly/3yV3OLf>.

13. Seven APs were imputed for 2002 and five for 2012, both with APs based on the 2000 census. For 2010, since the APs of all municipalities were used, 64 APs contained fewer than three establishments, with a minimum of three being imputed. For 2017, there were 38 imputations.

14. Available at: <https://bit.ly/3LwmyTN>.

For 2000, the years of study by weighting area (V4300) were extracted. For 2010, the education level information (V6400) was available, with the following structure:

- uneducated and incomplete elementary school;
- complete elementary and incomplete high school;
- complete high school and incomplete higher education;
- college degree; and
- not determined.

Based on this information, the model randomly transforms (uniform distribution) into years of study.[15]

The Central Bank series (in 433, 4390, 25497) described in section 6, contain the data required for initialization.

Finally, for 2010, the number of members per family is no longer exogenous – a parameter chosen by the modeler, and is replaced by the average size of families, within the scope of the APs, as determined by the IBGE in the 2010 census.

The process of generating the model families occurs once, before the start of the simulation, according to the choices made by the modeler. To save time, it is possible to use agents previously created in subsequent simulations, as long as the creation parameters remain the same.

6.1 Regions

The process of creating all entities in the *PolicySpace2* starts by importing the geographic limits of the minimum areas used, that is, the IBGE's APs. Thus, depending on the start year of the simulation (2000 or 2010), the corresponding shapefiles will be used. The information needed to create each region, as referenced in the model, is just its unique code – and its geographic boundaries.

Throughout the simulation, the region maintains a series of aggregated information regarding the families and firms located in its territory and updated monthly. They are: i) population; ii) IDHM; iii) GDP; iv) number of permits available for new construction; v) budget record, referring to transfers and taxes received; and vi) sum of displacements carried out by families.

These all start with zero and are endogenously calculated by the model, except for the IDHM index, whose value for the first month is read from data provided

15. Map between available information (educational level) and transformation in years of study: one for one or two; two for four or six or eight; three for nine or ten or eleven; four for twelve or thirteen or fourteen; and five for one or two or four or six or eight or nine.

by Ipea and FJP in the Municipal Development Atlas. From each region, using its AP code at IBGE, the other entities are created within the scope of each region.

6.2 Agents

The number of agents, or individuals, in each region is determined from the gender and age information for each AP. Additionally, years of study for each agent are derived from the results of the census sample. Thus, only the month of birth (uniform distribution) and a stipend of financial resources (also with uniform distribution, between 1 and 34) do not follow registration information.

During the simulation, other relevant factors for the agents are readjusted endogenously: i) belonging to the family (mortality, marriage); ii) employment and salary; and iii) commuting to work.

6.3 Families

The families will gather the agents' budget and carry out the purchase and sale or rental of properties. Participation in the goods market also occurs within the family. At the time of creation, the number of families depends on the number of individuals, and the exogenous parameter depends on the average number of members per family. For 2010, this information is read directly from the average number of members per family per AP from IBGE.

Once the agents and families are created, a process of allocation of individuals in each family is carried out. The generated agents are initially divided between adults (over 21 years old) and children. The first step seeks, insofar as agents are available, to allocate at least one adult to each family. The distribution seeks to maintain a similar number of adults per family, according to the number of adults and families in the region. Subsequently, in the same way, children are distributed among the existing families.

6.4 Residences

The number of homes created is always some percentage higher than the number of families, so there is always a number of empty homes (Nadalin and Igliori, 2016). This percentage is determined as a model parameter, suggesting values between 9% and 11% of the number of families. The residences created have a size between 20 m² and 120 m² and a quality level between 1 and 4. The two parameters are chosen uniformly.

The initial price of the residence is the product of its size, level of quality and the IDHM of the region in which the residence is located. As a result, throughout the *PolicySpace2*, the price composition depends on intrinsic characteristics of the residence (size and quality), but also on a location factor, which, as will be seen, varies as the model develops.

As for the address, in the municipalities where there are no subdivisions by APs, the location of the residences is chosen according to the proportion between urban and rural municipal, using the shapefiles of the IBGE for urbanized areas (2000 and 2010).[16] In these cases, given the probabilistic decision to locate in an urban or rural area, geographic coordinates that are contained in the corresponding urban or rural municipal polygons are selected. When the municipality has more than one AP, the location of the residence occurs in any location that is within the AP. Note that municipalities that contain more than one AP are more populous and contain APs with smaller territorial extensions.

A portion of the households created, determined by an exogenous parameter, is distributed linearly (one household per family on the list). The remaining portion is distributed randomly among all families. When the family receives a residence, it registers the property and, if it still doesn't have an address, it moves. In this way, some families may be left without a residence, while others may receive more than one. Families that at the end of the process remain without a property turn to the rental market. At the end of the process, all properties are registered in the name of a family.

6.5 Firms

The number of firms per APs is determined from the number of firms initially existing in the AP, according to data processed by Rais for 2000 and 2010. Additionally, a percentage of these firms, according to an exogenous parameter, is created as a construction firm, which will operate in the real estate construction market. In addition to the random location within the region, firms also receive an initial equity that follows a value taken from a beta distribution (with alpha parameter = 1.5 and beta = 10), multiplied by 10 thousand. The firms participate on the labor market, hiring and firing employees. The size and skill of their workforce determines the output that is sold on the goods market. Firms' locally conditioned decisions involve setting prices and wages and the timing of hiring and downsizing. Building firms additionally decide in which region to build new homes.

6.6 Banks

In this version, the *PolicySpace2* has only one bank that receives and remunerates customer deposits and makes loans. Its creation considers only an exogenous parameter, that is, the basic interest rate of the economy. Throughout the simulation, the series of the Central Bank related to the following indexes are used:

- the Broad National Consumer Price Index (IPCA) – series 433;

16. Available at: <https://bit.ly/3LyFJfC>.

- the average monthly interest rate on credit operations with earmarked resources (individuals, real estate financing at market rates) – series 25,497; and
- the interest rate (Selic accumulated in the month) – series 4,390.

7 ODD: SUBMODELS

This section describes in detail, substantiates and justifies sub-processes of the *PolicySpace2*, including the purpose and rationale of each sub-model, as well as the parameters and formulas. With this, we will detail the markets for goods, work and real estate, the rationality of firms, bank agents and real estate loans, in addition to demographic processes – mortality, fertility, immigration and marriage. Default parameter values are listed in the appendix of this book.

7.1 ODD: rationality of firms

The firms (i) participate in the labor market, hiring and firing workers (l), in the goods market, with sales to families (h) and, for construction-type firms, in the real estate market, producing and selling homes (H). The sequence involving the firms is:

- exogenous growth of new firms, according to observed population growth;
- the quantity produced varies according to the number of employees and their qualifications;
- when making sales, firms update balance sheet and monthly invoicing and pay consumption tax at the time of sale (details in the goods market);
- calculation and payment of salaries, proportional to qualification/productivity;
- payment of company tax and profit calculation;
- decision making on prices and adjustments;
- construction-type firms plan and build homes;
- decision making on activity on the labor market and participation; and
- participation in the real estate market for construction firms.

7.2 ODD: new firms

The positive number[17] of new firms is determined exogenously, maintaining the base of firms empirically observed in a given period (growth in the number of establishments between 2002 and 2012 for simulations starting in 2000 and

17. In this version of *PolicySpace2* no firms die. However, it may happen that there are firms that do not have employees and, therefore, do not generate new production.

between 2010 and 2017 for 2010 simulations). The new firms for each municipality will be located probabilistically in the most dynamic APs. Specifically, the firm is more likely to be located in APs whose average earnings and employees are also proportionately higher. Once the AP is chosen, the firm is created the same way as the firms created in the first month of the simulation.

7.3 ODD: production

When created, each firm (i) generates a product of its own. Although the simulation supports the creation of several products per firm, only one item is produced per firm. The firm's production (Q_i) is proportional to the qualification of each employee (q_l), raised to an alpha factor of exogenous productivity and adjusted by a beta premium.

$$Q_{i,t} = \sum_{l}^{L} \frac{q_l^{\alpha}}{\beta} . \quad (1)$$

Therefore, the quantity produced per firm ($Q_{i,t}$) is the sum, for all employees, of the years of study (qualification) adjusted by two productivity parameters, raised to alpha (α) and divided by beta (β).

7.4 ODD: decision making on prices – via inventory

The firm checks whether the quantity sold in the month is greater than the present inventory. If so, it increases the price by a percentage of mark-up (π) defined exogenously by the modeler. In this sense, it compares its reality (the production carried out) with the behavior of demand for decision-making whose order of magnitude is external. The frequency with which the firm checks whether prices change is determined by the parameter ζ.

7.5 ODD: decision making on salaries

The firms (i) decide the salaries ($\omega_{l,t}$)of each worker (l) according to total sales ($TR_{i,t}$) and current global unemployment (U_t) and weight it by the productivity of each worker (q_l^{α}), withholding the worker's tax at source (tax_l).

For construction firms, proceeds from the sale of real estate are accounted for over a period of 24 months (no), in order to maintain a more constant cash flow for salary payments, given the more concentrated sales and production.

$$\omega_{l,t} = TR_{i,t} * (1 - U_t) * \frac{q_l^{\alpha}}{\sum_l^L q^{\alpha}} * (1 - tax_l). \quad (2)$$

7.6 ODD: market for goods

Sales. Decision making on consumption and savings. Each family chooses the firm in which it will consume and the amount to be spent, deciding with equal probability ($P(.5)$) whether by price or by distance, given a sample of firms (ς). The amount of product purchased will depend on the price and the family's consumption decision. The goods and services are homogenous, and technology is fixed (Lengnick, 2013). Taxes on consumption are collected at the time of sale. The firm sells all the production requested by the family, up to the limit of its availability.

The decision of households between how much to allocate for immediate consumption and how much for savings is based on current macroeconomic modeling practice. Dawid and Gatti summarize the calculation of permanent income in this way ($PI_{h,t}$): "it is a linear function of current and expected future incomes and of financial wealth. (…) All income in excess of permanent income will be saved and added to financial wealth" (Dawid and Gatti, 2018, p. 78).

$$PI_{h,t} = i_t * \overline{Y_{h,t0-t}} + i_t * \frac{\overline{Y_{h,t0-t}}}{r_t} + w_t * r_t. \quad (3)$$

Using r_t for current interest (t), $i_t = r_t/(1 + r_t)$, $\overline{Y_{h,t0-t}}$ the average salary income of the family for all previous periods of the simulation and w_t is the family's asset wealth, including real estate and bank deposits.

7.7 ODD: real estate market

Every month of the simulation, the call to the real estate market takes place after all the previous sub-processes. The only process that takes place afterwards is the distribution of taxes and data collection. Market share is initially based on the selection of homes available for sale or rent and families interested in one or the other. On the supply side, housing availability is endogenous, with all vacant properties included in the market. On the demand side, there is an endogenous portion, generated from marriage and the formation of new families. Additionally, migrant families seek the market, and enter the simulation, based on the growth estimated by the IBGE annually. Finally, existing families are randomly chosen to participate in the market (σ), reflecting empirical statistics that suggest that, on average, about 6% of families move each year (Causa, Woloszko and Leite, 2019).

The rental market is defined by an exogenous portion of families and properties, given that the decision to buy or rent is difficult to rationalize, considering the uncertainties about future macroeconomic behavior (Malmendier and Steiny, 2017; Furtado and Souza, 2020). Households selected to participate in the market whose budget – including potential bank loans – does not contain sufficient funds to buy the cheapest property available on the market will participate only in the rental market. As a result, the real estate market starts with the construction of

four groups of agents: families looking for properties to buy or rent and vacant properties available for sale or rent.

In any case, the sale value of the properties is updated monthly (P_{ask}). The price is a direct result of the characteristics of the property ($H_{s,q}$) (size and quality) and its location ($N_{m,t}$). The location, in turn, is also updated monthly by the neighborhood's QLI (AP do IBGE) (m). The indicator depends on the taxes collected (tax_t) and passed on to the municipality, weighted by population variation ($\frac{pop_{m,t-1}}{pop_{m,t}}$) and by a linear magnitude adjustment parameter (ψ).

$$N_{m,t} += \sum_m tax_t * \psi * \frac{pop_{m,t-1}}{pop_{m,t}}. \quad (4)$$

Additionally, the price may (or may not) be discounted by the size of the global offer of properties (V) for sale at RM, depending on a decision parameter; and also by the proportion of family income in the neighborhood normalized between zero and one for the set of RM (τ) (Ge, 2017). Finally, the number of months the property has been for sale (T) can interfere with the price, limited in its fall (γ) and with adjusted intensity (κ).

$$P_{ask} = (1 + V) * H_{s,q} * N_{m,t} * (1 + \tau * N_q) * ((1 - \gamma) * e^{\kappa * T} + \gamma). \quad (5)$$

On the family side, the supply (P_{offer}) includes a home loan estimate (L_h) when savings are not enough. Families seek to buy the best property, equivalent to the most expensive (Goldstein, 2017). The final price (P) traded is the simple average of the asking and offer price.

$$P_{offer} = S_h \vee S_h + L_h \ if \ P_{ask} < P_{offer}$$

$$P = \frac{(P_{ask} + P_{offer})}{2} \quad (6)$$

The bank loan is limited by the factor *loan-to-value* (LTV), so that the ratio between the loan amount and the price of the property cannot exceed a certain proportion. Additionally, there is an upper limit (ρ^+) and a lower one (ρ^-) for the final price. When the selling price is above the total offer, but within the limits of the lower limit, there is a probability that the seller will accept the discount proportionally to the current vacancy in the market $P(\sum Listed / \sum h)$.

$$\frac{L_h}{P} \leq LTV$$

$$if \ \frac{P_{ask}}{P_{offer}} > \rho_+ \longrightarrow P = P_{offer} * \frac{\rho_+}{2}$$

$$if P_{ask} > S_h > \rho_- \longrightarrow P = S_h \mid P(\sum Listed / \sum h) \quad (7)$$

Box 1 presents the sequential listing of events that occur in the real estate market.

BOX 1
Real estate market: sequence of steps

1) Random selection of families interested in buying or renting. Families created through marriage and newly arrived immigrant families are added.

2) Inclusion of all unoccupied residences.

3) Updating of prices for all real estate (sales and rent).

4) Families interested in purchasing consult the bank for the possibility of potential loans. They check what their credit limit is, given the age of the oldest member, long-term family budget, and interest.

5) Entry into the real estate market takes place in order of purchasing power, with families with greater resources and access to credit choosing first.

6) Among the unoccupied households whose owners are families, and not builders, a percentage is selected[1] for the rental market. Therefore, the size of the housing supply for rent is exogenous. On the supply side, endogenously, those interested in rents are families without financial resources to purchase.

7) Next, families randomly choose a subsample of properties.[2] They order the properties in the group starting with the most expensive, which indicates the highest quality (Gilbert, Hawksworth, and Swinney, 2009; Goldstein, 2017), and check whether their savings, or savings plus credit, are enough to buy the home. If there are no properties in their group or if the bank does not provide the loan, and the existing savings are not enough to make the purchase, the family leaves the market.

8) The transaction price is the average of the household's savings and the calculated house price, limited to a higher proportion by an exogenous parameter. In this way, there is a match between supply and demand, with the seller correctly estimating the buyer's ability to pay, and the buyer performing an accurate analysis of the property's value.

9) In the event that the family's savings are less than the estimated selling price, the family can make an offer with a value lower than the seller's request. The probability that the seller will accept is equal to the size of the offer. Therefore, if there is a 10% vacancy for properties in a given month, there is a 10% chance that the seller will accept the offer.

10) Once the transaction is completed, the property transfer tax is collected; and the money transferred from the buying family to the seller or construction firm.

11) The purchasing family then has at least two residences and decides whether to move or not.

12) Families and residences for rent are sent to the rental market. The rental market also welcomes immigrant or newlywed families.

13) The family, in the rental market, is also looking for a subsample of real estate.[3] They randomly chooses a property whose rent value is compatible with their monthly expenses (through the calculation of permanent income).

14) If there are no properties in these conditions, the family will seek to negotiate a discount that may vary according to the size of the properties available. The lower the number of properties on offer, the lower the requested discount.

15) Once the property, family and price have been chosen, the family that already has a fixed residence (rented or owned) checks if the property to be rented is of better quality (more expensive), in relation to the current one. The family that is not allocated (immigrant or newly married) moves.

16) The rent payment is collected.

Author's elaboration.
Notes: [1] Parameter: *RENTAL_SHARE*: default value = 0.4.
[2] Parameter: *SIZE_MARKET*: default value = 10.
[3] The same parameter of the real estate market is used, *SIZE_MARKET*, multiplied by three, in order to guarantee a larger subsample in the rental market, since it is more competitive.

7.8 ODD: sales

In the case of sales, families looking for a property to buy are ordered, and those with greater financial resources – including possible bank loans – choose first. Each family then "visits" (assembles a group of possibilities) that is three times the number of firms that the family consults in the goods market. Typically, with the default values, the family initially examines thirty properties among those for sale; removes from the sample the properties that are more expensive than its ability to pay, with the possibility of borrowing; and then tries to buy the best property; that is, the most expensive (Goldstein, 2017).

When applying for a loan, the success of the transaction is dependent on credit approval by the bank. If the savings balance is sufficient, or if they get the loan, the family buys the property. The value of real estate financing (L_h) is at most a percentage (χ) of the permanent income of the family (PI_h) and the maximum between the number of months (m) until the oldest family member reaches 75 years of age or the loan reaches 360 months. If the loan is not granted by the bank, the family tries to purchase the second property on their list.

$$L_h = PI_h * \chi * m. \tag{8}$$

The property price is based, on the one hand, on the family's ability to pay and, on the other, on the calculated price of the property. The logic is that the seller estimates the maximum value the family has available, and the buyer makes the offer based on the calculated price of the property. The final price is established as the simple average of the two. If the previous step is met; that is, if the savings are greater than the estimated price of the property or if the savings plus the successful loan is greater than the price, then the transaction is signed. The property is transferred and registered to the purchasing family. Resources change hands and ITBI is paid for the region where the property is located.

Every time the family buys a property, it evaluates the possibility of moving to the new property. If the family does not have another residence, they will move to the property purchased. If they have another home, they will move to the lowest-priced property – thus reflecting its location, size and quality – if all adults in the family are unemployed. If at least one adult in the family is employed, the family will move to the property with the highest value.

The rental and sales market is described in the next subsection.

7.9 ODD: rent

As in the sales market, families looking for rent examine a sample of rental properties. The rental price is given by a fixed percentage of the property price, which is variable. The family initially seeks a property that is within their monthly payment possibilities, according to the calculation of their permanent income. If they

do not find one, they then make an offer for the cheapest property among those initially selected. The percentage reduction in the offer made is equivalent to the size of properties available on the market. If the standard maximum number of rental properties is available, this reduction is 0.03 percentage point (pp), or close to 10% of the standard index (0.29%) on the property price. If the list of available properties is restricted, this reduction request is smaller. Finally, after negotiation, in the case of new families (migrants, marriage), the contract is signed and the family moves. If the family already has a residence in the RM, it checks if the quality (price) of the new residence is better. Otherwise, it gives up the rental. In cases where families are unable to honor rent payments, landlords pay the loss. In any case, default numbers remain low throughout the simulation.

7.10 ODD: civil construction market

Construction firms are derived from the main entity firms, with some specific changes. There are two main methods: i) plan and operationalize construction of a new residence; and ii) and actually build one. The first planning stage is to choose the region for construction, according to those that have lots available. The lots (called in the simulation *licenses*) are offered by the city as new subdivisions and cost the index price of the region ($N_{m,t}$) times the percentage of the cost of the lot in relation to the cost of the project. Determining the size of the new household (H_s) and the quality (H_q) chosen are random. However, they impact cost, which is calculated as the product of size and quality, and the firm's productivity, which is a function of its profit margin $f(\pi)$. The builder, then, based on the planning of the house, chooses similar houses – that is, with a difference in size greater or less than ten and with greater or lesser quality than one – where lots are available. Then the average prices are calculated , limited to 100 households per region (APs) under analysis. The construction company chooses to build in the region (N) with the highest profit $N_{\pi,m,t}$.

$$N_{\pi,m,t} = \overline{P_{ask,m,t}} - \left(H_s * H_q * f(\pi) * N_{m,t} * (1 + v)\right). \quad (9)$$

The process of building the residence itself occurs through the accumulation of products that the traditional firm produces. When the amount of products accumulated is greater than or equal to the cost of construction, the firm makes the financial adjustment, registers the new property and makes it available for sale on the real estate market. The size of the offer (property vacancy V) makes up the prices at the time of negotiation.

7.11 ODD: banks and real estate financing

The financial system of *PolicySpace2* is simplified and aims only to remunerate households' deposits and provide resources for financing on the real estate market. A bank only controls the loan bureaucracy and household deposits. Firstly, during the simulated month, the bank collects the payments of the families' real estate financing; then, it opens up the possibility of credit for financing families in the real estate market; and, finally, it remunerates household investments.

The bank has restrictions that are observed when applying for loans to families to finance the purchase of real estate. The bank must have cash in excess of the loan application. In addition, it is necessary that the total of resources already made available to society does not exceed the percentage defined by the modeler (the mandatory regulation fit). Finally, the bank does not grant a new loan to families that have not completed the payment of previous transactions. Each family can therefore only have one active loan.

The maximum available credit can be consulted by the family and is obtained by calculating its permanent income, limited to the maximum percentage of indebtedness, given by an exogenous parameter. Additionally, the number of years converted into months is considered for the oldest member of the family to reach the maximum age. Finally, the amount possibly to be borrowed is defined by the maximum monthly commitment times the number of months until the monthly term, divided by the interest. Additionally, the loan is limited to a property price ratio, stipulated by the LTV parameter.

Interest on deposits is fixed, exogenously established, fixed at the time of the contract, according to the Central Bank series, and credited monthly. The cost of financing also follows the market value observed for individuals. The installments are charged from the deposits made by the customer and available in the account. If the resources are sufficient for the monthly payment owed, it is paid. Any overdue installments are accumulated and can be paid in subsequent periods, immediately after there is a balance.

7.12 ODD: demography – mortality, fertility, aging and inheritance

Three processes of the agents' life cycle – given their dynamics – are inserted in the *PolicySpace2*: mortality, fertility and aging.

Aging is operated directly. Given the birthday month that each agent receives in the act of creation (*sic*), when the current month is the birthday month, the agent's age is increased by one year. The birthday month is also used as the annual month of check-up of the agent, checking the official probability, according to the state mortality table by gender and calendar year, and the possibility of fertility. Women aged between 14 and 50 years are also evaluated in terms of

their likelihood of becoming pregnant, also in accordance with state fertility data, by age and calendar year. The birth process is like the initial agent creation process. The child is added to the parent's family.

When a death occurs, the death certificate is registered (the data are available in the list named *grave*). If the deceased agent is not the last member of the family, the real estate, savings and debt remain with the family. The agent is dropped from the firm's records if he or she worked. However, if the deceased agent is the last member of the family, the existence of relatives from the original family is verified, if the agent has married from the beginning of the simulation (2010).[18] In this case, an inventory is needed and a series of checks are carried out.

1) The residential property is vacant.
2) If the deceased agent owes a debt to the bank and relatives, the relative who receives the most expensive property also receives the debt. If there are still other relatives and properties, they are randomly distributed (given the immediate indivisibility of the property). If there is only debt, it is distributed randomly among the relatives.
3) The savings balance is withdrawn from the bank and distributed equally among relatives.

7.13 ODD: immigration

The immigration process takes place at the beginning of the monthly processes, right after the demographic check (aging, mortality, fertility) and before consumption and interaction in the markets. The main purpose of this sub-module is to keep the total population compatible with the growth levels observed in the metropolises over the period. Thus, for each year, the population equivalent each month to 1/12 of the migrants is created and added to the model. To this end, estimated municipal data for the 2001-2017 period are used. Missing data are estimated by a simple linear function.

The generation process is similar to the beginning of the simulation of the *PolicySpace2*. By municipalities, the new estimated agents are created and then allocated to families, in the same way as the initial generator module. The new families then go through the process of acquiring or renting properties. Unlike the initial moment, in which all families obtain a property, in the migratory process, respecting the logic that the creation of properties is endogenous to the model,

18. Note that, in this case, the model's genealogical record of relatives only operates for marriages from the start year of the simulation. It is not feasible to estimate previous family ties.

families that cannot obtain a property – due to lack of resources or lack of supply in the rental market – are not added to the simulation. When they obtain residency, new agents and families are registered in the model.

7.14 ODD: weddings

The possibility of marriage occurs shortly after immigration. The insertion of marriage into *PolicySpace2* brings dynamism to families. It is possible to create new families from single adults or with the separation of existing couples and the formation of new unions. This family dynamic affects the economic support of the model in several ways:

- first, the family is the financial decision-making collective, participating in the property and real estate markets together;
- the family is also the repository of wealth, both in terms of real estate held in the portfolio and in bank deposits; and
- additionally, family changes lead to the endogenous configuration of participation in the real estate market, since, when married, family members with other adults need to acquire or rent a new home.

The process starts exogenously, according to the parameter that determines the proportion of agents that will participate in the process. In the standard model, this initial proportion is 3.4% of people per month. From this contingent of people, a second probability check by age is applied. Finally, an additional constraint with truncation is considered, with zero probability of marriages for agents up to 20 years old. Gender restrictions are not considered. The selected people are shuffled and matched two by two. The following options are considered for each engaged pair.

1) If both original families have at least one other adult (age 21 or older), the new spouses leave the family and form a new family if they are successful in the real estate market.
2) If only one of the families has another adult, then the new spouse of the family that has an adult leaves the family and moves into the family with the other new spouse. In this sense, he or she leaves behind the family goods, but starts to share the goods of the new family.
3) If both families have no other adults, but possibly have children, then they merge into a new single family, with all the assets of the component families.

7.15 ODD: labor market

The labor market processes are the penultimate occurrence of the month, immediately preceding the real estate market. The first step is the offer of the agents, followed by the interest of the firms and the adjustment between candidates and companies. The choices of interested workers are weighted by their mobility and the salaries offered. Firms do not evaluate the labor market each month. They enter the job market following the exogenous frequency parameter (ι); of course, this can be adjusted to every month, for example. When in the market, firms participate as a contractor if they make a profit – or financial stability, zero profit. When there is a loss, they send an employee away, who is chosen at random.

The group of candidates comprises all those who are not retired (less than 70 years old), are not minors (over 16) and are not currently working. The list of job applicants is randomly shuffled every month. Job seekers evaluate the (endogenous) distances between home and business, their financial capacity and the consequent use of the public or private transport system and the salaries potentially offered in the ranking of offers.

Pairing. First, firms are randomly divided between the group that will seek candidates according to the qualification criterion and the group that emphasizes proximity. Group sizes are defined by an exogenous parameter (η) which can even be zero (all by qualification) or one (all by proximity). Firms in each group are ordered in descending order by the base wages offered, considering current unemployment in the standard model. In practice, this means that companies are ranked in terms of a percentage of their recent turnover. In addition, the higher overall employment is, the lower the percentage of firms' sales that will be predicted for payment of salaries. Firms with high revenues choose first.

Each firm then selects a random pool of candidates from among those who remain through the process without receiving an acceptance from any firm. The size of this group of interviews is exogenously determined (σ). The ranking of candidates involves an adjustment of the interests of the firm and of the candidate's interests. On the firm's side, qualification is included in the calculation; from the candidate's point of view, the potential salary of the firm ($w_{l,t}$) and the distance between their residence and the firm ($d_{l,h\,-\,i,t}$), weighted by the transport system available to the candidate ($c^{tr}_{l,t}$), given their previous income level. In practice, candidates with access to a private vehicle penalize distance more heavily, both for the monetary cost and the cost of travel time.

$$s_{l,i,t} = q_l + \sum_i w_{l,t} - d_{l,h-i,t} * c^{tr}_{l,t}. \tag{10}$$

In pairing only by proximity, qualification is not included in the calculation, and the choice of the firm is based on proximity, weighted by the transportation

system available to the candidate. According to the level of the last salary deciles (endogenous) and empirical data, the model uses the probabilities associated with the income deciles to identify workers with and without a private vehicle. The process is started again in the following month, creating new lists of firms and candidates and conducting pairing.

7.16 ODD: collection and distribution of taxes

The process of collecting and distributing taxes maintained the process described in Furtado (2018b; 2018c).[19] For each triggering event, five types of taxes are collected. They are: on household consumption (proxy for the Tax on Circulation of Goods and Services – ICMS); on wages paid to workers (*proxy* for the Individual Income Tax – IRPF); on corporate profits (proxy for the Corporate Income Tax – IRPJ); about the property (*proxy* for property tax – IPTU); and on the transfer of real estate (proxy for the ITBI). Once collected, taxes are redistributed at the end of the month according to two rules, established through the following parameters:

- presence or absence of the FPM, with a default value of presence; and
- maintenance of municipal budgets as they are or, alternatively, merging the municipal funds into a single budget within the scope of the RM (ACP), with the status quo used as the default value.

7.16.1 ODD: FPM

The first form of distribution occurs according to the FPM (*FPM_DISTRIBUTION* = *true*). The collection is given from a percentage (23.5%)[20] of taxes on workers' wages and firms' profits. Distribution among the municipalities of an RM follows the same proportionality seen in the real distribution of FPM.

7.16.2 ODD: merging municipal budgets

The second form of distribution follows the alternative proposal of merging the municipal budget and, consequently, its redistribution in an egalitarian way, weighted by the population, among the municipalities. The status quo, still, *ALTERNATIVE0* = *true*, keeps the municipalities independent, so that the municipal collection (municipal taxes and ICMS share) generates benefits only for the municipality where the companies are located, regardless of the workers' residence.

All funds collected and transferred to the municipal treasury are converted linearly through parameter ($N_{m,t}$) and become an increase or decrease in the municipal QLI,

19. In that simulation, the extreme cases of resources distributed exclusively locally or equitably were also tested.
20. This percentage follows the FPM legislation on IRPF and IRPJ. The percentage can be changed via the parameter *TAXES_STRUCTURE*, with the FPM key. There is no IPI in the model. The exogenous proportionality is observed annually until 2016. Thereafter, the values for 2016 are used.

according to the formula presented in equation 9. Note that the parameters only change the way in which the taxes collected are spatially distributed; they do not change the amount of resources. However, redistribution alone is sufficient to generate distinct and robust effects on macroeconomic indicators.

7.17 ODD: designing policy experiments

This subsection describes the mechanisms implemented to carry out the test of experimental design of public policies at the municipal level. The discussion and results of the analysis are contained in chapter 6. Based on endogenous tax resources collected in each municipality, according to the five tax types (IRPF, IRPJ, ICMS, ITBI, IPTU), the experiment consists of retaining a percentage, defined by a parameter (δ), and applying it into three separate policies. The applications are compared with the simulation for which there is no retention of resources and there is no policy enforcement, which is considered the standard case.

In the application of policy alternatives, an endogenous registry of families is prepared based on the list of families with the lowest permanent income ($PI_{h,t}$) to the exogenously determined quantile (θ). When the policy is applied, the families that were included in the registry during the last year and still reside in the same municipality are ranked according to the permanent income calculation, so that the poorest family will be the first to receive any policy aid.

Public policies at the municipal level are described below.

1) Baseline: in the standard case, there is no retention of resources, and the investment normally occurs to increase the municipal QLI.

2) Acquisition and distribution of real estate: in the experiment in which *POLICIES* has the value *buy*, the available resource is used to purchase municipal properties and transfer ownership to families. In this case, the properties that are ready and still available in the portfolio of construction companies and located in the municipality implementing the policy are selected. The properties are then ordered so that the cheapest available will be the first to be purchased by the municipal government. Families who own property are excluded from this policy, and only those who are tenants are eligible. With the families and properties ordered and the amount to be invested available, the municipality buys the properties and transfers them to the families successively, until the resources are exhausted. Recipient families move immediately. The ITBI that applies to the transaction is collected normally and transferred to the municipal coffers, which in practice configures a discount to the municipality in relation to the market price offered by the construction company.

3) *Vouchers* for rent payment: in the experiment in which *POLICIES* is designated as *rent*, in the same manner, only families that do not have their own property are eligible. In this case, again, as long as available resources last, the municipality distributes vouchers that guarantee the payment of the rent of the current residence of the families for the next 24 months. If the family moves to another property, the amount related to the remaining payments, if any, is reverted to the same fund and will benefit other families. The voucher is also only provided once every two years to the same family. However, if the family is added to the registry again at the end of the period, it may possibly receive the aid again.

4) Monetary aid. The third experiment is selected when *POLICIES* is set to *wage*. In this case, the entire available monthly resource is distributed equally among the families of each municipal registry as pecuniary aid. Families remain on the register for a period of one year. In this case, there is no requirement for the absence of own property. That is; if the family's income is below the income quantile, as determined by the policy, it will be included in the register and receive the monthly aid from available resources, divided by the number of families qualified in that month.

8 OPERATIONALIZATION OF SIMULATION

The model simulation *PolicySpace2* requires the installation of the free and open-source program Python[21] and several of its libraries.[22]

The default simulation uses Python version 3.6, but we also simulated it in versions 3.7 and 3.8. Geographic libraries (*gdal*, *fiona*, *shapely and geopandas*) are not immediately installable, so we suggest installing via the Python library aggregator called Conda.[23] Our Conda version was 4.8.4. We also use, throughout production and testing, the educational license interface *PyCharm Professional*, made available by *JetBrains*. The simulation was performed concurrently and interchangeably on computers with Windows and Linux operating systems. We also suggest the creation of a specific environment for the simulation, in order to avoid conflicts between library versions. Use the following sequence of commands in the terminal (with Conda installed) to create, activate the environment and install the following libraries:

```
conda create --name ps2 python=3.6
conda activate ps2
```

21. Available at: <https://bit.ly/3wN29Eu>.
22. To access the complete list, see the GitHub repository. Available at: <https://bit.ly/3PEHhZ1>.
23. Available at: <https://bit.ly/3wCMybM>.

```
conda install shapely gdal -c conda-forge
conda install fiona pandas geopandas numba
descartes scipy seaborn pyproj matplotlib six
cycler statsmodels joblib scikit-learn flask
flask-wtf psutil -c conda-forge
```

With this, the modeler will have created an environment, activated the environment and installed the main libraries together, ensuring the compatibility of versions between them.

To run the simulation itself, it is necessary to clone the repository on GitHub, which can also be done in a computer terminal, with the Git program installed, using the command *git clone*.[24]

Next, set at least the option *output_path* of the file *conf/run.py*, in order to choose where to write the model's table and graph output. Other changes can be made in the parameters module, in the file *conf/params.py*.

The *PolicySpace2* contains automated execution of several parallel simulations, using more than one core from the computer. All commands accept the -n 3 parameters to specify the number of times – for example, three – that the simulation will be run, presenting individual results and the averages. Additionally, you can specify -c 4, to identify the number of *cores of* the computer that will be used simultaneously. Thus, the simplest command for a simulation is *run*:

```
python main.py run
```

To run a simulation with a given set of parameters ten times, using two computer cores, use the command:

```
python main.py -c 2 -n 10 run
```

The sensitivity analysis, also built into the simulation, requests that for each continuous parameter, the modeler inform, in the following order, separated by a colon: parameter name: minimum parameter value: maximum parameter value and number of intervals between the minimum and maximum. As a result:

```
python main.py sensitivity ALPHA:0:1:7
```

In the case of parameters of the true or false type, just the parameter name is enough, for example:

```
python main.py sensitivity WAGE_IGNORE_
UNEMPLOYMENT
```

24. Available at: <https://bit.ly/3sU1sZc>.

Especially in the case of comparison between RMs, it is enough for the modeler to include the names of the regions of interest, separated by a hyphen and enclosed in double quotes, as in the following example:

```
python main.py sensitivity "PROCESSING_ACPS-
BRASILIA-CAMPINAS-FORTALEZA-BELO HORIZONTE"
```

It is also possible to combine continuous, Boolean parameters or RM names, as long as the parameters are separated by spaces:

```
python main.py -n 4 -c 12 sensitivity
MARKUP:0.05:0.15:4 WAGE_IGNORE_UNEMPLOYMENT
"PROCESSING_ACPS-BRASILIA-VITORIA"
```

CHAPTER 4

VALIDATION, EVALUATION AND INITIAL RESULTS

1 TRACE APPLICATION

This description of *PolicySpace2* tries to get as close as possible to the proposal for validation and evaluation of simulation models encapsulated in the Transparent and Comprehensive Model Evaludation (TRACE) proposal, "which provides supporting evidence that our model was thoughtfully designed, correctly implemented, thoroughly tested, well understood, and appropriately used for its intended purpose" (Grimm et al., 2014, p. 131).

It can be said that the TRACE proposal would be a simulation analysis step that evolves from the analysis-validation-results triad to a fusion of the terms "evaluation" and "validation" in order to describe and evaluate the complete process of modeling and, therefore, better assess the quality and credibility of the model (Augusiak, Brink and Grimm, 2014; Grimm et al., 2014; Schmolke et al., 2010).

Thus, we will see the principles on which the TRACE proposal is based, incorporated into the description of *PolicySpace2*.

1.1 Problem formulation

Explanation of the decision-making context in which the model will be used. This was done in the section *TRACE – formulation of the problem*, from chapter 3.

1.2 Description of the model

As recommended by TRACE, the description of the *PolicySpace2* follows the protocol Overview, Design Concepts and Details (ODD) and is made throughout chapter 3.

1.3 Evaluation of data and parameters

This item evaluates the quality of the data used to parameterize the model and the standards used to calibrate the model. Agent input and generation data are all from official databases. Calibration of the model, conducted in order to obtain reasonable macroeconomic indicators, as well as a distribution of prices in the real estate market similar to those observed, was done endogenously – that is, observing the model results themselves to assess their insertion

in the original purpose. The decision on the parameters followed data from the literature, when known. For those parameters that are difficult to actually identify, exhaustive sections of sensitivity analysis were carried out, whose comments on the results follow in chapter 5. The ODD protocol, in turn, suggests that the parameters be described in each sub-module. Thus, we explain the parameters in the corresponding sub-modules, together with the formulas that include them. Their values are in the appendix. Additional parameters are present in the *PolicySpace2* and their logic, as follows.

1) The five parameters that work as *proxy* of the main taxes are also approximate, average parameters, estimated in the literature (Afonso, 2014): on consumption, 30% of the Tax on the Circulation of Goods and Services (ICMS); 15% of the Individual Income Tax (IRPF) and Corporate Income Tax (IRPJ) on work and on corporate profits; on real estate transactions, the Property Transfer Tax (ITBI); and on property, the Urban Property and Territorial Tax (IPTU), 0.5%. Respectively: *TAX_CONSUMPTION*, *TAX_LABOR*, *TAX_FIRM*, *TAX_ESTATE_TRANSACTION*, *TAX_PROPERTY*.

2) Bank conditions regarding the possibility of financing were also used according to data observed for the Brazilian case: *MAX_LOAN_AGE*, maximum age of the oldest borrower at the end of the financing term (75 years); *MAX_LOAN_BANK_PERCENT* (ν), maximum rate of bank loans in relation to demand deposits (70%); *LOAN_PAYMENT_TO_PERMANENT_INCOME*, commitment to pay monthly family installments in relation to their permanent income (50%); and *MAX_LOAN_TO_VALUE* (LTV), referring to the maximum loan amount in relation to the price of the financed property (30%).

3) *PERCENTAGE_ENTERING_ESTATE_MARKET* (ϕ), frequency of family participation in the real estate market – approximately 6% of families move each year (Causa, Woloszko and Leite, 2019).

4) Overpricing of firms *MARKUP* (π), that seek a rate of profit after costs of 5%. These empirical values usually go up to 15%, although neoclassical theory predicts zero profits. This parameter is also examined in the sensitivity analysis.

5) Samples for groups of job applicants, home search and number of firms surveyed in the property market. These parameters generate results that are robust in relation to variances. *HIRING_ SAMPLE_SIZE* (σ) and *SIZE_MARKET* (ς).

6) An important parameter for the model is the conversion of resources collected by the municipality to change the quality of life indicator

MUNICIPAL_EFFICIENCY_MANAGEMENT (ψ). This parameter has been calibrated so that the indicator follows as *proxy* of the Municipal Human Development Index (IDHM). Its initial value in 2010 is equal to that of the indicator and evolves to be close to unity at the end of the period.

7) Perhaps the most relevant set of parameters of the model, which is at the same time difficult to identify, although with interesting interpretation content, is the duo of productivity parameters – *PRODUCTIVITY_EXPONENT* (α), *PRODUCTIVITY_ MAGNITUDE_DIVISOR* (β). Together – the first as an exponent, the second as a divisor, this determines the quantity produced by the sum of the qualifications of the workers of the firms. Their values were endogenously determined by model calibration. Although they do not have an equivalent that we know of, they serve to indicate what happens in the economy and to what extent, when there is a relative increase or decrease in the productivity of workers. They are exhaustively worked on in the sensitivity analysis.

8) Two other parameters, with much less influence on the model, but with a difficult empirical counterpart and that reflect behavioral observations recorded in the literature (Blinder, 1994), are those referring to the frequency with which the firm participates in the labor market and reflects changes in the prices (*LABOR_MARKET* – ι).

9) Five other parameters explicitly refer to the presence, absence or magnitude of implementation of rules and mechanisms. They are: the percentage of firms that include proximity as a method of choice for ranking candidates (*PCT_DISTANCE_HIRING* – η), parameter that can be set to 0; the presence or absence of the municipal resource distribution rule using the FPM rule (*FPM_DISTRIBUTION*); the distribution of municipal resources according to the current municipal division, or as if the metropolitan region behaved as a single municipality (*ALTERNATIVE*); the presence or absence of the influence of global unemployment on wage decisions (*WAGE_IGNORE_UNEMPLOYMENT*); and the influence of the size of the real estate supply on the price calculation (*OFFER_SIZE_ON_PRICE*).

10) Neighborhood effect (*NEIGHBORHOOD_EFFECT* – τ): the influence of the average income of neighborhood families on property prices has already been estimated at around two-thirds of the total (Furtado, 2009).

11) Initial parameters: various parameters of the *PolicySpace2* are effective only in the initial month of the simulation and derive from empirical observations. Then they are replaced by endogenous interactions. In particular: initial percentage of families who rent (*RENTAL_SHARE*);

size of the surplus offer of real estate, vacancy (*HOUSE_VACANCY*); and proportion of the price of the property as a basis for the cost of rent (*INITIAL_RENTAL_PRICE*).

12) Property vacancy time: these two parameters – maximum discount (*MAX_OFFER_DISCOUNT* – γ) and speed of discount increase (*ON_MARKET_DECAY_FACTOR* – κ) – associate the time the property remains unoccupied as an influence on the depreciation of the estimated sale price. It has also been tested with various values and has little influence on the results.

13) Real estate negotiation process: these two parameters – *CAPPED_TOP_VALUE* (ρ+) and *CAPPED_LOW_VALUE* (ρ–) – limit the volatility of the negotiation process, excluding possibilities in which the family savings are twice the estimated price, for example, and the seller manages to impose a price higher (or lower) than the established limits.

14) Transport cost: two parameters weight the transport cost as a criterion for ranking firms that offer vacancies by the candidate (*PRIVATE_TRANSIT_COST* and *PUBLIC_TRANSIT_COST*). The candidate himself calculates the indicator considering the distances to the firms and the probability that he or she owns or does not own a private vehicle.

15) Land cost: it is the percentage of the construction cost passed on to the municipal government as a form of return for the purchase of land (*LOT_COST* – υ). There is no precise estimate of the ratio between the cost of land and the cost of the property, which may even vary in different trajectories. As a rule of thumb, the most common indicator is between 10% and 25% of the property price (Bostic, Longhofer, and Redfearn, 2007).

16) Deadline for payment of funds from real estate sales in the payment of salaries (*CONSTRUCTION_ACC_CASH_FLOW* – n): given that the volume of funds from real estate sales is substantial, the cash flow of companies and households needs to be organized in such a way that the inflow of capital is not used immediately in the following month, as was the case in the *PolicySpace* (Furtado, 2018c). So, in *PolicySpace2*, families can deposit financial resources that exceed their permanent income plus their emergency reserve (six months); construction firms, in turn, when selling properties from their portfolio, distribute the resources among their employees (n) over a number of months.

1.4 Conceptual evaluation of the model

The concept of the *PolicySpace2* is additively designed from the understanding of how the literature characterizes the real estate market. Based on traditional models that are very abstract (Dipasquale and Wheaton, 1994), or from the understanding that their empirical results are insufficient (Glaeser and Nathanson, 2017), foundations were sought in the literature so that the processes, as a whole, were similar to those observed. The negotiation process in the real estate market, in particular, built on the junction of household savings and the calculated hedonic price of properties (Rosen, 1974), with parametric and spatial limits (Furtado, 2009), seems to be sufficiently grounded. Furthermore, endogenous wage-generating processes are grounded in worker productivity, as modeled by previous work (Gaffeo et al., 2008; Lengnick, 2013), and follow patterns already established in the literature (Dawid and Gatti, 2018) and described according to best practices (Augusiak, Brink and Grimm, 2014; Grimm et al., 2020).

1.5 Verification of model results

The model results and their comparison with real data are done in sections 4 and 5 of this chapter. Additionally, TRACE recommends that the extent to which results are generated from environmental data or model inputs be made explicit. In the case of the real estate market in *PolicySpace2*, there is no information regarding properties introduced as input data in the model. The information refers only to companies, agents and families, the spatial configuration and demographic processes of change over the period. At the municipal level, the HDI indicator is used as a reference for the Quality of Life Index (QLI) in 2010, for each municipality in the metropolitan region under analysis.

1.6 Model analysis

The sensitivity analysis that seeks to verify the robustness of the simulation to variations in parameters is carried out in chapter 5, precisely because it makes it possible, at the same time, to verify the relevance of certain parameters on the simulation, but also to understand possible consequences of the model to exogenous shocks. If the default configuration manages to minimally replicate the phenomenon in question, then changes in parameters – for example, worker productivity or the relevance given to the impact of neighborhood on prices – can illuminate aspects of public policy.

1.7 Corroboration of model results

This TRACE item verifies whether data and patterns that were not used, and perhaps not even known at the time of the model's conception and development, corroborate the results. For the case of *PolicySpace2*, we used property data collected mostly during the first half of 2020, when much of the model was already developed.

Furthermore, as mentioned in the previous item, the simulation does not use real estate data. That said, it is worth clarifying that the descriptive analysis of the real data raised relevant aspects of understanding the mechanisms, especially highlighting elements that are not present in the model. In the case of the metropolitan region of the Federal District, which is used in the standard case of comparison between real and simulated data, there are neighborhoods with extremely high prices, but do not present sufficient factual elements (amenities, proximity, infrastructure) to justify their prices other than the launch of a "new luxury neighborhood," with prices higher than all other neighborhoods in the capital. The real data also highlighted the importance of keeping the property still on the market, until the purchase proposals (that is, the families' savings in the *PolicySpace2*) were compatible with the price estimated by the seller.

These observations, together with previously developed material that specifically points to the attractiveness of the neighborhood through its perception and its influence on prices (Furtado, 2009; Galster, 2001), led to the incorporation of the average household income in the process of composition of the seller's price in the model. Also introduced in the model, after evaluating the real data, was the price depreciation factor according to the time it remains on offer in the market. In any case, both these implementations can be "turned off" from the model by setting the parameters to zero.

2 VERIFICATION AND TESTING

Computer programs are always subject to errors and executions and may not work exactly the way the modeler imagined (Galán et al., 2009). *PolicySpace2* it is no different, and it is possible that some implementation will run differently than imagined. Some procedures were implemented to ensure that inconsistencies and implementation errors were minimized or non-existent.

1) A simulation with all parameters and save options listed as true generates 63 different graphs and the corresponding worksheets with monthly details and states for each agent. With this, the modeler can observe indicators on the behavior of families, banks, firms, regions and markets that provide a very accurate drawing of the evolution of processes over the analyzed period.

2) The sensitivity analysis performed in an automated way and already built into the programming allows testing situations in which some rules and certain mechanisms are absent and checking whether the generated graphs confirm their absence or presence. For example, the resource distribution parameter (*FPM_DISTRIBUTION*), when chosen as false, generates graphs with null distribution of resources in this modality, as expected. The same occurs with regard to the number of families awarded equal to zero, when the policy distribution factor is turned off.

3) At various times during the execution of the simulation program, commands of the type assert conduct verification during processing, thereby ensuring that families do not remain without an address or that properties always have owners.

4) A few specific tests were also added, such as verifying whether construction firms increased the supply of real estate; whether the bank effectively lends resources to families; and whether there are any families without an address.

5) Perhaps the most rigorous verification is exactly the process of describing, simulating and analyzing the results. For the description, each process of the code itself was revisited, checked and tested. For the results, the graphs and possible parameter combinations were exhaustively simulated.

6) Finally, a specific check was made for the flows of resources between the agents in order to guarantee that there was no "creation" of resources throughout the processes and the model could be fitted as consistent cash flow. In other words, there is no creation of resources beyond the initial amount in the generation of agents. Specifically, the construction of resources takes place through the productivity of workers in firms. The bank only operates with funds deposited by the families themselves, in addition to the initial capital. Markets also only operate based on the payment availabilities of firms or households. Underlying pricing decision processes may vary – for example, in transformation of municipal resources in the alteration of the quality of life indicator or in the markup decision of the firm – but prices are only actually determined according to the existence of resources.

3 CHARACTERIZATION OF EMPIRICAL DATA FOR VALIDATION

PolicySpace2 will seek validation through the comparison of empirical data on prices and characteristics of properties for the Areas of Concentration of Population (ACPs) of Brasília, with the Federal District included and the adjacent municipalities in the area. Rental and sales data were collected from websites between October 2018 and June 2020, on 41 different dates, more regularly from March 2020 onwards. The information is filled in by individual users and realtors and made

available without a rigidly structured format, so there may be inaccuracies and possible errors in the data record. Thus, the base was simplified, excluding extreme values (quantiles above and below 0.05) and observations without data for floor area, for example. Details were sought – when available – referring to: i) address; ii) district; iii) day of the offer of the property and day of collection of information; iv) condominium expenses; v) floor area; vi) number of bathrooms; vii) number of rooms; viii) number of vacancies; and ix) latitude and longitude. Additionally, for those properties with addresses and without georeferenced information, the Galileo ©ESRI System, available at Ipea, was used to add latitude and longitude, when the described address so allows.

The comparative empirical database has the following median characteristics: the typical property for rent in the region of Brasília and surroundings in the first half of 2020, based on the median of data from 8,840 offers, is priced at R$ 2,500.00 – floor space of 115 m^2, two bathrooms, three bedrooms, two parking spaces, condominium fees/Property Tax (IPTU) of R$ 638. It has been announced for nineteen days and has a cost per square meter of R$ 20.24 in 66 different neighborhoods.

The typical property for sale, in turn, based on 23,103 observations, in 61 different neighborhoods, is on offer for R$ 750 thousand. It has a floor area of 126 m^2, three bedrooms and three bathrooms, with two parking spaces. The selling price per median square meter is R$ 6,011.

4 RESULTS: MACROECONOMIC INDICATORS

In this section, we return to the specific purpose of the model and verify that the results achieved are compatible and adequate. The initial purpose was summarized as follows: "[*PolicySpace2* seeks] to verify whether the behavior of the model's economic indicators remains within reasonable margins, while the real estate market also performs similarly to the observed real market". In chapter 5 we use results from the *PolicySpace2* to illustrate its capacity as a descriptive model, which allows for analogies and serves as a basis for reasoning about the real estate market in an endogenously integrated way with the rest of the economic system, and in chapter 6 we carry out the housing policy test.

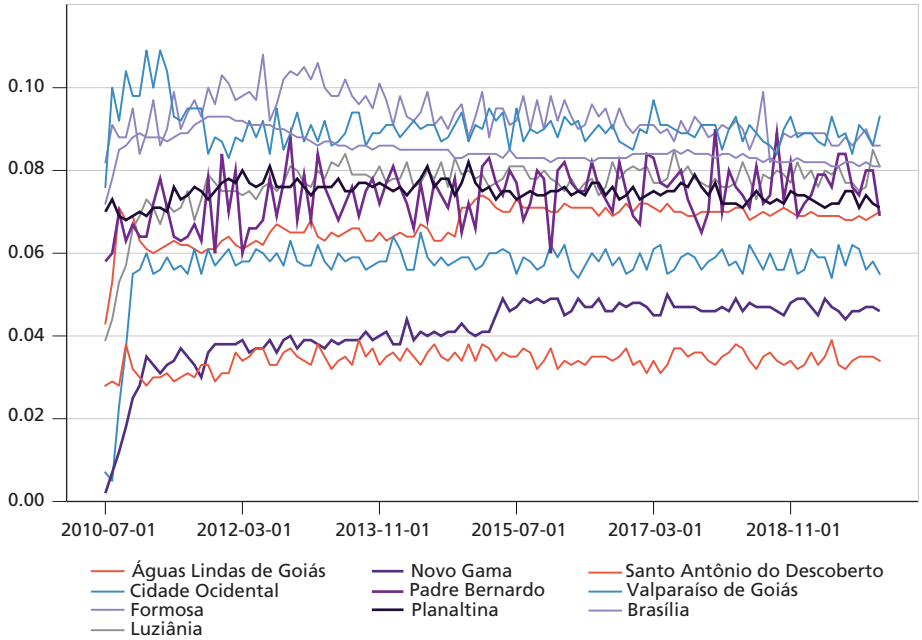
Considered the standard simulation, for the case of the Federal District, with parameters established according to their value described in the appendix of this book – and standard formatting on the GitHub platform[1] – we have general macroeconomic indicators, as follows.[2]

1. Available at: <https://bit.ly/3yOuz3I>.

2. The results were simulated twenty times, and the average of the results is shown. For some figures (which include regional data – figure 1 –, for example), only the result of a simulation is presented (although the general trend is verified. Parameter variations are also presented against twenty simulations of each parameter value. By default, we excluded the first six months of the simulation from the results.

1) The period's gross domestic product (GDP) rises a little at the beginning of the simulation and then remains with regular variations (figure 1). Volatility is reduced after the initial period, varying by 1 or 2 percentage points (pp) around zero. Non-linear endogenous variation is observed in the curves. There is variability among municipal behaviors.

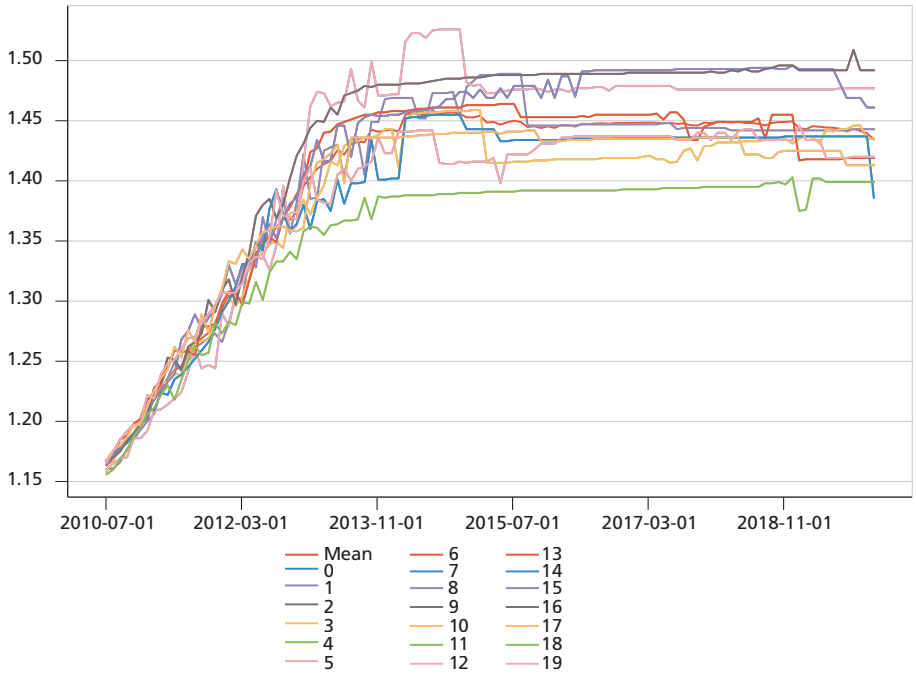
FIGURE 1
ACPs of Brasília: evolution of GDP by municipalities (2010-2020)



Author's elaboration.

2) Prices grew by around 40% in the period, with higher inflation volatility in the first three years of the simulation, which then remained with a lower variation (figure 2).

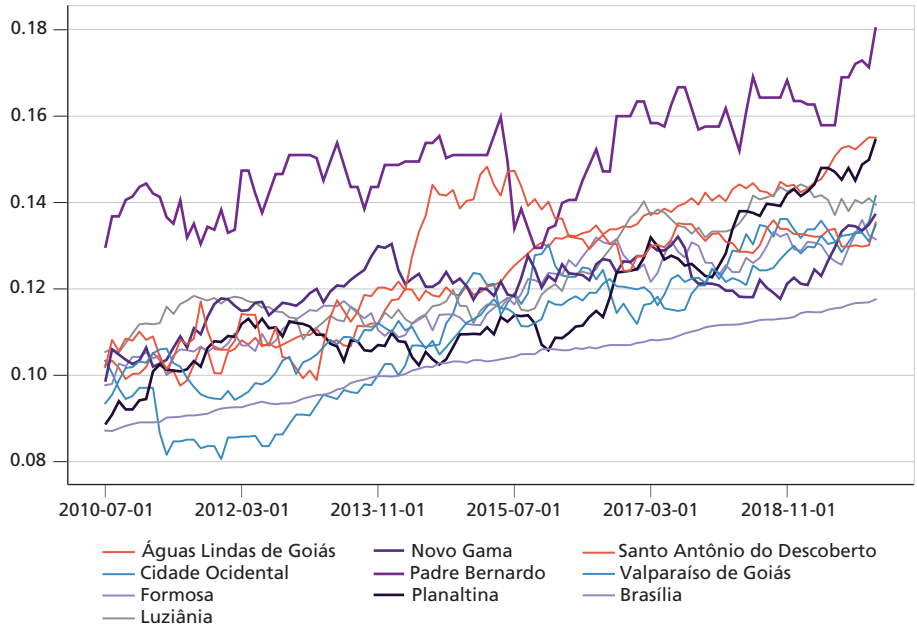
FIGURE 2
ACPs of Brasília: average price level (2010) = 1.00, twenty simulations (2010-2020)



Author's elaboration.

3) Unemployment, in the case of Brasília, and the standard configuration of parameters show a continuous increase, rising from approximately 8% at the beginning of the period to 11% at the end (figure 3). As expected, there is greater volatility and unemployment at higher levels for the surrounding municipalities, with Padre Bernardo, in Goiás, reaching the highest level of unemployment, in the range of 16%. Unemployment is not necessarily increasing but is within the range of up to 15% for other metropolitan regions tested with the same set of parameters.

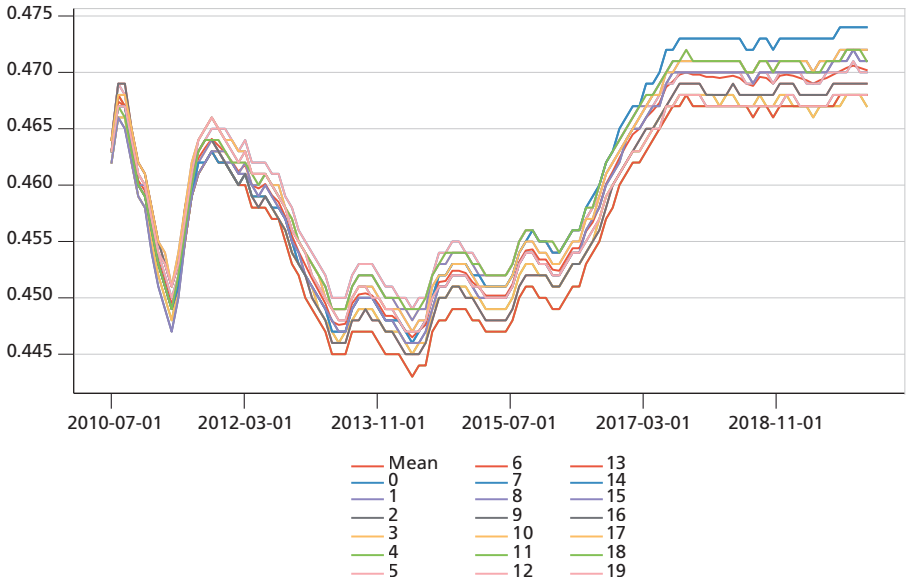
FIGURE 3
ACPs of Brasília: evolution of regional unemployment (2010-2020)



Author's elaboration.

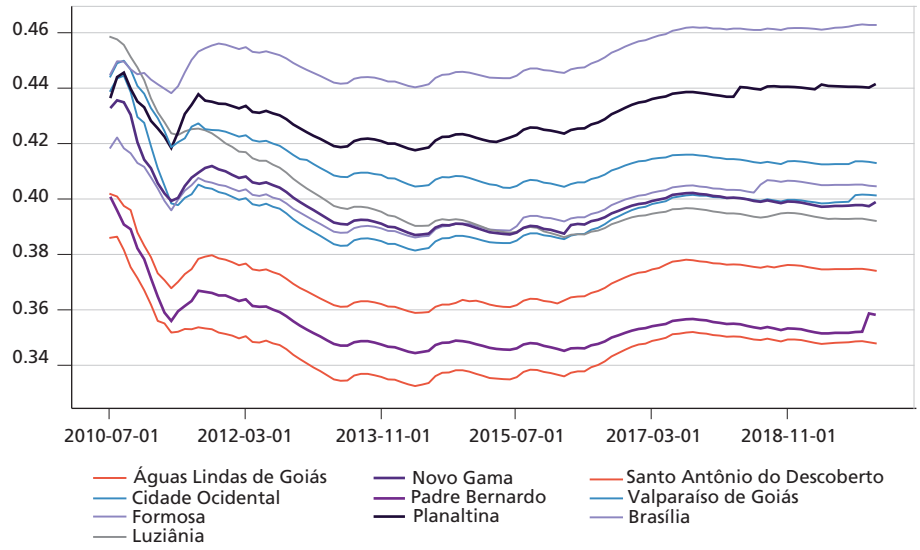
4) The Gini coefficient varies throughout the simulation, reaching an average of 0.47 at the end of the period (figure 4). However, to calculate the municipal Gini, we have Brasília with a value close to 0.46 and the surrounding municipalities with lower values, more homogeneous throughout the simulation, with values between 0.34 and 0.46 (figure 5). In fact, poorer regions, such as the surroundings of the Federal District, tend to be more homogeneous than the municipal seats and metropolitan regions as a whole.

FIGURE 4
ACPs of Brasília: evolution of the Gini coefficient (2010-2020)



Author's elaboration.

FIGURE 5
ACPs of Brasília: evolution of the Gini coefficient for the municipalities (2010-2020)



Author's elaboration.

These four indicators, taken together, seem to present behaviors and levels close to what should be expected from an economy like the Brazilian one, in the context of the metropolitan region of the Federal District and surroundings, characterizing *PolicySpace2* as a simulation that manages to present general macroeconomic indicators within reasonable parameters.

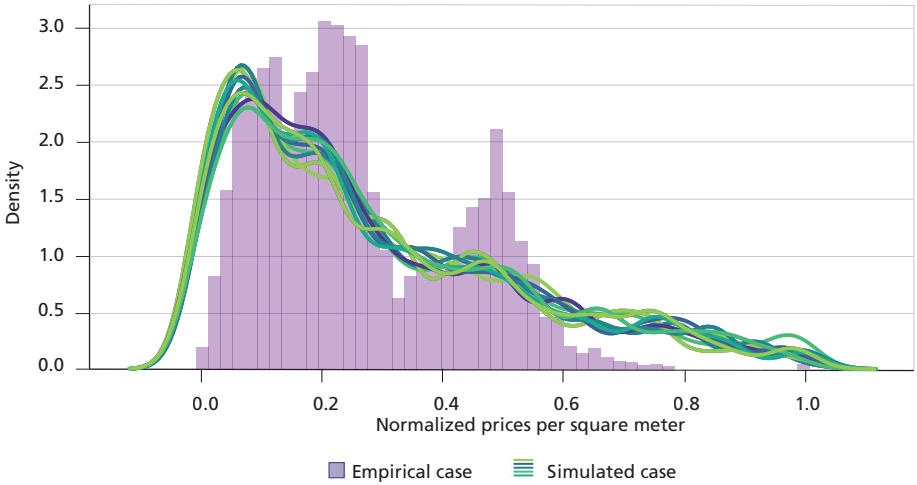
Additionally, other simulation indicators that characterize the economy can be summarized in this way. Regarding the behavior of banks, there is a regular and continuous increase in the loan base, with an increase in average maturities; and increase in deposit levels, starting in the second year of the simulation, with the number of customers in arrears at relatively high levels. The value of loans remains at constant levels. Among construction firms, just over half of them see an increase in the number of employees of around 20%, while the rest show stability or a less pronounced increase in personnel. Household savings increase throughout the simulation, with variation in permanent income, in line with the observed interest rate fluctuation. On average, household consumption increases in the first three years, then drops a little and remains unchanged. Firms have reduced their initial capital, with some volatility and a certain increase in the last two years. Profits are highly volatile, although they remain, in most months, in positive territory. Finally, it should be noted, as detailed in the following section, that *PolicySpace2* replicates some basic mechanisms expected of the economy, as illustrated in the introduction. Increased productivity generates, for example, lower prices, while the reduction in the number of firms consulted in decision-making by families leads to increased prices.

5 RESULTS: REAL ESTATE MARKET

The comparison of real and simulated data for the real estate market for buying and selling real estate is done through the histograms of normalized prices per square meter.

The histogram suggests that the actual data collected for the Federal District include two peaks of price concentration – the first and highest in the cheapest values and another peak in the average values, with few properties among the most expensive (figure 6). The prices for the simulated data also peak at the cheapest values but are more evenly distributed than the real data for the more expensive properties.

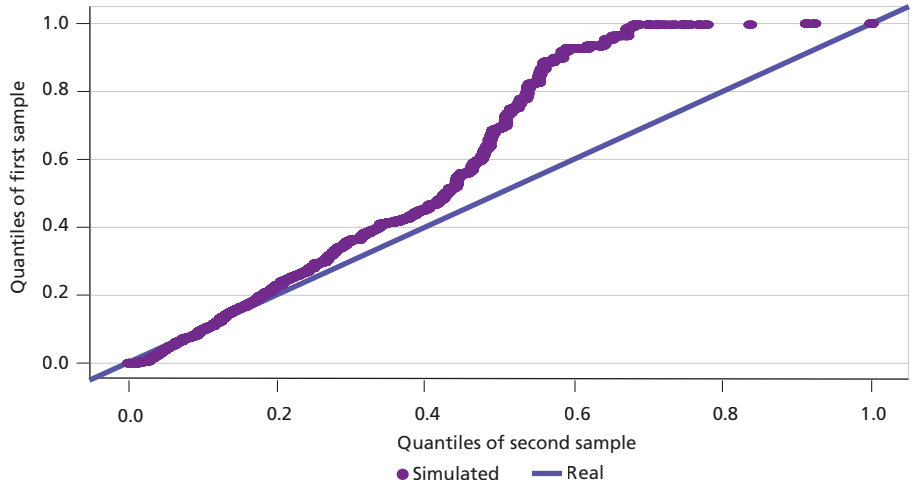
FIGURE 6
Brasília: comparative histograms of real estate prices for the empirical case and the simulated case (2010-2020)



Author's elaboration.

This behavior is most explicit on the quantile-quantile (QQ) plot, a probability plot used to compare two distributions, plotting the quantile of one distribution against the quantile of another. In fact, the behavior remains similar until just before the 0.5 quantile, when there is a shift in the curve of simulated data with a greater presence of more expensive properties than those in the real database (figure 7).

FIGURE 7
Brasília: QQ chart for empirical and simulated data (2010-2020)

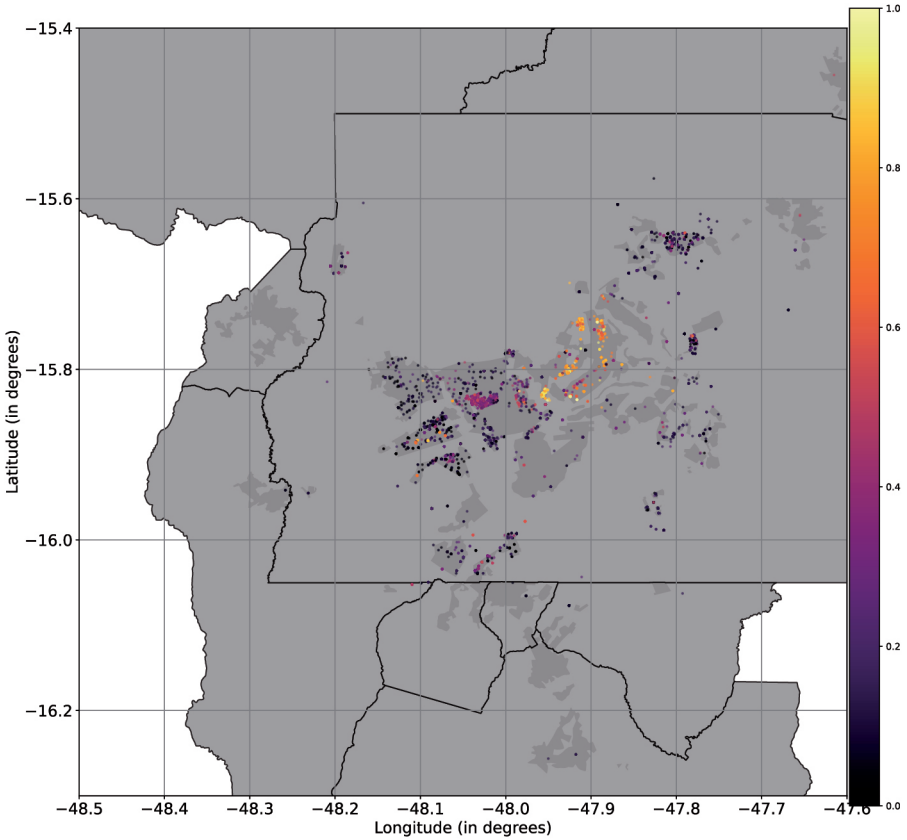


Author's elaboration.

Finally, the spatial analysis of property distribution shows that the real data for the Federal District are located in regions where there are not necessarily firms offering jobs or access to commerce. Preferably, exclusively horizontal single-family residential areas (such as the Lago Sul and Lago Norte regions) or vertical multi-family residential areas (figure 8).

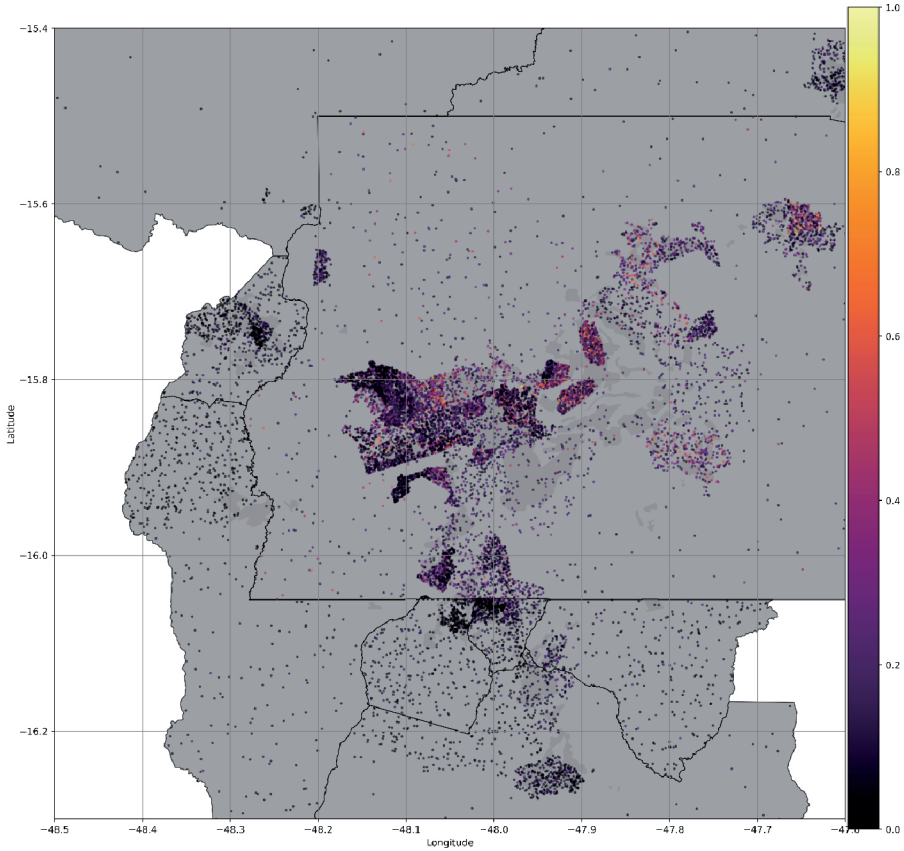
The simulated data, in turn, favor regions of the Federal District that concentrate population, jobs and firms, notably the most southwestern portion of the territory, and are more homogeneously distributed, both in urban and rural areas (figure 9).

FIGURE 8
Distribution of empirical real estate sales data, normalized, cost per square meter (2020)



Author's elaboration.

FIGURE 9
Distribution of real estate data from the simulation, normalized, prices per square meter, values for the last month of the simulation (2010-2020)

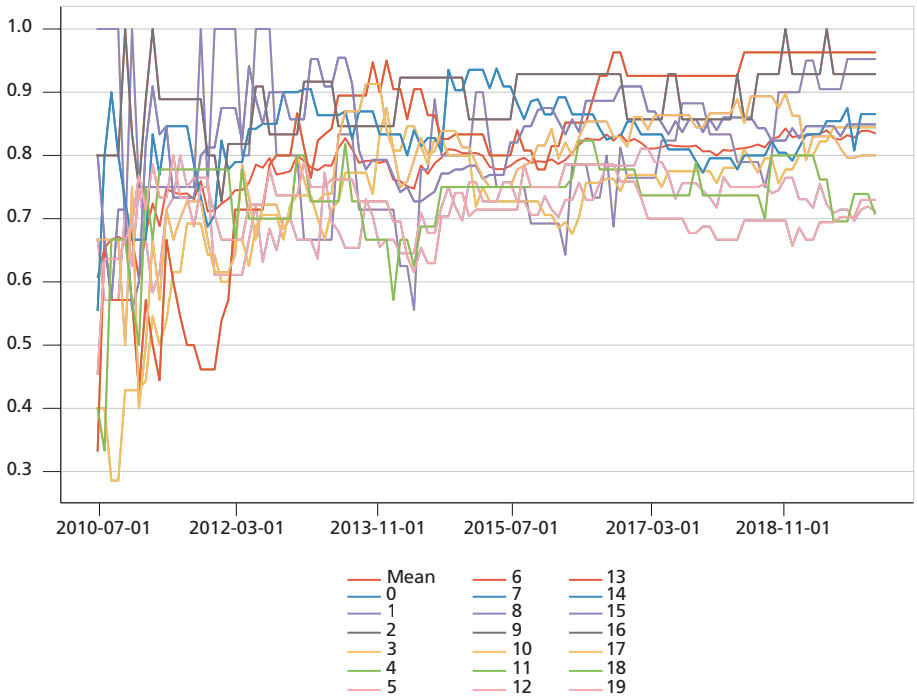


Author's elaboration.

6 DIVERGENT BEHAVIORS

Three behaviors of *PolicySpace2* seem to differ from results compatible with the expected. Two of them refer to the inadequacy of families' salaries to cover their obligations. In the first case, a percentage of high-level families (80%) apply for loans from the bank but are unable to keep their payments up to date (figure 10). Note that the simulation uses real interest on real estate financing for a population that is representative in terms of inequality of the Brazilian reality. Our hypothesis is that this result demonstrates what would happen if all families, indiscriminately and without bias, requested real estate loans from the financial agent.

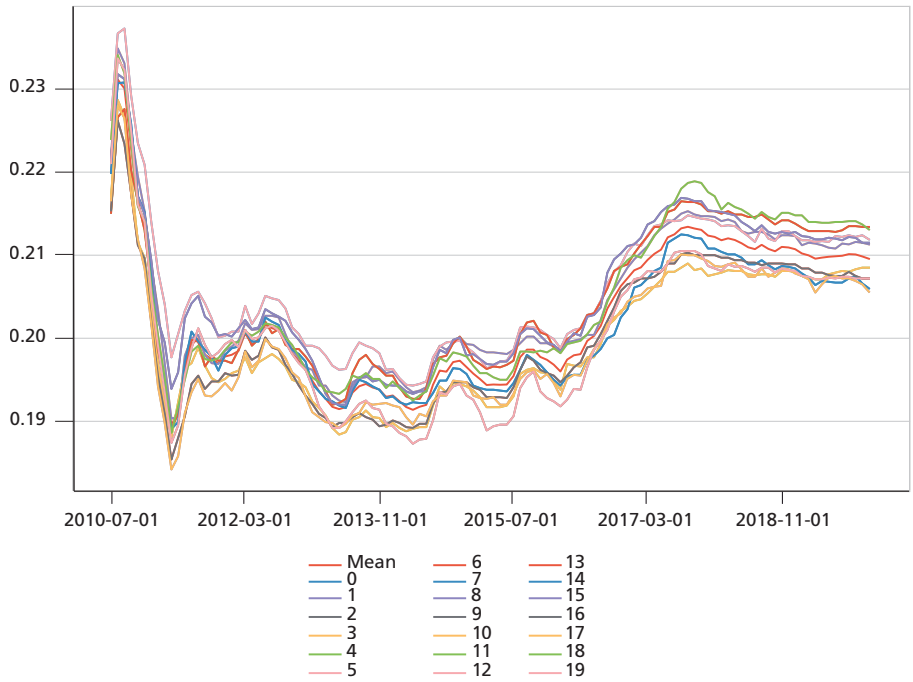
FIGURE 10
Non-performing real estate loans (2010-2020)
(In %)



Author's elaboration.

Additionally, only about 20% of families who rent are able to pay rents that are below the 30% threshold of their permanent income (figure 11). This number should be around 70% of families. In other words, the model's current rents seem to be far above the households' ability to pay. This probably stems from the mechanisms of construction of the model that directs all families without their own property and that are not successful in the buying and selling market for the rental market. Therefore, part of the poorest families in the simulation participate in the rental market. The empirical reality, however, includes families without financial resources but who own their homes, albeit under precarious conditions.

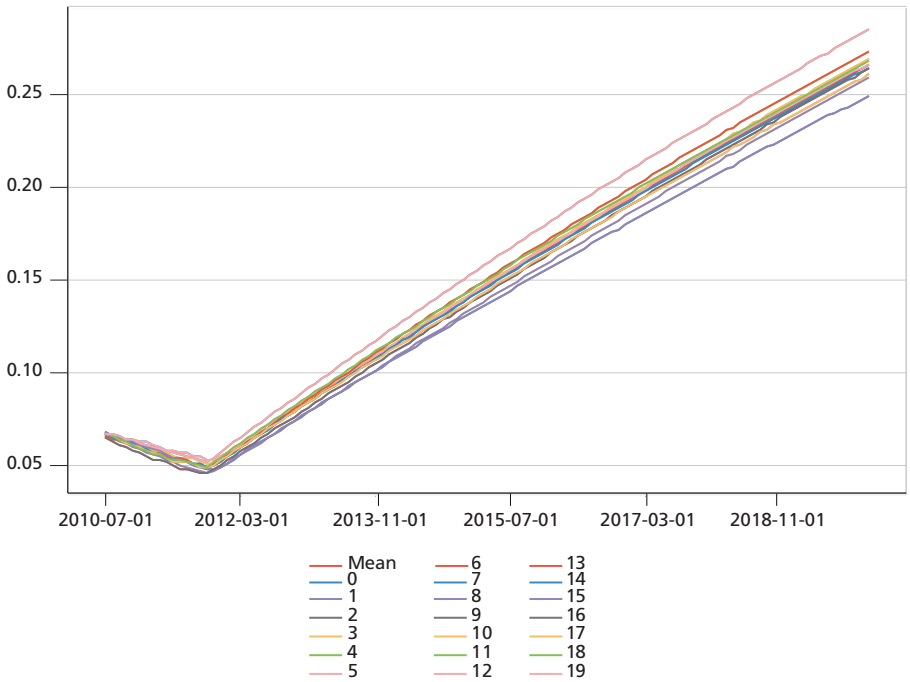
FIGURE 11
Families whose rent is below 30% of their permanent income (2010-2020)
(In %)



Author's elaboration.

The third mechanism that presents inadequate behavior is the evolution of vacancy throughout the process (figure 12). In the first years of the model, while the civil construction system is still planning the construction of new properties, vacancy drops consistently, reaching only 5% of the total properties in the simulation. From the second year onwards, however, construction companies begin to deliver the finished properties and end the period with an expected vacancy around 25%, which is higher than the expected value of 10% to 15%.

FIGURE 12
Brasília: vacancies in the simulation (2010-2020)
(In %)



Author's elaboration.

CHAPTER 5

SENSITIVITY ANALYSIS: DESCRIPTION AND ANALOGIES

In this chapter, we return to the model's purpose of describing real estate market mechanisms in an integrated way with the rest of the economic system. These results are obtained insofar as the sensitivity analysis, that is, tests of variation in parameters and rules of the model, influence alterations in the results, when compared to the standard version. The variation of parameters is typical in agent-based modeling (ABM). Structural testing of rules and mechanisms is less common, but is present in *PolicySpace* (Furtado, 2018c) and Goldstein (2017). The results are indicative and present contributions of relative and comparative behavior.

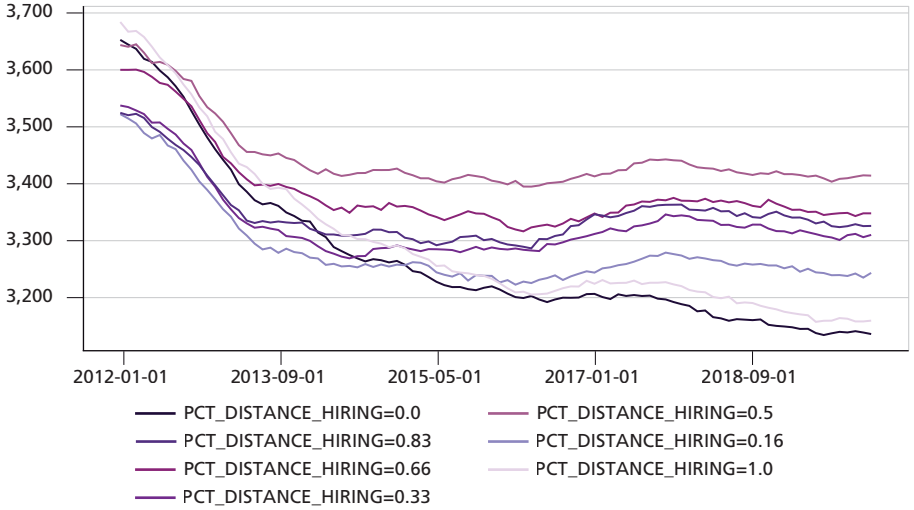
1 STRUCTURAL TEST OF RULES AND MECHANISMS

We will first test the inclusion of rules and mechanisms specific to the *PolicySpace2*, namely, the criterion of choice in the labor market by firms by proximity, to the detriment of purely qualification; then the effect of average neighborhood income on property prices; global unemployment as an element that influences firms' wage decisions; and the relative relevance of the supply in the real estate market.

1.1 Proximity to the labor market (η)

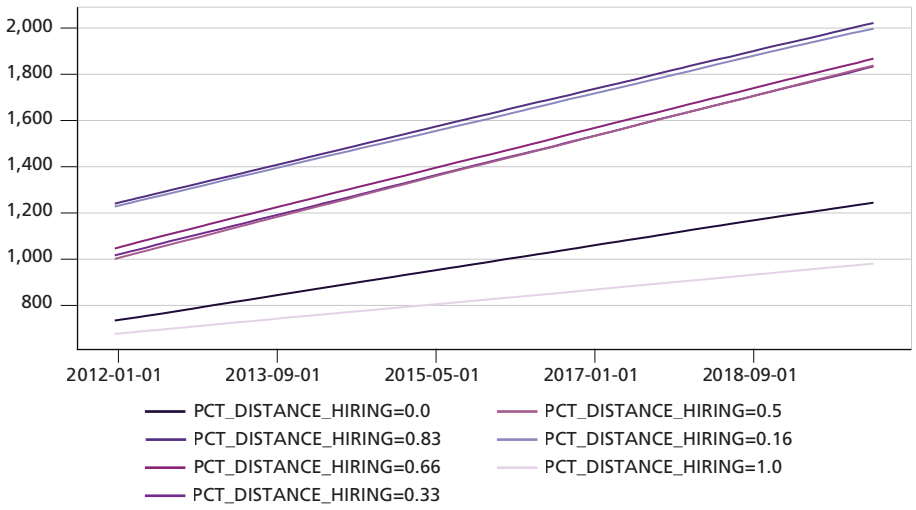
Our hypothesis is that the parameter of proximity to the labor market (η) in the *PolicySpace2* makes the fit between firms and workers locally optimized. However, it is suboptimal in the context of the metropolitan region as a whole. Both values (for the parameter equal to 0 – absence of the distance rule and all candidates are evaluated by qualification; and 1 – only proximity is relevant in hiring) lead to lower economic performance in relation to intermediate parameters. Given the concentration of a large part of the population with lower qualifications in the metropolitan peripheries, together with a smaller number of firms in these municipalities, extreme adjustment, by qualification or proximity, leads to relevant imbalances in the economy to the point of impacting general economic production and the gross domestic product – GDP (figure 1). In fact, total mobility is lower when adjustments are made entirely by proximity (figure 2). Adjustment fully based on qualification generates the second lowest level of mobility. This effect, however, derives from the fact that unemployment also reaches another level, going from values close to 12% to values above 20% of the economically active population (figure 3). In other words, mobility only decreases at the expense of a much larger number of unemployed.

FIGURE 1
GDP result for the variation of the percentage parameter of candidates to be chosen by proximity criterion, with an average of twenty simulations per parameter – Brasília (2010-2020)



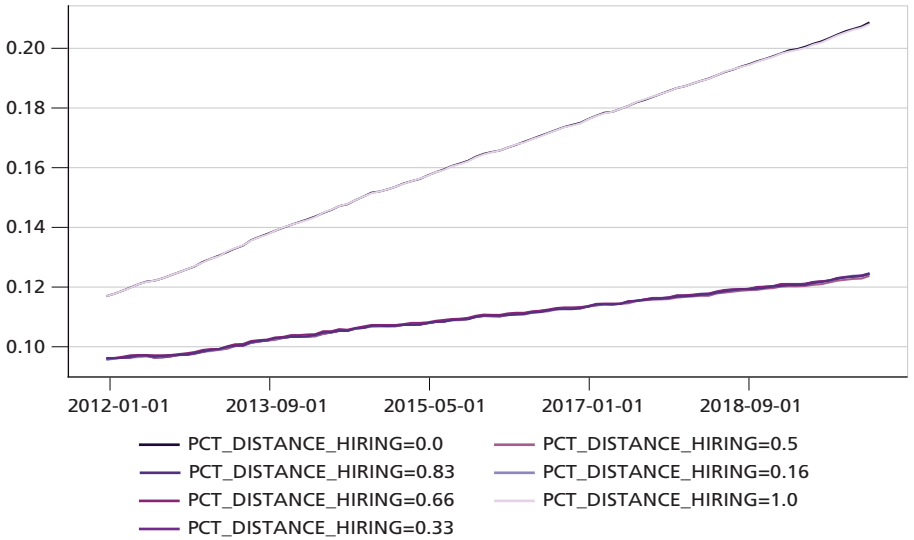
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 2
Total displacement of workers for the variation of the parameter of percentage of candidates to be chosen by the criterion of proximity, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 3
Unemployment result for the variation of the parameter of percentage of candidates to be chosen by proximity criterion, with an average of twenty simulations per parameter – Brasília (2010-2020)

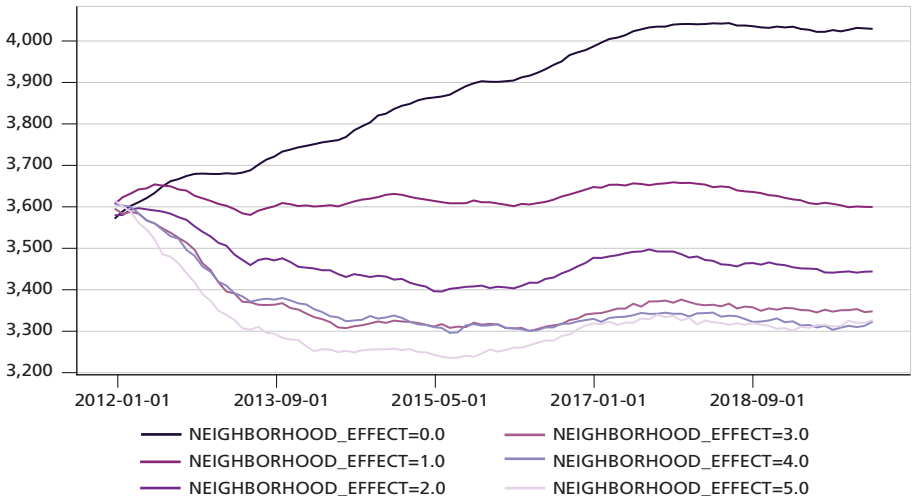


Author's elaboration.
Obs.: Agents – 1.0% of population.

1.2 Neighborhood effect on property prices (τ)

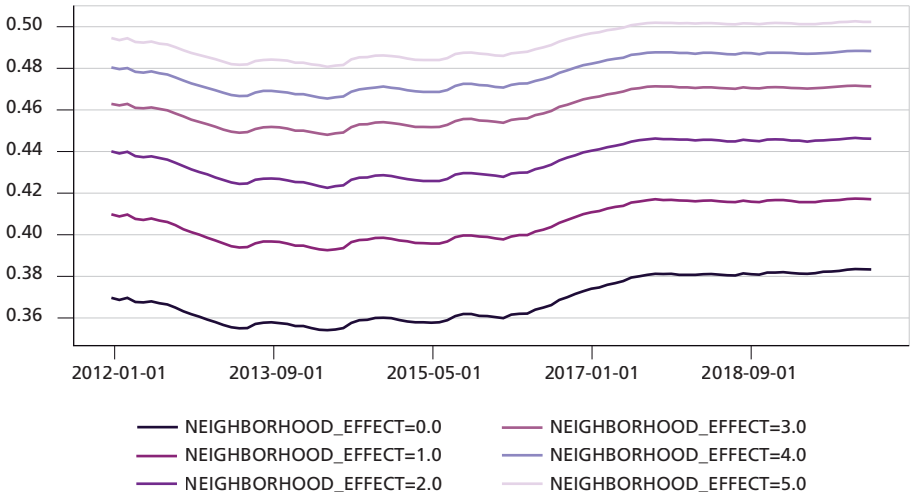
The increase in the relevance of the neighborhood in the composition of prices increases the price of real estate, which restricts purchases to a smaller number of families and reduces GDP (figure 4). With a more restricted real estate market, inequality increases (figure 5). The best scenario occurs when the neighborhood effect is null and the offer price is based only on fundamentals, without the perception that the average income of families in the neighborhood is relevant. With zero effect, GDP is higher, inequality is lower and there is less delay in payments on real estate financing, although there is a slight increase in general prices in the economy, given the greater purchasing power of families that spend less money on real estate.

FIGURE 4
GDP result for the variation of the neighborhood effect intensity parameter on property prices, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 5
Result of the Gini coefficient for the variation of the neighborhood effect intensity parameter on real estate prices, with an average of twenty simulations per parameter – Brasília (2010-2020)

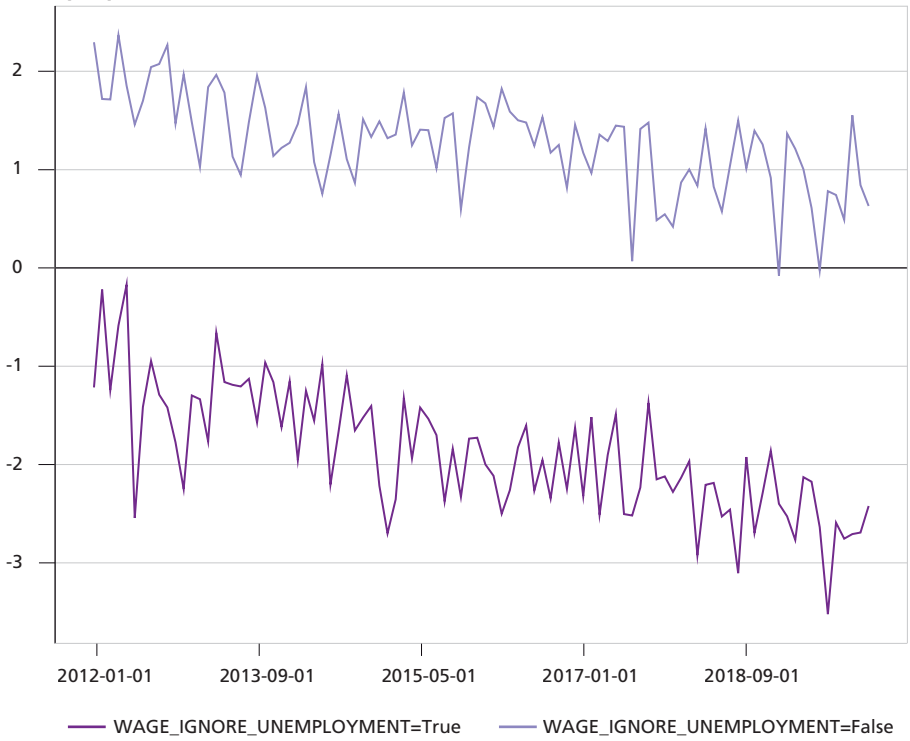


Author's elaboration.
Obs.: Agents – 1.0% of population.

1.3 Global unemployment as a factor influencing salary decisions (*U*)

The parameter that establishes whether firms observe global unemployment when deciding on the wages to be paid essentially interferes with the performance of the firm. Given that demand volatility is of high magnitude, the fact of being conservative in the wage decision – that is, reducing the level of wages according to global unemployment, in the standard configuration of the model – leads to the maintenance of positive profits, while the decision to distribute all the resources collected leads to recurring losses (figure 6).

FIGURE 6
Result of the firms' profit for the variation of the parameter of inclusion or exclusion of global unemployment in the salary decision, with an average of twenty simulations per parameter – Brasília (2010-2020)

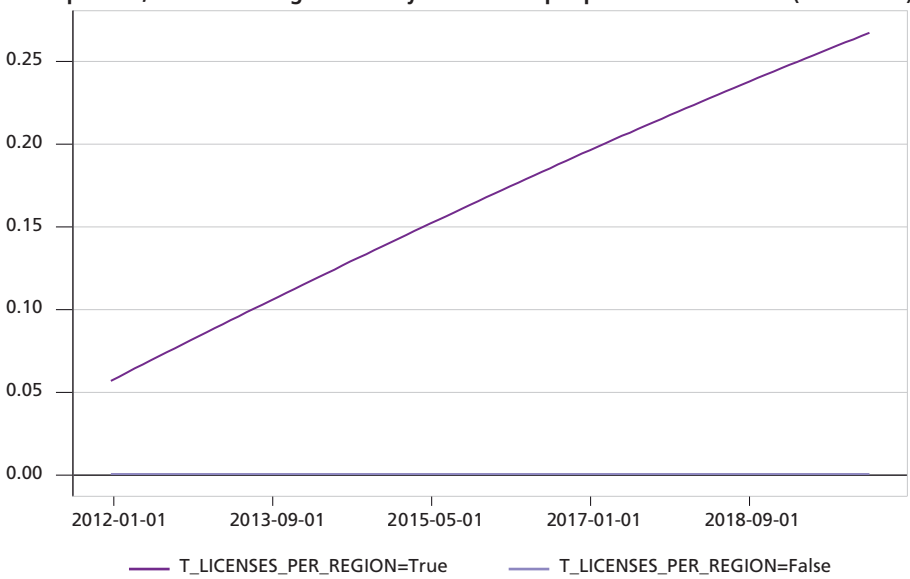


Author's elaboration.
Obs.: Agents – 1.0% of population.

1.4 Relative influence of supply

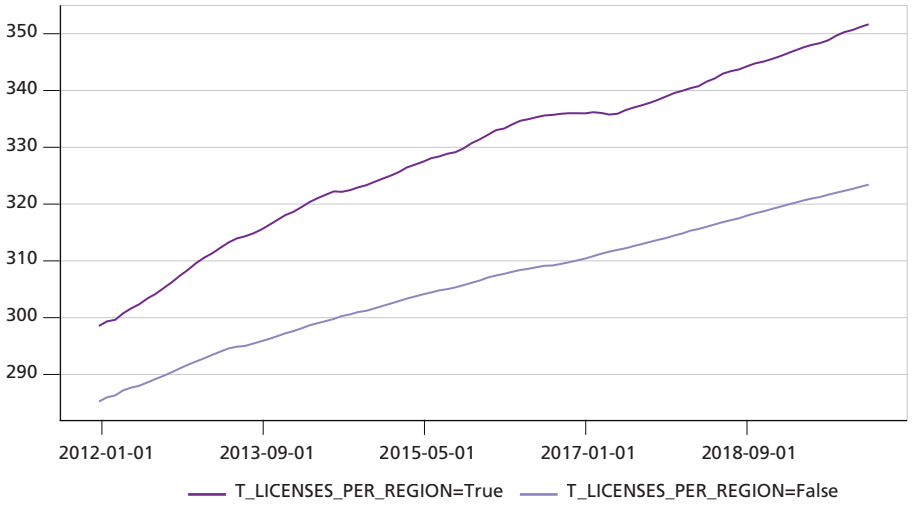
The total restriction of licenses in the model generates a shortage of properties and the inactivity of construction firms (figure 7). This effect leads to a general slowdown in the economy, with a worsening of GDP performance and an increase in inequality and default. In addition, there is an even greater restriction on renters, with fewer families obtaining affordable rents. In turn, property prices are slightly higher when there is more supply (figure 8). Although it may seem counterintuitive, this result derives from the greater general heating of the economy, with greater consumption, greater savings, more investments at the municipal level and greater inflation, but with lower inequality.

FIGURE 7
Result of the vacancy rate for the variation of the parameter of availability of construction permits, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 8
Result of real estate prices for the variation of the parameter of availability of construction permits, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

2 UNDERSTANDING THE MECHANISMS

This section analyzing the results of the *PolicySpace2* aims to contribute to the understanding of a broad array of public policies. Although the results presented here are not exhaustive, given the complexity and number of possible results and combinations, we note the following topics:

- the relevance of workers' productivity;
- the speed and magnitude of the resources obtained from the sale of properties and their ability to boost the entire economy;
- the effects of scale;
- the efficiency in municipal management; and
- the redistribution of fiscal budgets among metropolitan municipalities.

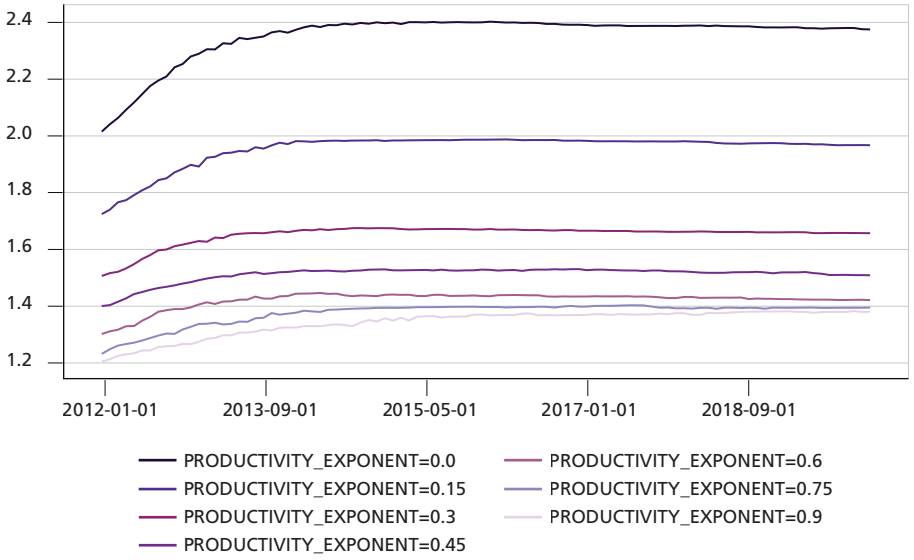
Note that all variables, from various agents, are registered in each simulation. Therefore, although we present a small and finite number of graphs and comments for each analyzed item, all results are available for each analysis. Thus, any of the exercises performed also include other results (listed in subsection 5.11 of chapter 3) not necessarily presented in the items in this section.

2.1 Productivity (α, β)

PolicySpace2 seems to be interesting for discussing worker productivity and its general influence on the economy. In fact, the productivity parameters together are quite relevant to the overall performance of the model. The parameters operate directly on the quantity of products produced per worker, given their qualification.

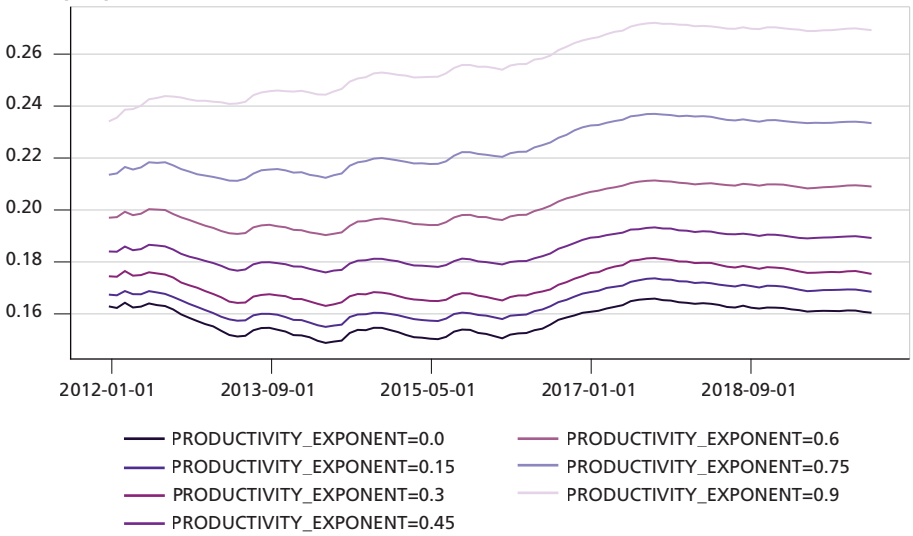
As expected, higher productivity; that is, higher exponential parameter and lower divisor, leads to a much lower price pattern in the economy as a whole (figure 9). As wages are also distributed internally to firms according to the productivity of each worker, families obtain more income, and a higher percentage of families are able to pay rent costs (figure 10). However, the much greater dynamism of the economy, given by the change in productivity parameters, leads to a large production of new properties by construction companies and, despite the increase in the supply of homes (figure 11), an increase in prices, given the availability of household savings (figure 12). The greater request for real estate financing does not cause an increase in arrears (figure 13).

FIGURE 9
Result of the general prices of the economy for variation of the productivity exponent parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



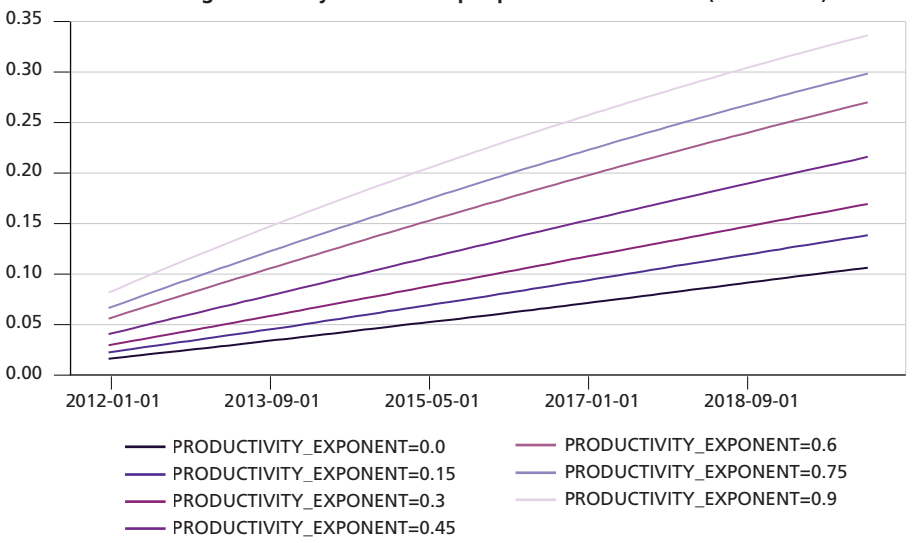
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 10
Result of the percentage of families whose rent is less than 30% of income for variation of the productivity exponent parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



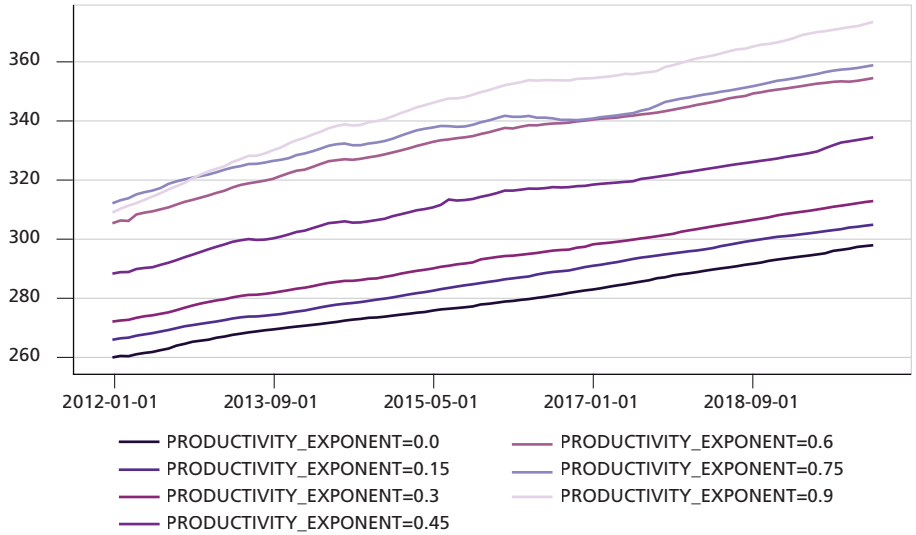
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 11
Result of residential vacancy for variation of the productivity exponent parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



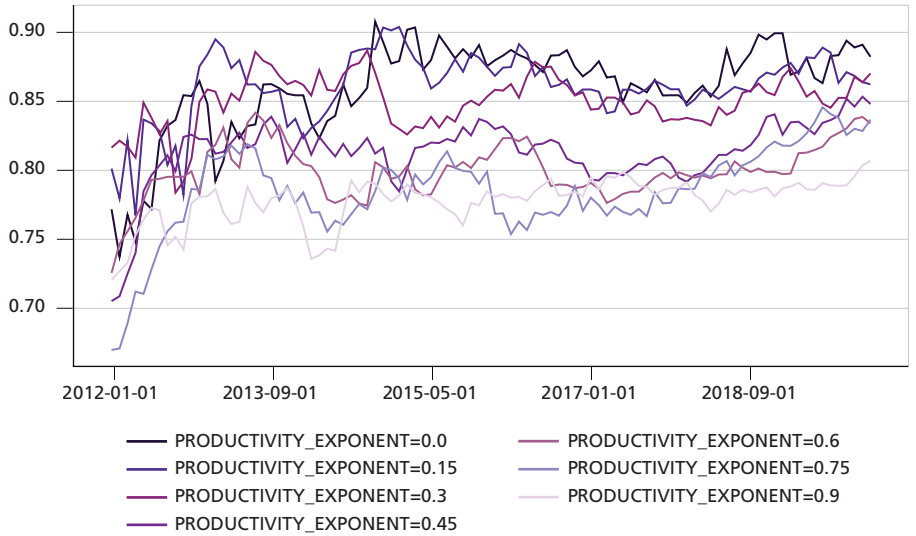
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 12
Result of real estate prices for variation of the productivity exponent parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 13
Result of the percentage of families with delay in real estate financing for variation of the productivity exponent parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

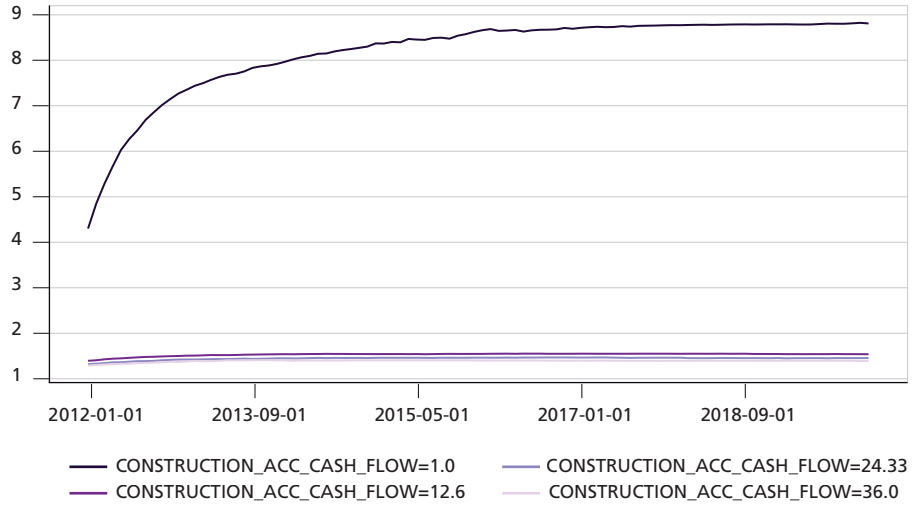
2.2 Resource embedding speed (η)

One of the parameters that characterize the behavior of construction firms is the softening of the distribution of funds collected at the time of sale among the firm's workers, in the form of wages. In general, the variation between 12 or 36 months of this parameter does not significantly change the results. There is a clear distinction, however, when this parameter is reduced to 1. In this case, in the following month, after the sale, all the revenue, minus the firm's profits, is distributed among the workers. This change is not in the size of the distribution, only in the time it is distributed, all at once, or, more regularly, over two years, which is the standard value.

Without any quantitative change, this endogenous process generates significant effects on the behavior of the economy as a whole. Prices rise almost tenfold (figure 14), as do firms' profits (figure 15).

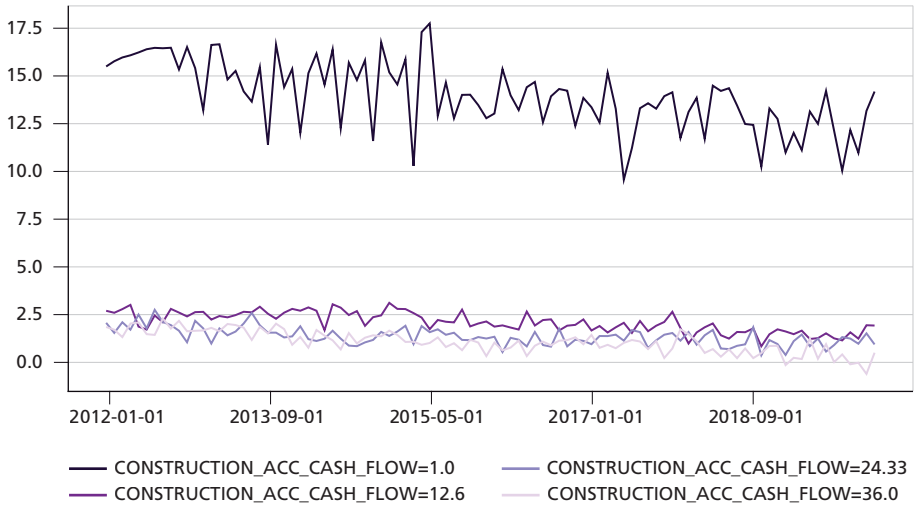
Inequality, in turn, decreases by around 0.05 points in the Gini coefficient (figure 16). What happens is that, given the design of the model, in periods when there are no sales, construction companies have a mechanism that anticipates revenue installments and begins to pay salaries, which reflects the expectations of future resources of the planned properties. This payment of wages on properties built but not yet sold originates from the firm's own capital. As a result, what actually happens is that in periods when there are no real estate sales, the construction company maintains, with its own budget, the workers' salaries determined in high periods. This leads to a decline in company's capital (figure 17), however, with higher production, higher salaries and savings, and with a larger number of families able to pay rent. In practice, this exercise reflects an effort by firms to pay higher wages and its effects on the economy as a whole.

FIGURE 14
Result of the general price index for variation of the parameter of months for the distribution of resources in the construction companies, with an average of twenty simulations per parameter – Brasília (2010-2020)



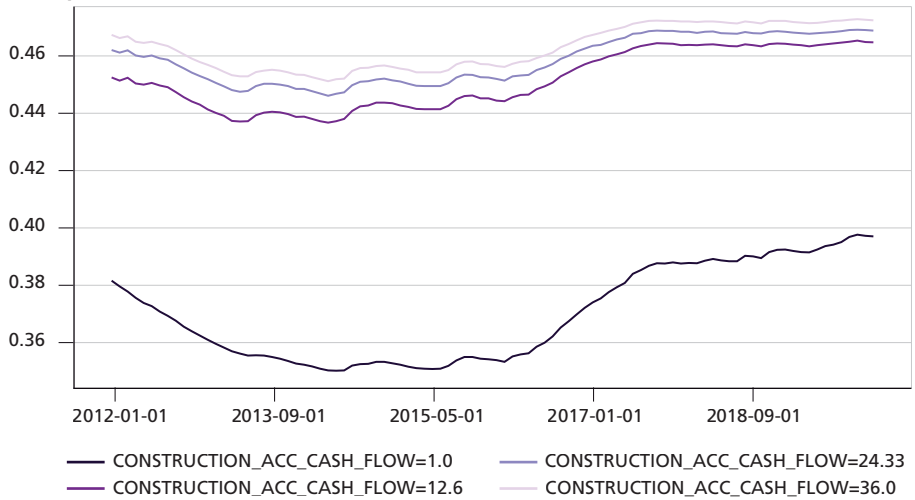
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 15
Result of the companies' profit for variation of the parameter of months for the distribution of resources in the construction companies, with an average of twenty simulations per parameter – Brasília (2010-2020)



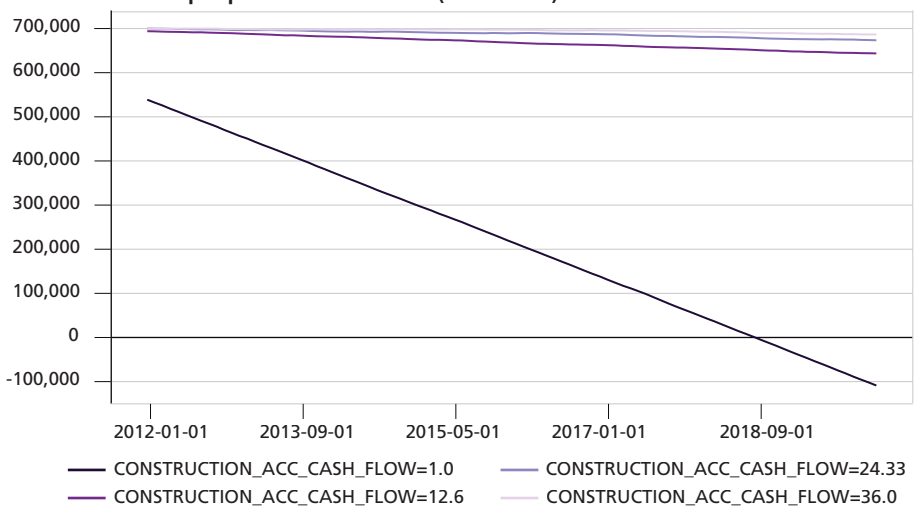
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 16
Result of the Gini coefficient for variation of the parameter of months for the distribution of resources in the construction companies, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 17
Result of the general balance of companies for variation of the parameter of months for distribution of resources in the construction companies, with an average of twenty simulations per parameter – Brasília (2010-2020)



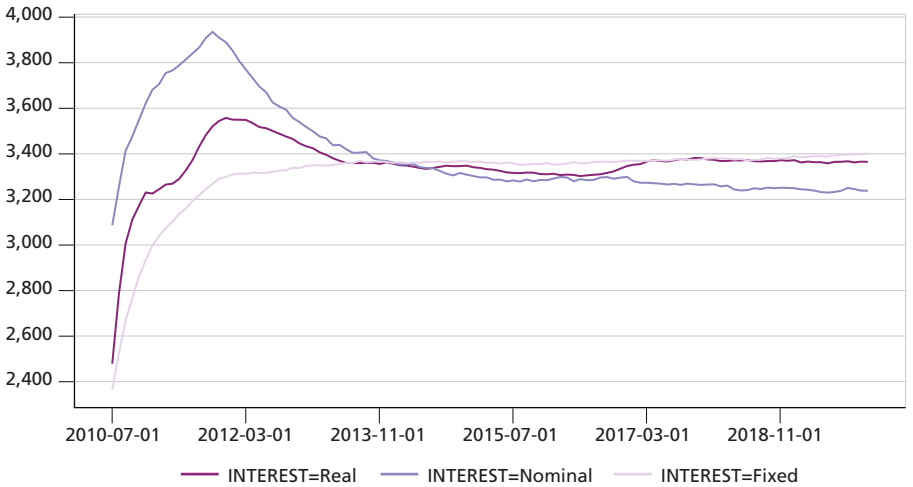
Author's elaboration.
Obs.: Agents – 1.0% of population.

2.3 Loans and interest

The general loan conditions in the simulation are restrictive, so that only a small portion of the families obtain access to financing. The restrictions – detailed in subsection 7.10.1 of chapter 3 – include the amount of the loan in relation to the value of the property, the monthly and permanent income of the family, in addition to the maximum term for the oldest borrower and the availability of funds in the bank. The most relevant parameter is the maximum ratio of the loan value in relation to the value of the property, described in the literature as loan-to-value (LTV). In general, a more permissive LTV of 80% leads, as expected, to an increase in arrears, a marginal reduction in unemployment, with also marginal increases in corporate profits, GDP and the Gini coefficient.

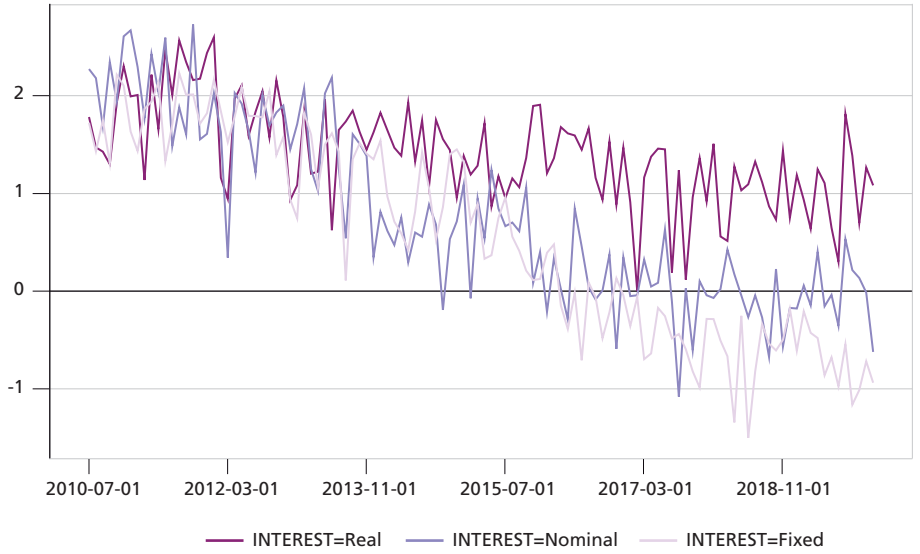
Three types of exogenous interest inflows are tested in the sensitivity analysis. Nominal interest, as described in the official series; real interest – that is, nominal interest minus inflation measured in the reference month; and fixed interest throughout the period (0.2% per month). Interest rates bring much more volatility to the simulation, although there are no changes in the trends presented by the indicators. Volatility is transmitted to the model through the calculation of permanent income. Prices rise to higher levels, with nominal and lower interest rates for real or fixed rates. Over the period, lower and fixed interest rates slightly benefit GDP (figure 18). However, real interest, with a similar GDP result, seems to be more sustainable, if the average profits of firms are considered (figure 19).

FIGURE 18
GDP result for the variation of the interest input parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 19
Result of the average profits of the firms for variation of the interest input parameter, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

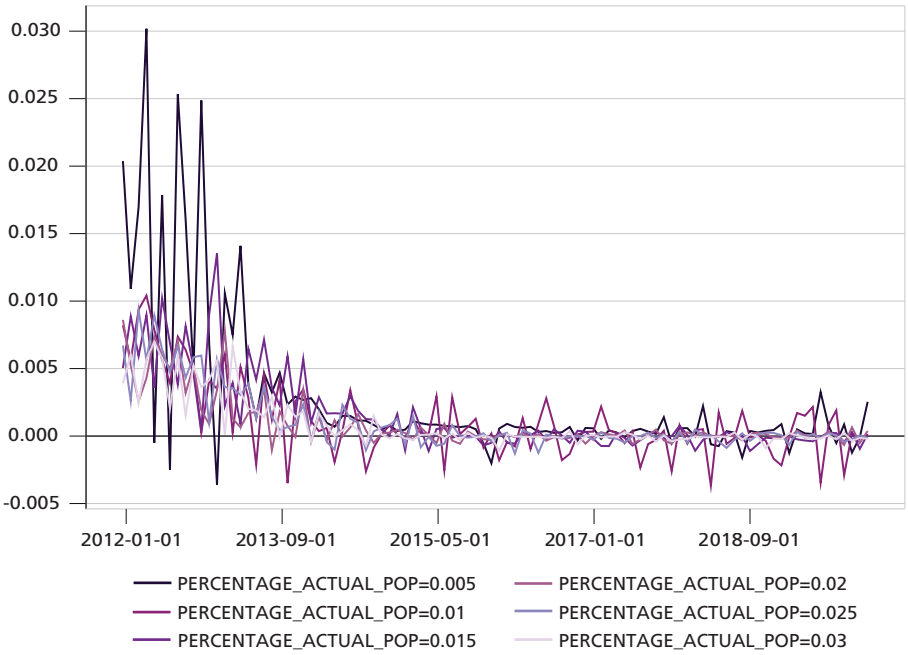
2.4 Trading, population impact and real estate market dynamics

In the *PolicySpace2* trading mechanisms have relatively little influence on market composition. Both the lower and upper limits for traded prices and the influence of the number of properties on offer, according to the processes designed, change the results little. Likewise, the parameter that determines the size of the influence of current real estate vacancy on estimated prices shows little variability in relation to the standard model – although greater influence leads to lower general prices and lower real estate prices (in which case the influence would be direct) but only slightly lower.

Population increases have scaling effects on the results, which are sometimes superlinear (Bettencourt, 2013). Considering this factor, note that the standard simulation of *PolicySpace2* and its validation refer to the configuration for the Areas of Population Concentration (ACPs) of Brasília, with 1% of the population. With a smaller population, there is greater volatility in monthly inflation (figure 20). However, on the financial market, payment of interest on the financial remuneration of the capital of families increases volatility with the increase in the population of agents (figure 21). Unemployment and house

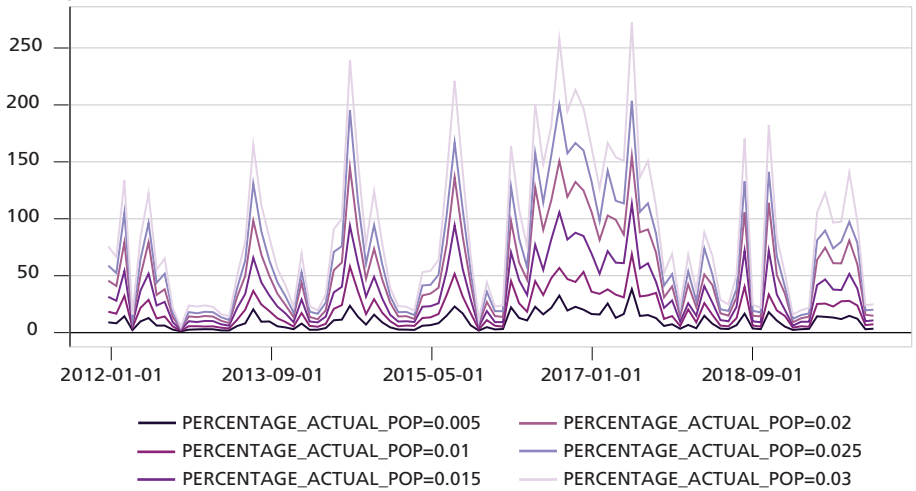
prices behave as predicted by theory with superlinear increases. Thus, for a few agents, unemployment reaches zero (figure 22) and real estate prices present the lowest level (figure 23). In the case with more agents and more competition, there is better allocation based on qualification, more unemployment and also greater inequality, with greater payment of taxes (figure 24). Unemployment and inequality lead to greater difficulty in meeting rent obligations among families (figure 25).

FIGURE 20
Monthly inflation result for variation of the population percentage parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



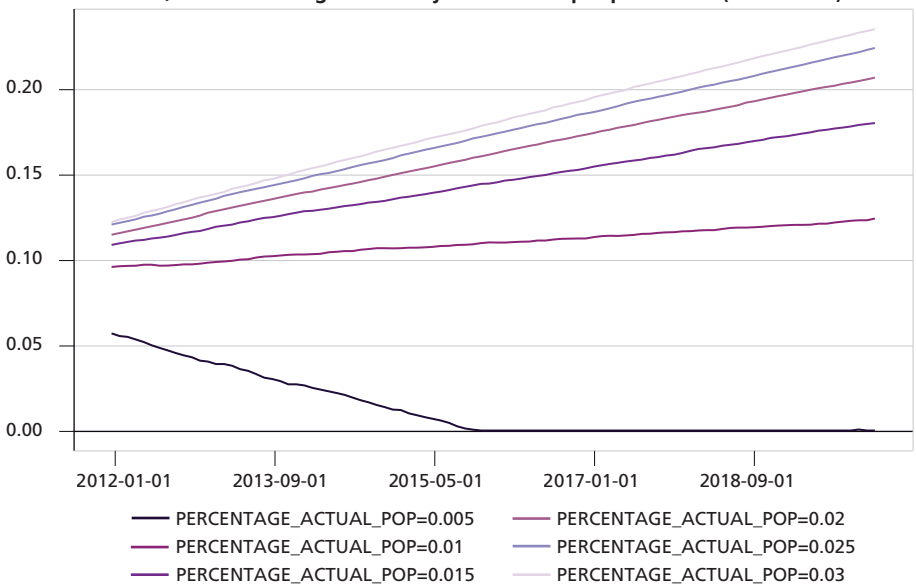
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 21
Result of taxes paid by the bank on customer interest for variation of the population percentage parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



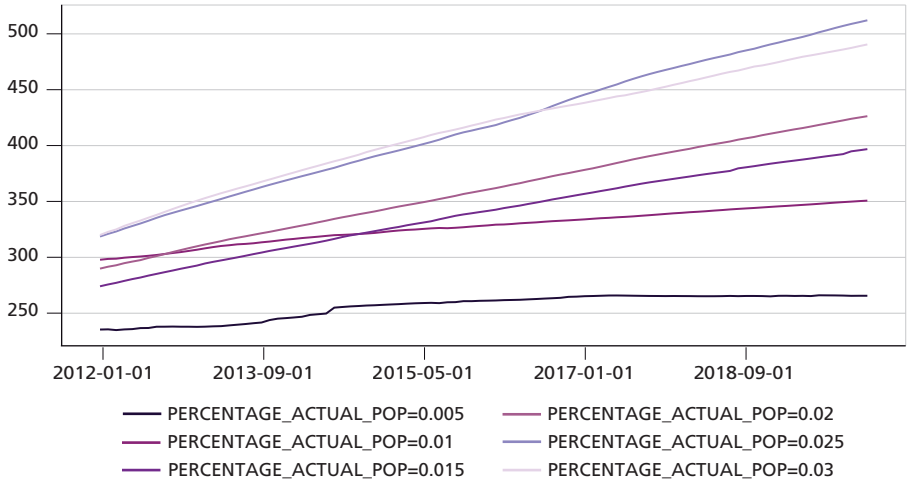
Author's elaboration.

FIGURE 22
Unemployment result for variation of the population percentage parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



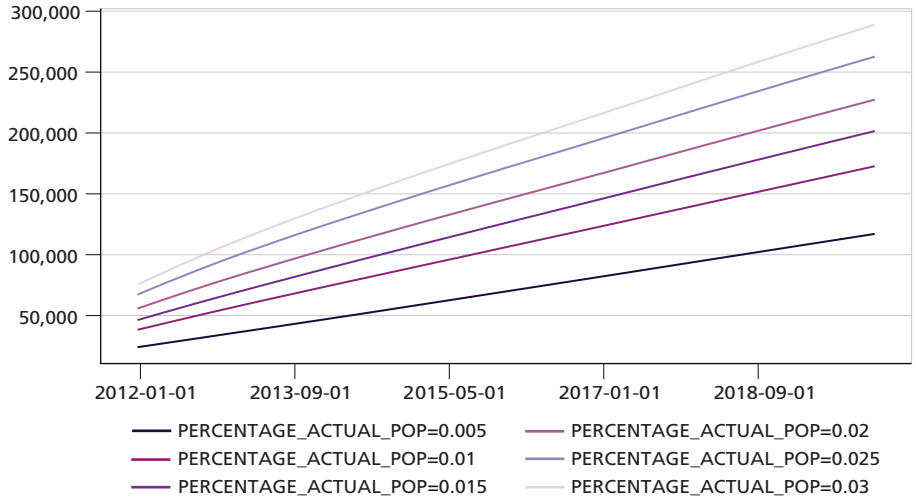
Author's elaboration.

FIGURE 23
Result of property prices for variation of the percentage of population parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



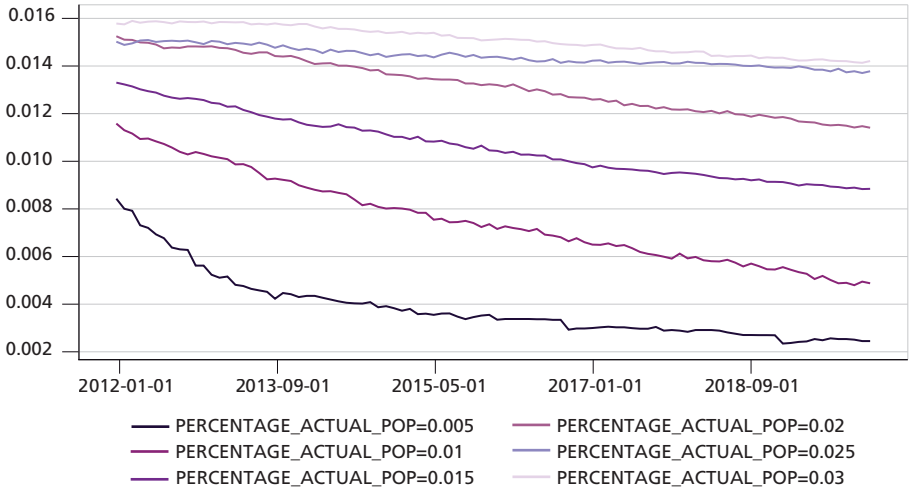
Author's elaboration.

FIGURE 24
Result of taxes collected in the municipalities for variation of the percentage of population parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



Author's elaboration.

FIGURE 25
Result of the percentage of families that are unable to make the monthly rent payment for variation of the percentage of population parameter to be simulated, with an average of twenty simulations per parameter (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

The dynamization of the real estate market, through the increase of families that participate in the market each month, leads to an increase in prices and GDP, with maintenance of unemployment and an increase in inequality. It also leads to a reduction in the percentage of defaulting borrowers in the banking system. Finally, when a very small number of families go to the market, there is an increase in the number of vacant properties.

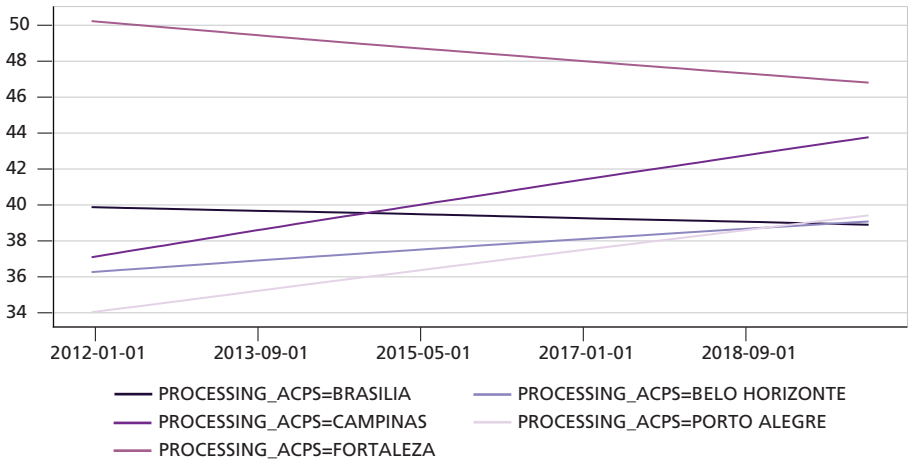
2.5 Still on non-linearity and scale: big cities

PolicySpace2 is simulated from official 2010 data. Therefore, there is an initial configuration of workers and their qualifications, family size, age composition, gender, location, number and location of firms, Municipal Human Development Index (IDHM) that is different for each metropolitan region. This initial composition, despite the use of exactly the same mechanisms and the same parameters, results in different behavior between the metropolises. We selected five medium-sized metropolises for comparison with each other.

The composition and behavior of the average number of workers per companies present very different results. While Fortaleza and Brasília show a decline in the average number of workers per firm, the other three show an increase with different slopes (figure 26). In turn, unemployment is increasing for Brasília and Belo Horizonte, decreasing for Porto Alegre and Campinas, while it remains relatively stable for Fortaleza

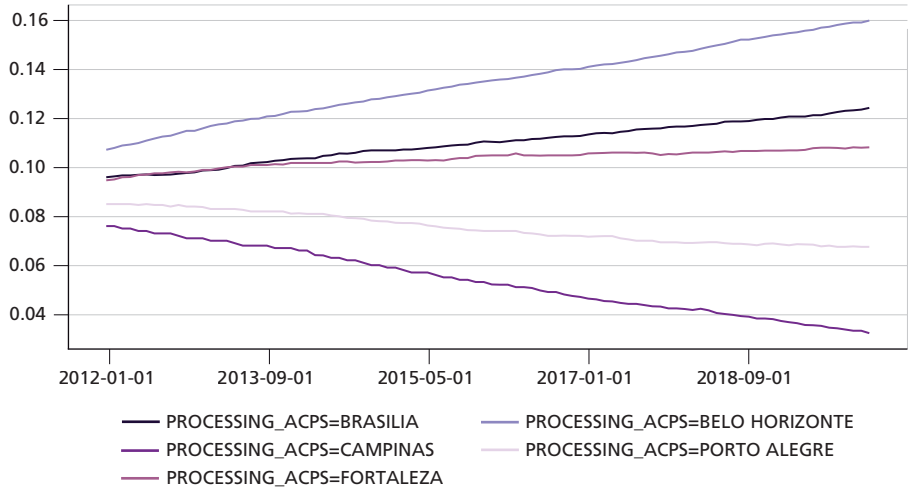
(figure 27). Finally, Brasília seems to distance itself from the other metropolitan regions with a more pronounced increase in real estate in the period analyzed.

FIGURE 26
The result of the average number of workers per firm for variation of the analyzed metropolitan region, with an average of twenty simulations per metropolitan region (2010-2020)



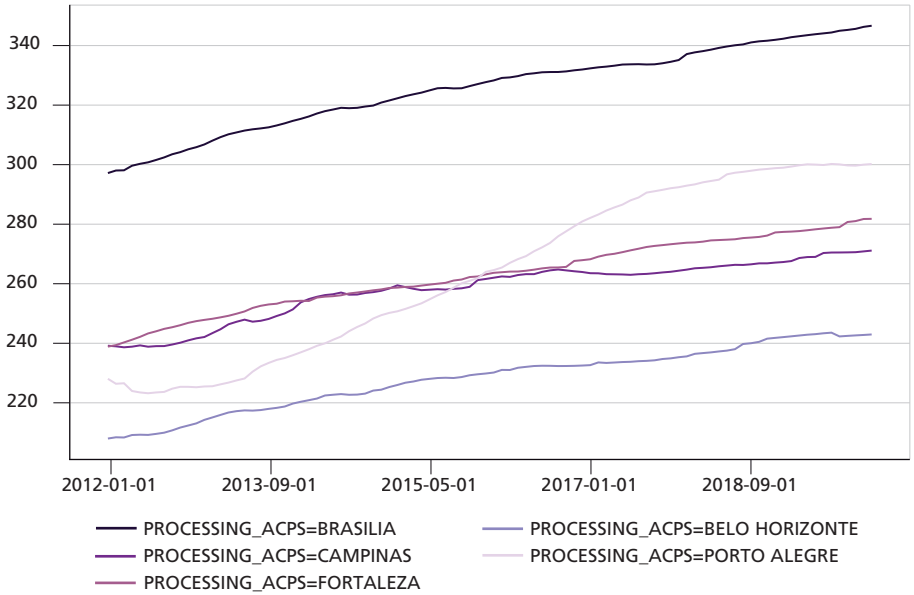
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 27
Unemployment result for variation of the analyzed metropolitan region, with an average of twenty simulations per metropolitan region (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 28
Result of average property prices for variation of the analyzed metropolitan region, with an average of twenty simulations per metropolitan region (2010-2020)



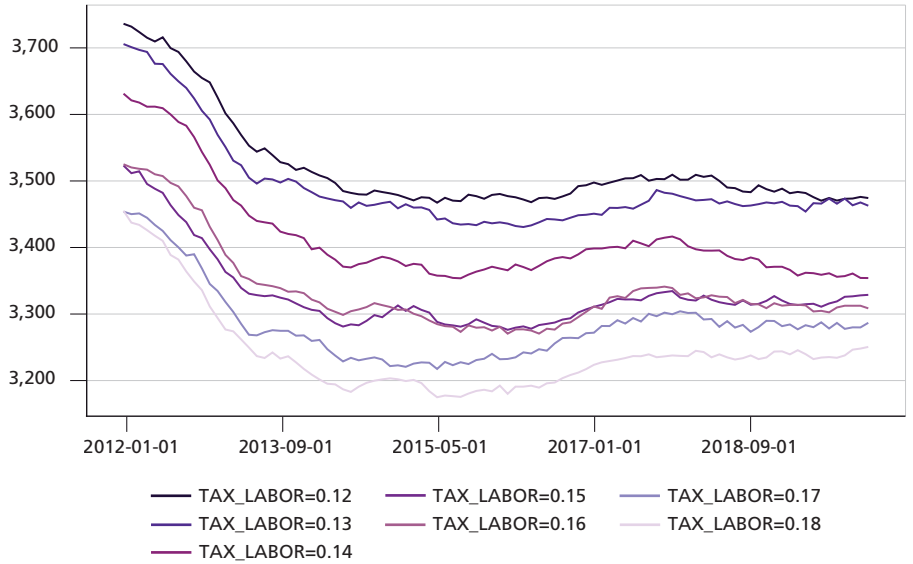
Author's elaboration.
Obs.: Agents – 1.0% of population.

2.6 Taxes

Property Tax (IPTU) is much smaller than the other taxes. Even so, when the rate increases, a reduction in consumption by families is noted, as is a worsening of economic indicators in general, with reduced GDP and increased inequality. In turn, the Property Transfer Tax (ITBI) generates small changes in the economy when rates are increased.

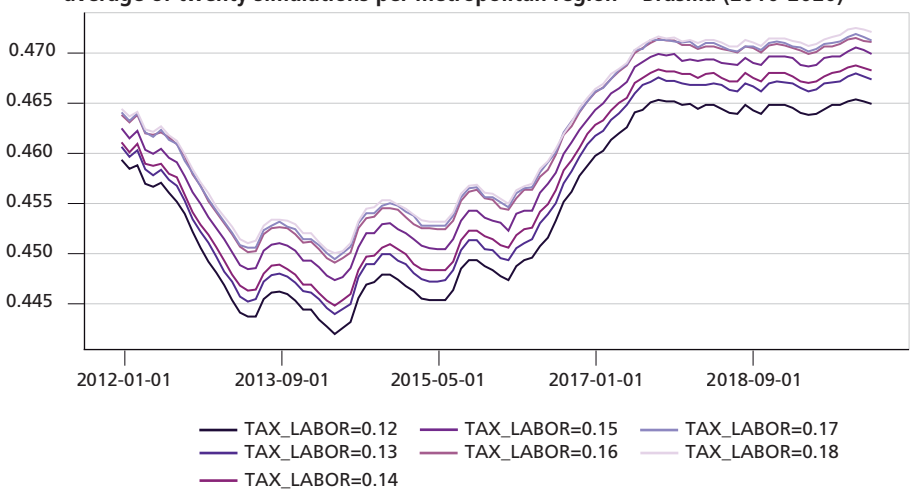
The Corporate Income Tax (IRPJ) seems to influence the economy less in the default configuration of the *PolicySpace2*, compared to the tax on work – Personal Income Tax (IRPF). Tax rate reductions on IRPF have beneficial effects on the economy as a whole; with more resources available, there is greater participation of families in the market, with an increase in prices and well-being, greater production (figure 29) and less inequality (figure 30).

FIGURE 29
GDP result for the variation of the labor tax rate parameter, with an average of twenty simulations per metropolitan region – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 30
Result of the Gini coefficient for variation of the labor tax rate parameter, with an average of twenty simulations per metropolitan region – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

2.7 Municipal management efficiencies

Given the mechanisms and configuration of the *PolicySpace2*, the efficiency of municipal management does not affect some aspects, such as the general consumption of families, the total number of employees per firm or worker mobility. However, since management transforms fixed resources into improving the quality of public services offered, these influence the formation of real estate prices, which then affect other sectors of the economy. The effects are linear, so that the increase in the coefficient of the efficiency parameter leads to an increase in real estate prices, inflation, inequality and also in renting families who obtain affordable rent.

2.8 Other effects

Additionally, other parameters were also tested, such as the sample size of firms that families consult in the goods and services market, the frequency with which the firm participates in the labor market and checks prices, the cost of the lot in the construction of new real estate and the cost of public and private transport.

In the case of the sample of firms consulted, the results differ only when a single firm is consulted, indicating possible effects of reduced competition and concentration of companies, resulting in an increase in inequality and prices, but also in the greater overall production of the economy.

The zero-cost test for public transport – which influences as a criterion in the selection of candidates in the labor market and, in practice, would result in a null effect of distance – also significantly alters the results, in relation to any other positive value. Overall, inflation is more stable, there is a little more inequality, lower consumption and lower GDP, but with lower unemployment as well. There is a significant increase (about five times higher) in the distance traveled by workers together in relation to other values.

3 FISCAL ANALYSIS IN THE METROPOLITAN SCOPE

This section revisits the analysis of the distribution of fiscal resources among municipalities carried out in the *PolicySpace* model (Furtado, 2018c). Despite the numerous changes made in this version, the results are confirmed and reinforced.

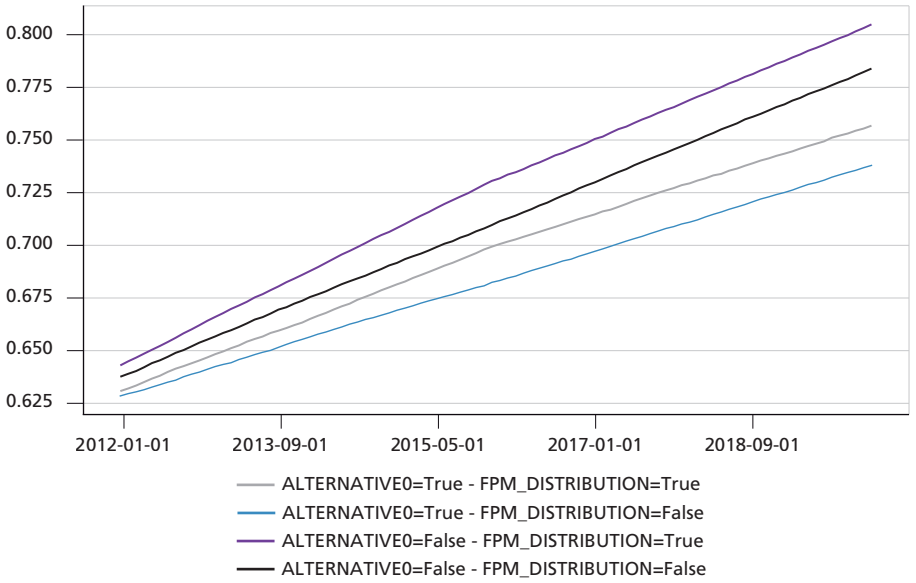
In *PolicySpace*, four combinations of parameters tested the reallocation of collected financial resources and their redistribution in local (the collecting and receiving municipality is the same) and egalitarian criteria (any collection within the scope of the ACP is redistributed equally among the participating municipalities, weighted by the population, or in accordance with the rules of the Municipal Participation Fund – FPM). With that, the *alternative0* and *fpm_distribution* rules, as patterns designated as true, reflect the current situation. When *alternative0* is false, the model only redistributes resources endogenously, as if ACP municipalities

had a single box. When *fpm_distribution* is false, the distribution criterion via FPM becomes non-existent.

From the theoretical point of view, according to qualitative evidence listed in the literature (Furtado, Krause and França, 2013), the preferable spatial configuration from the point of view of society as a whole and the effective provision of network service to metropolitan citizens would be the union of municipalities with economic affiliation and pendular movement, precisely the ACPs, and maintenance of the FPM, considering its progressive effect in the scope of metropolitan regions.

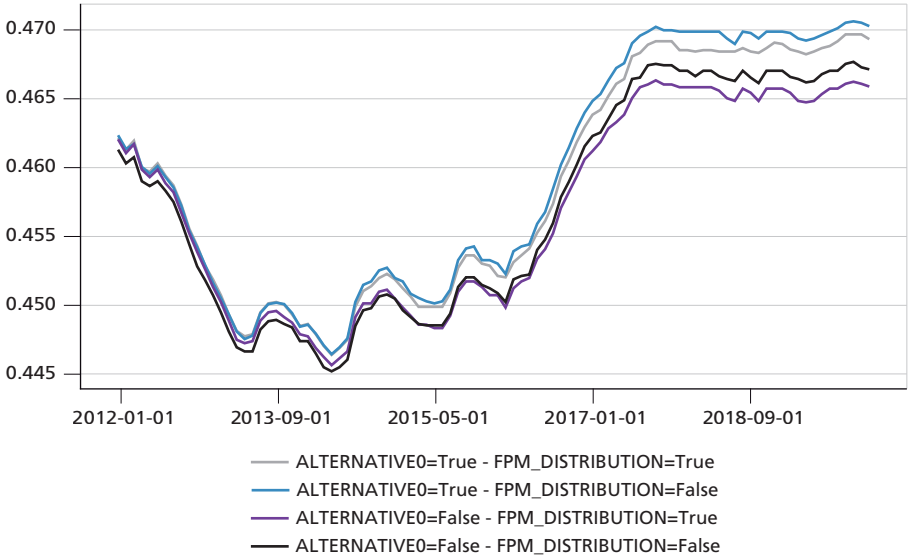
Figure 31 summarizes the endogenous amount of investment made in the municipalities for each different distribution configuration. Comparatively, the figure suggests that there is a greater distribution of municipal resources when municipalities have a single box (alternative0 is false) and the FPM is maintained in the current standards (*fpm_distribution* is true). Furthermore, it confirms the results of the previous model, whose main indication was the distributive relevance of the FPM within the metropolitan regions. In fact, the lack of FPM as a distribution criterion (figure 32) generates, comparatively, more inequality.

FIGURE 31
Result of the Quality of Life Index - which reflects the grouping of municipal revenue – for different configurations of distributive parameters, with an average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: 1. Agents – 1.0% of population.
2. Gray – status quo; purple – budgetary union of metropolitan municipalities in a single entity; blue – absence of FPM as a distributive criterion; black – union of municipalities and absence of FPM.

FIGURE 32
Result of the Gini coefficient for different configurations of distributive parameters, average of twenty simulations per parameter – Brasília (2010-2020)



Author's elaboration.
Obs.: 1. Agents – 1.0% of population.
2. Gray – status quo; purple – budgetary union of metropolitan municipalities in a single entity; blue – absence of FPM as a distributive criterion; black – union of municipalities and absence of FPM.

CHAPTER 6

PUBLIC POLICY TEST: PROPERTY ACQUISITION GRANTS, RENTAL PAYMENT OR CASH ASSISTANCE?

The decision between buying or renting a residential property does not have a correct financial answer, since information about future behavior of property appreciation, interest rates and inflation is unknown (Furtado and Souza, 2020). However, housing policies and the national imagination coincide in the understanding that home ownership should be something to pursue (Davies, 2013; Brazil, 2014). In fact, a recent analysis by the Organization for Economic Co-operation and Development – OECD (Causa, Woloszko and Leite, 2019) which studies the relationships between inequalities, housing policies and homeownership or rent identified that among member countries those with a lower percentage of owners exhibited greater inequality. This suggests that property ownership would contribute positively to the distribution of wealth. However, the authors add that it is also common to observe countries whose families are rich in wealth, but with a low flow of income, which also occurs in the Brazilian case. Poor states, such as Maranhão, maintain high rates of property ownership (Furtado and Galindo, 2010).

In terms of public policies, although there is no evidence whether the policy should favor families who rent or who own (Causa, Woloszko and Leite, 2019), typical policies favor owners who make up the average electorate.

In the United States, for example, households do not pay implicit rent taxes and earn discounts on interest payments on mortgages (Chan, Haughwout and Tracy, 2015). Also in Brazil, there is no levying of taxes on implicit rental income or on capital gains in the acquisition of financed property. Installments paid, insurance and interest that make up the initial capital invested in the payment of taxes are excluded.

From the point of view of families and society, there are indications that a higher proportion of owners in relation to tenants would promote greater engagement in communities, social capital and, consequently, higher priced properties (Malmendier and Steiny, 2017). Families that opt for rent, in turn, enjoy greater mobility as they do not focus their investments on real estate and are less subject to variations in this market. McAfee and Brynjolfsson (2017) assess that a new consensus is forming in which renting is better than owning.

In terms of the size of the property stock, there is no doubt that the percentage of Brazilian families that simply do not have enough resources to pay for the purchase or financing of their own home is also relevant. Data from the National Household Sample Survey (PNAD) 2014 by the Brazilian Institute of Geography and Statistics (IBGE), compiled in the real estate credit analysis carried out by Fioravante and Furtado (2018) suggest that almost forty million Brazilian families, more than 56% of the total, receive up to R$ 2,600 per month (2016 reais).

There is some housing policy effort to use vacant properties – which are around 10% of the total in the Brazilian case (Nadalin, Furtado and Rabetti, 2018) – for the allocation of social housing. Vacant public buildings are the priority objects of the policies. Although this is of interest, the amount does not seem to be enough to reduce household demand for housing.

In this context, *PolicySpace2* performs a simple test: given a fixed percentage of the municipal budget, the financial resources are applied alternately in three different policies and the results are compared with the execution of the simulation without any policy. Implementation details are described in subsection 7.10.9 in chapter 3. The contribution of this experiment, in our view, is precisely the remarkable endogeneity of the entire process. The following are endogenous to the simulation.

1) Family wages and employment relationship.
2) Family consumption and inclusion in the list of beneficiaries, according to the calculation of each family's permanent income.
3) The municipal collection itself, through the *proxy* of five taxes that are collected during the monthly stages of the simulation.
4) The process triggered after the application of the policy, which are:
    a) the family that obtains possession of the property (and becomes the owner);
    b) stops paying rent for 24 months; or
    c) that increases monthly income – this monetary-financial increase generates repercussions in the following months in the context of the simulation itself.

Additionally, since policies are simulated with exactly the same set of rules and parameters, their ability to compare results with each other is enhanced.

1 RESULTS OF COMPARISON BETWEEN POLICIES

In order to simplify the analysis, we will name each of the policies as:

- property (*buy*) – when the properties are transferred to the families;
- rent (*rent*) – in the case where families receive the voucher payment of rent for the next 24 months;
- aid (*wage*) – when resources are divided and distributed among registered families in terms of monetary assistance; and
- absence of policy (*no_policy*) – for the case in which the model is simulated in the standard form and the money collected by the municipalities is fully invested in improving the quality of life.

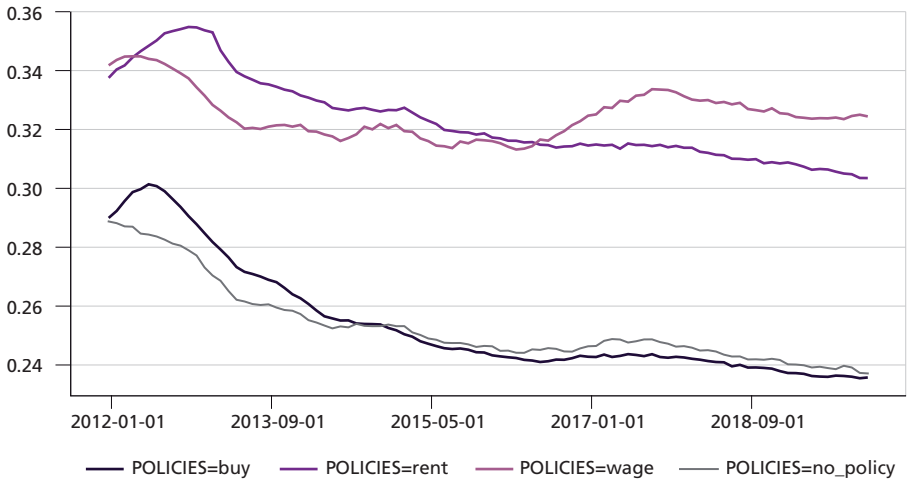
Fundamentally, although the (endogenous) volume of resources invested in each policy is quite similar,[1] the group that benefits from each of the policies is different in terms of size, given the per-family costs of each policy. As a result, public investment in the property modality serves, in the standard case, an average of 10.7 families per month. Comparatively, 42.2 families receive a voucher for rent and 1,060.3 families are awarded the monetary assistance, in the context of 1% of the simulated population, each month. It is also necessary to consider that the effects of policies are different in time. While the home belongs to the family on a permanent basis, rent is restricted to periods of 24 months, and aid is only received in a given month. In fact, the proposed policy design in the aid modality is the distribution of a small amount of money to a larger number (first decile of endogenous poverty) of families.

With this, while property and rent policies are aimed at a smaller number of families, although they are focused primarily and gradually on those with less wealth, the aid policy works in practice as a redistribution of resources collected annually and divided among families in the lower part of the distribution of wealth in the municipality.

The numerous indicators of the comparative results between the three policies and the baseline scenario suggest that the aid achieves better results in practically all indicators, for example, in the indicator of the percentage of families that rent and whose rent value does not exceed 30% of their permanent income or in the indicator that follows the monthly consumption of families (figure 1). However, the greater dynamism of the economy, given by the increase in household consumption, in the case of the aid and rent policy, also leads to an increase in the indicator of prices in the order of 15 percentage points (pp) over the ten years of the simulation (figure 2).

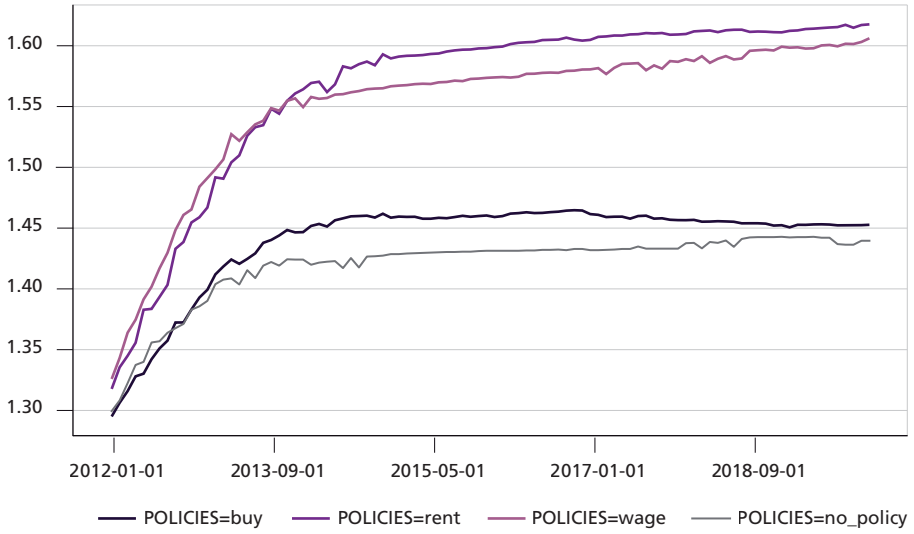
1. The values are not exactly the same, as there are endogenous changes to the simulation that affect the fundraising for each policy. Additionally, the application may vary at the margin, since the resources to buy the next property, for example, are not enough and it is necessary to wait for the following month to make the investment.

FIGURE 1
Average household consumption indicator for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

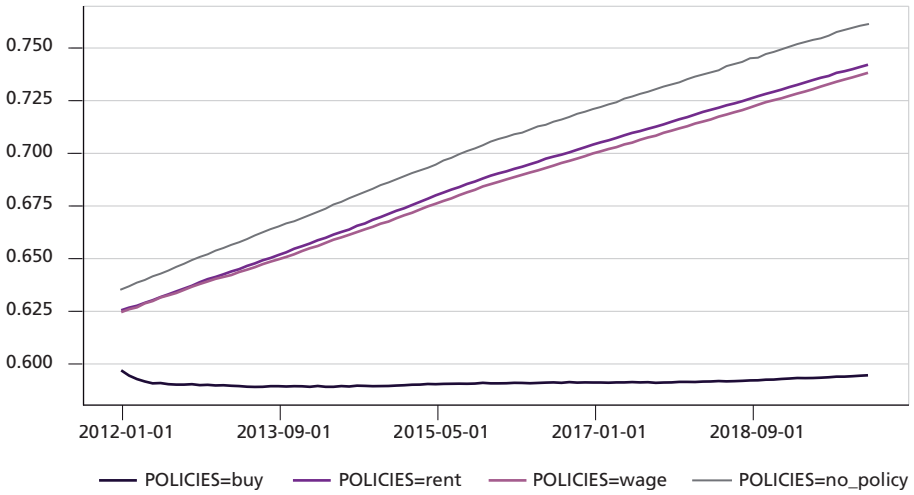
FIGURE 2
Price indicator for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

The endogenous and cyclical character of the *PolicySpace2* makes it possible to analyze how the municipal collection behaves after the intervention of policies. As described, the Quality of Life Index (QLI) is the indicator that accumulates municipal investments weighted by the population and reflected in a *proxy* of better quality of life (infrastructure). As expected, given that part of the revenues (20% in the standard model) is directed to the application of policies, the "no policy" case presents the highest QLI growth value (figure 3). Aid and rent policies are capable of promoting the dynamism of the economy through household consumption (aid recipients and property owners). In a very contrasting way, the property policy, since it immobilizes the capital in the properties, affects the transfer of general resources to the municipality to the point that collection is just enough to maintain the previous levels.

FIGURE 3
QLI, which reflects the capacity of municipal investments, for the different tests of policies, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)

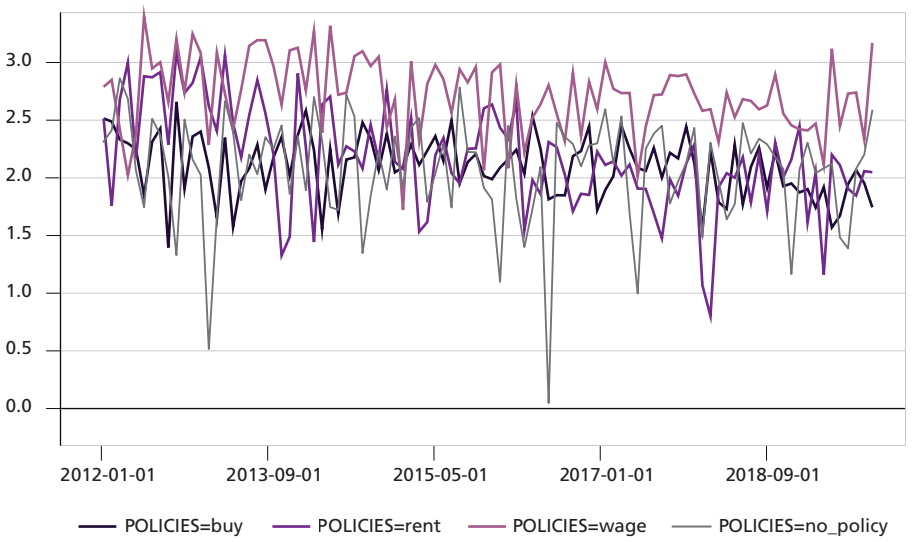


Author's elaboration.
Obs.: Agents – 1.0% of population.

Household savings and firm profits also benefit from economic dynamics. In the first case, households save more compared to the standard case for aid and rent policies, and less for the property case. The difference between the firms' profits is less pronounced, although statistics for the period indicate that the aid promotes an average profit of 2.46 – compared to 2.01 for rent, 1.96 for property and 1.87 for the case of "no policies". Additionally, all policies reduce the volatility of firms' profits, given that there is greater availability of resources and more permanent demand.

The standard deviation of firms' profit for the "no policy" case is 0.51, compared with 0.49 for rent, 0.46 for aid and 0.35 for property. In fact, probably inflated by the earnings of construction firms, property policy is significantly the most beneficial to firms' capital accumulation. The average balance sheet of firms with the property policy is 719,686 for the period, a value that drops to 694,741 with the aid policy, 692,451 for "no policy" and 692,315 for rent. In other words, the level of the last three is almost 4% lower than that reached by the property policy.

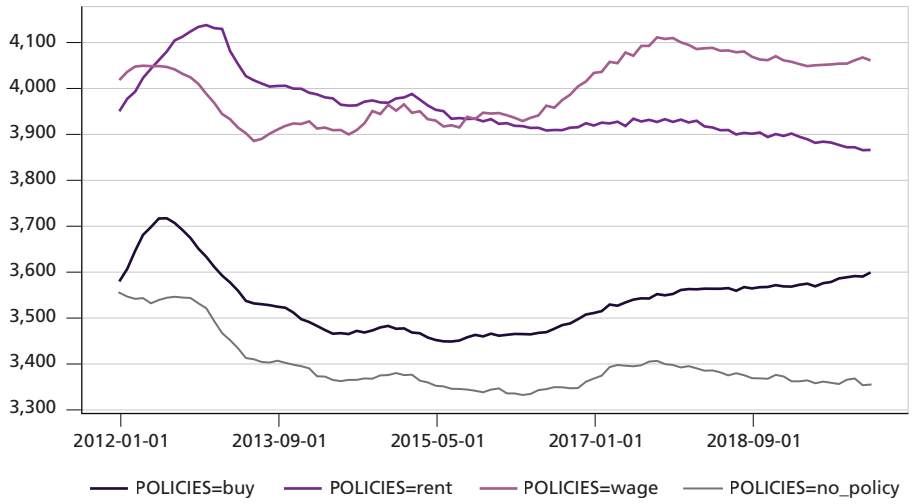
FIGURE 4
Indicator of firms' profits for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

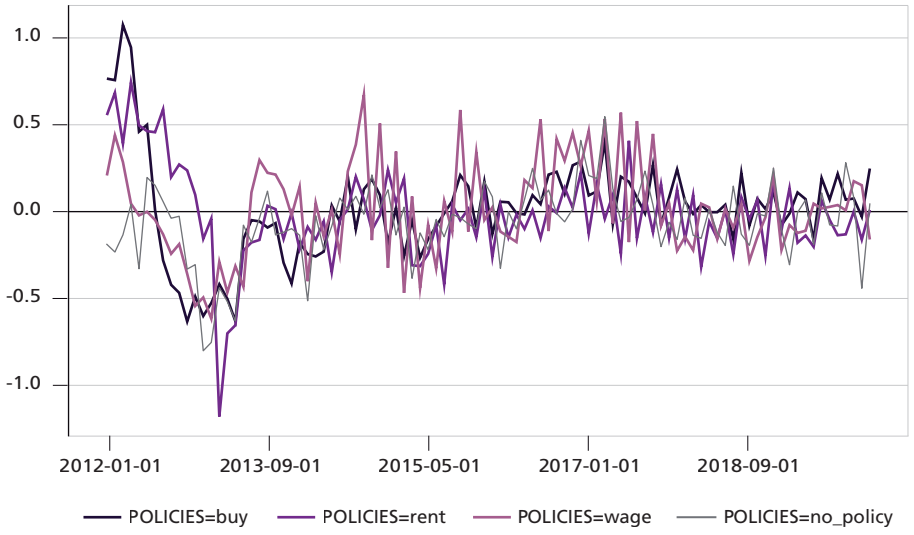
The evolution of the gross domestic product (GDP) indicator suggests that there is a persistent maintenance of gains from all policies in relation to the "no policy," with the aid policy standing out in the second half of the period, followed by the rent policy (figure 5). The property policy also shows some recovery, especially in the second half of the period, albeit insufficient (figure 6). There are no differences between the average unemployment indicators among the four tested policies.

FIGURE 5
GDP for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

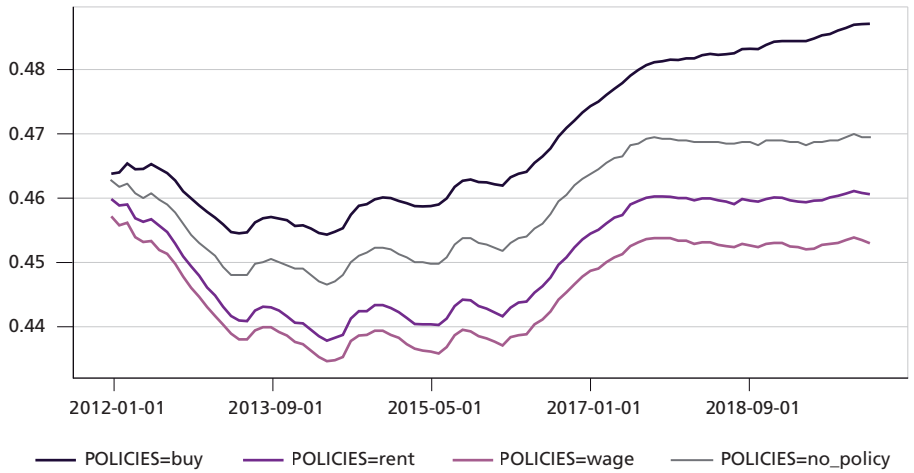
FIGURE 6
GDP variation for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

The Gini coefficient indicates the presence of greater inequality at the end of the period successively for the policies of property, "no policy," rent and assistance (figure 7). In particular, the property policy shows increasing inequality in the last third of the period, while the remaining three alternatives remain relatively constant. Comparatively, the average of the indicator is 0.02 pp higher in the property policy.

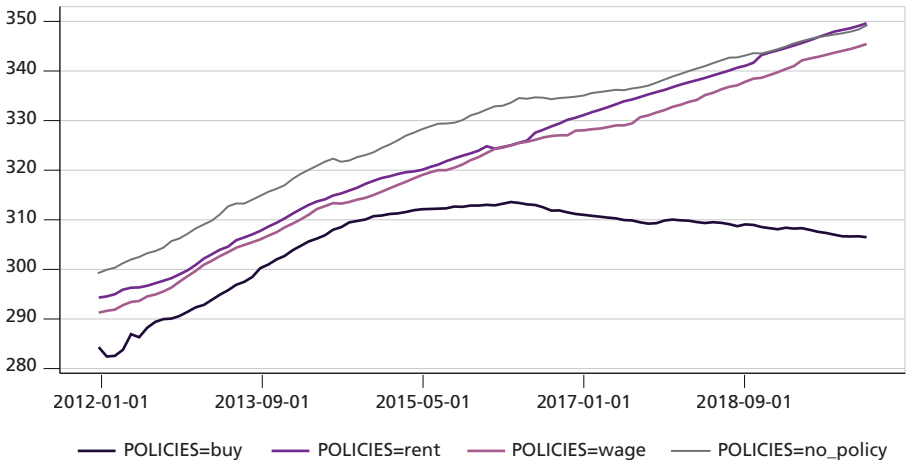
FIGURE 7
Gini coefficient for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

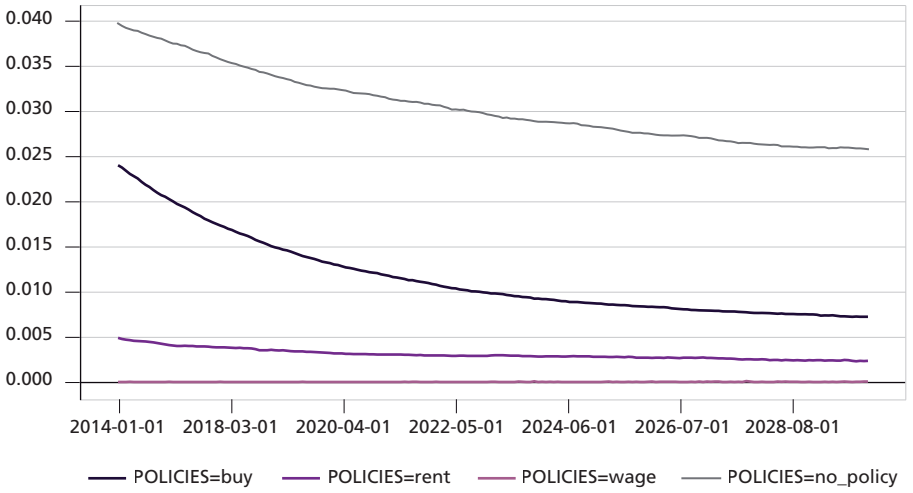
Property prices – according to the equations in subsection 7.7 of chapter 3 – reflect several mechanisms at the same time. In addition to the fixed characteristics of the properties, they are influenced by the supply side of the cost of the neighborhood (given by the application of tax resources – figure 3 – and population variation); the income of families residing in the neighborhood; the size of the real estate supply; and the time of the property was offered on the market. On the demand side, property prices are also influenced by household savings and obtaining mortgage loans. These combined effects generally produce a pattern of constant small increments in house prices. The property policy slightly alters this pattern and from the middle of the period it shows a maintenance trend, with a slight drop in property prices (figures 8 to 10). This effect may be due to the combination of lower appreciation of neighborhoods (lower amount of endogenously collected resources), lower savings by families in the neighborhoods and lower savings capacity in the purchase of properties. As an opposite effect, there is less vacancy when the policy is property, given that the municipality plays a relevant role as a real estate buyer.

FIGURE 8
Property prices for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



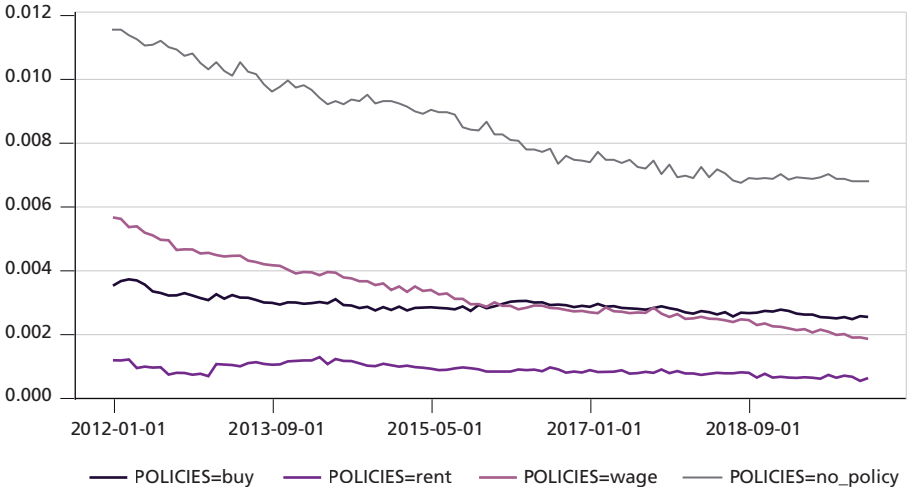
Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 9
Percentage of families without consumption in a given month for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 10
Percentage of families that rent and do not pay their rent to property owners for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2010-2020)



Author's elaboration.
Obs.: Agents – 1.0% of population.

2 ROBUSTNESS IN POLICY ANALYSIS

As with the sensitivity analysis of the model as a whole, we also subjected the policy tests to some variations to see if the results were unique to a given configuration or if they were repeated by default. Thus, results were tested for intra-metropolitan inequality (table 1), other cities (table 2), other periods for registering families (six months – standard and one year), other deciles for registering families (0.1 – standard, 0.2 and 0.3) and alternative simulation periods (2010-2020 – standard and 2010-2030), in addition to another spatial and familiar input base, from 2000 census data (2010 census – standard), in the long period (2000-2030). The result set confirms that the assistance policy seems to be the one with the best impact on society, followed very closely by the rent policy. The property policy generates more inequality in all simulations performed.

From the point of view of spatial analysis and inequality, the results also remain the same. The assistance policy generates effects of lower inequality between the municipalities that make up the Population Concentration Area (ACP) of Brasília (table 1).

TABLE 1
ACPs of Brasília: Gini coefficient results for municipalities, according to policy application

Municipality	Property	Aid	Lack of policies	Rent
Águas Lindas de Goiás	0.4138	0.3538	0.3753	0.3628
Cidade Ocidental	0.4238	0.3863	0.3961	0.3888
Formosa	0.4317	0.3850	0.3996	0.3911
Luziânia	0.4484	0.3961	0.4069	0.4002
Novo Gama	0.4427	0.3761	0.3994	0.3826
Padre Bernardo	0.3905	0.3414	0.3694	0.3559
Planaltina	0.4451	0.4105	0.4303	0.4235
Santo Antônio do Descoberto	0.3953	0.3436	0.3597	0.3430
Valparaíso de Goiás	0.4444	0.3983	0.4179	0.4051
Brasília	0.4854	0.4467	0.4619	0.4521

Author's elaboration.

Among the five medium-sized cities used for comparison, the general behavior is very similar despite the very different initial territorial and family configuration, as shown by the results of subsection 2.5, of chapter 5 carried out with the same cities. However, in all of them, the Gini coefficient shows less inequality in the aid policy, with Fortaleza and Brasília also reaching the same level in the rental policy, to two decimal places (table 2). GDP and household consumption were also higher for aid, with the worst result being achieved by the absence of policy or, in the case of household consumption, tied with property policy.

TABLE 2
Average values over the entire period for selected variables in five illustrative metropolitan regions
2A – Gini coefficient

	Property	Rent	Aid	Lack of policies
Brasília	0.47	0.45	0.45	0.46
Belo Horizonte	0.42	0.41	0.40	0.41
Campinas	0.44	0.42	0.41	0.42
Fortaleza	0.44	0.42	0.42	0.43
Porto Alegre	0.44	0.43	0.42	0.43

2B – GDP

	Property	Rent	Aid	Lack of policies
Brasília	3.410,3	3.768,7	3.814,3	3.298,3
Belo Horizonte	5.664,1	6.174,4	6.326,6	5.520,1
Campinas	3.545,7	3.782,7	3.905,1	3.312,4
Fortaleza	3.684,9	3.954,9	4.025,4	3.545,3
Porto Alegre	4.052,6	4.258,0	4.341,3	3.882,2

2C – Household consumption

	Property	Rent	Aid	Lack of policies
Brasília	0.25	0.31	0.31	0.25
Belo Horizonte	0.28	0.34	0.35	0.28
Campinas	0,32	0,38	0.40	0.31
Fortaleza	0.29	0.34	0.35	0.29
Porto Alegre	0.31	0,36	0,37	0.31

2D – Price index

	Property	Rent	Aid	Lack of policies
Brasília	1.39	1,49	1,48	1,38
Belo Horizonte	1,74	1,96	2,01	1,71
Campinas	1,56	1,76	1,83	1,55
Fortaleza	1,41	1,54	1.57	1.39
Porto Alegre	1.57	1,81	1,87	1,58

2E – Unemployment

	Property	Rent	Aid	Lack of policies
Brasília	0.11	0.11	0.11	0.11
Belo Horizonte	0.13	0.13	0.13	0.13
Campinas	0.06	0.06	0.06	0.06
Fortaleza	0.10	0.10	0.10	0.10
Porto Alegre	0.08	0.08	0.08	0.08

2F – Real estate prices

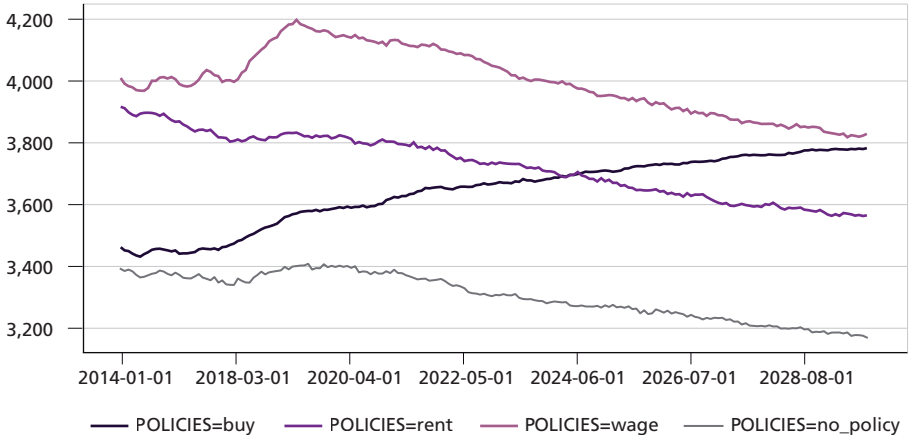
	Property	Rent	Aid	Lack of policies
Brasília	308,56	322,86	320,71	327,56
Belo Horizonte	223,44	225,13	222,86	225,78
Campinas	255,45	254,76	249,55	260,09
Fortaleza	256,47	267,39	266,32	270,93
Porto Alegre	261,24	261,14	262,09	266,59

Author's elaboration.

It is also clear that lower inequality and higher household income and savings promote a small relative increase in general prices, with the absence of policy being the least inflationary behavior – except for the case of Fortaleza, where the property policy achieves a lower price increase. In no city was there any change in the average levels of unemployment (although different from each other) due to the application of any policies. Property prices show greater variability with higher prices, but very close with the absence of policy and lower prices alternating between the other three possibilities.

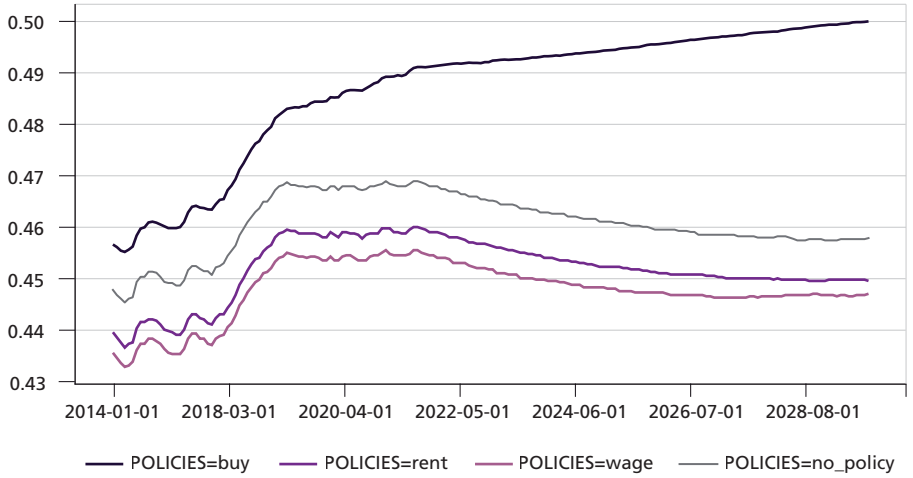
In the long-term analysis, the GDP growth trend in the application of the property policy stands out (figure 11). Although it does not reach the aid policy in absolute terms, its upward trajectory signals that it would eventually surpass the GDP results, compared to aid. However, this growth in GDP takes place at the expense of increasing inequality (figure 12), while all policies project a tendency for inequality to remain at lower levels of the indicator.

FIGURE 11
GDP variation in the long simulation for the different policy tests, with an average of twenty simulations per policy for the standard case – Brasília (2000-2030)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 12
Variation of the Gini coefficient in the long simulation for the different policy tests, with an average of twenty simulations per policy for the default case – Brasília (2000-2030)

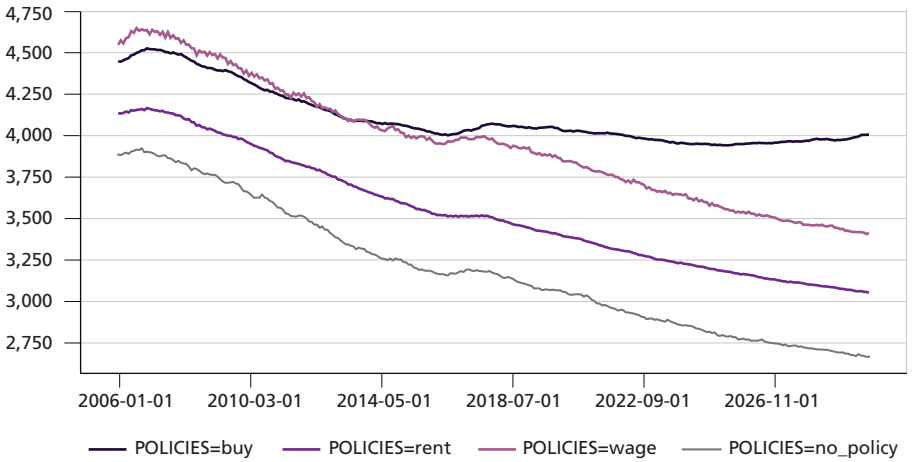


Author's elaboration.
Obs.: Agents – 1.0% of population.

Finally, from a database quite different from the others, since it uses data and spatiality from the 2000 census, the results are confirmed, with the property policy reaching a higher GDP at the end of the long period of thirty years (2000- 2030 and figure 13), but again with high inequality costs (figure 14). Thus, as in previous

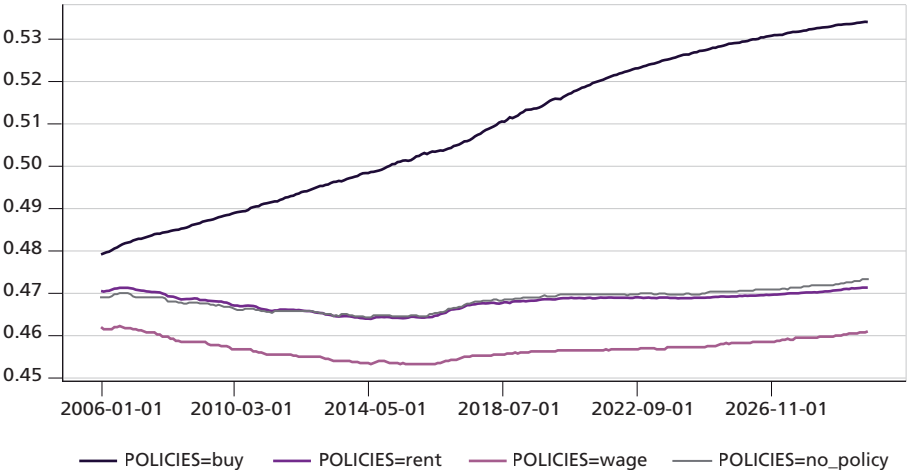
analyses, it seems to us that aid and rent policies manage to deliver reasonable levels of GDP (in relation to "no policy"), with lower absolute levels of inequality.

FIGURE 13
GDP variation in the super-long simulation for the different policy tests, from the spatial and family basis of the 2000 census, with an average of twenty simulations per policy for the standard case (2000-2030)



Author's elaboration.
Obs.: Agents – 1.0% of population.

FIGURE 14
Variation of the Gini coefficient in the super-long simulation for the different policy tests, from the spatial and family basis of the 2000 census, with an average of twenty simulations per policy for the standard case – Brasília (2000-2030)



Author's elaboration.
Obs.: Agents – 1.0% of population.

3 CONSIDERATIONS ON HOUSING POLICY

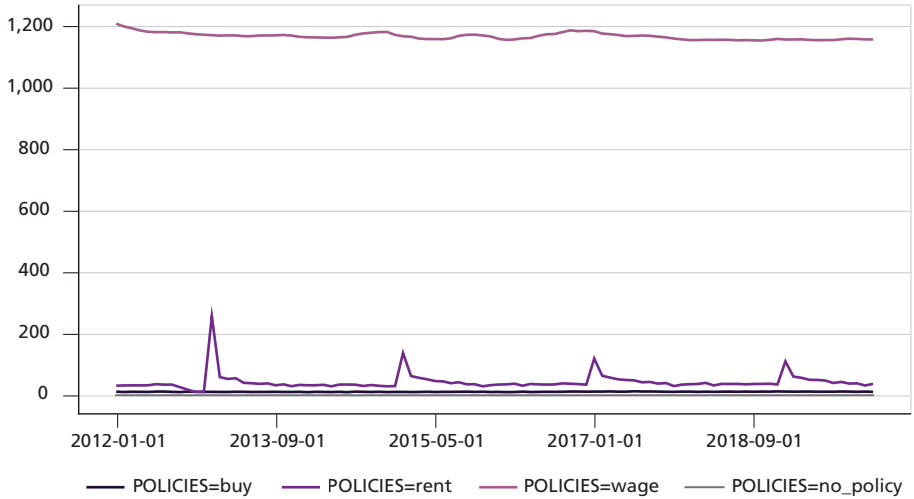
With the analysis of policy tests carried out, we can say that for the simulated standard case, from endogenous processes, derived from the construction of empirical families and firms and from mechanisms in the literature, there are strong indications that the distribution of resources in the form of aid appears to be more beneficial when compared to buying and transferring real estate or promoting vouchers for rent. Specifically in terms of housing policy, the rental policy is quite competitive with the results achieved by the aid.

However, some more general considerations are relevant in this context. The rental policy, as shown in the graph of resources implemented monthly, is periodically renewed every 24 months, suggesting that the families who receive the resources need them to be maintained on a regular basis. This continuous demand may indicate the need for maintenance of the rental policy on an ongoing basis, even serving families that are not necessarily the same.

In turn, since the property policy requires resources about four times higher than rent per family, it serves a much more restricted number of families – and, therefore, seems to indicate high regressivity, leading to a relevant and growing increase in inequality in the population as a whole. Additionally, *PolicySpace2* seems to capture the fact that the resources invested in the property are immobilized in assets and interrupt the irrigation of resources in the rest of the economy, leading to a reduction in consumption, apparently with gains only for the construction companies, to the detriment of the industry in a more general way. This occurs even though the selection of families that receive the properties is always strictly focused, among the most vulnerable in the registry in every month. On the positive side, the property policy generates the lowest price increase effect, although it is discreet in the other policies.

From the strict point of view of housing policy, this text does not necessarily exclude the option of purchasing and distributing properties to vulnerable families. The exercise carried out only demonstrates that with the same amount of resources, endogenously originating locally in the simulated economy itself, the aid policy is clearly more progressive, with less monetary value, for a greater number of families. Among the choices of housing policies, the rental policy also seems to generate greater progressivity in relation to the property policy, although it is explicit that the "housing" issue per se is not resolved. By the way, this is not resolved with the property policy, given that the number of families that remain in the register remains relatively constant, with a small reduction, precisely in the rental policy (figure 15).

FIGURE 15
Variation in the number of families awarded each policy test, with an average of twenty simulations per policy for the standard case – Brasília (2000-2030)



Author's elaboration.
Obs.: Agents – 1.0% of population.

CHAPTER 7

FINAL REMARKS

This book presents, elaborates on and shows the rationale behind the model called *PolicySpace2*. In addition, it validates this model and reviews some public policies and their results. The model relies on decision-making processes of workers and their families and firms in an empirical and spatial context based on data from 2010 for the 46 ACPs (Áreas de Concentração de População – Areas of Concentrated Population) in Brazilian metropolitan regions. The grounds for the mechanisms and the interaction of agents in the goods, labor and real estate markets follow suggestions from the literature, and we list motives and practices when they are innovative. The methodology used in the construction of *PolicySpace2* is called Agent-Based Modeling (ABM) and its description follows the precepts of the Overview, Design Concepts and Details (ODD) protocol, as well as Transparent and Comprehensive Model Evaludation (TRACE) methodology.

The purpose of this book is to build an empirical model of the real estate market for the Brazilian use case in order to describe and understand market mechanisms, in addition to driving analogies that may possibly suggest alternative policies.

In the simulation process, it is possible to understand the order of magnitude and relevance of changing parameters, rules, agent characteristics and implementation or absence of any public policy or exogenous change. The results are conditioned on the processes that are described and choices that are made.

Model validation is performed according to its purposes. In the case of *PolicySpace2*, it is possible to demonstrate that the model is robust with regard to the alteration of parameters and mechanisms, so that exogenous variations generally keep the model within adequate behaviors. Specifically, we classify this reasonable behavior based on a set of four parameters:

- GDP does not show exponential behavior or tends to zero, for example (it keeps endogenous variations and moderate growth);
- inflation has a stable monthly value (up to 2% of monthly variation) and does not generate hyperinflation, or zero inflation (except when workers' productivity has very low parameters);

- inequality among families evolves to a number close to those observed (around 0.470); and
- unemployment does not exceed 20% of workers, for several configurations of parameters.

Specifically in the case of the real estate market, *PolicySpace2* only partially reflects the price distribution, with close similarity in the first half of the distribution. The simulated spatial distribution is similar to the one we observed; however, the location is more dependent on and oriented to the location of the firms, and, in the present case, we see more valuable properties in the absence of job offers and the presence of other factors.

The preliminary results of the simulation made by *PolicySpace2* allow us to draw some conclusions. The relevance of the real estate market and its consequences throughout the economy is evident. The simple increase of families' participation in the market, the influx of families or the change in the size scale of the metropolitan area leads to effects in the real estate market that reverberate in better quality of life, savings, profits and, sometimes, less inequality.

In an endogenous way, given the configuration of *PolicySpace2*, productivity increases seem to be the most influential factor in the general behavior of the economy and its results. In the real estate market, in particular, the ability of municipalities to transform funds that are collected into life quality improvements is also relevant to make the economy more dynamic.

On a parallel basis, it is also possible to note that better salary distributions, with less retention of resources by the firms, in the format outlined in *PolicySpace2*, simultaneously suggest economic gains and lower inequality. However, it should be noted that the reinvestment of firms' capital is not incorporated as feedback in the presented interaction system.

Other elements already identified in the previous version of the model were reinforced by this analysis, which to a large extent, is more detailed than the previous one. One of them is the identification that the parameter that defines hiring only by proximity or only by qualification seems to be inadequate as an empirical explanation. In both the current and previous models, the restriction of only one criterion in the labor market leads to economic results far below those observed with intermediate parameters. This seems to suggest that, in fact, there is an "optimal" combination of criteria between spatial location and training and qualification that benefits firms and candidates.

Another result reinforced in the *PolicySpace2* is the endogenous redistribution of resources collected by the municipalities with criteria preferably for equality,

within the scope of the metropolitan region, to the detriment of the binomial local collection and local distribution.

Also, in accordance with the configuration adopted in the *PolicySpace2*, the most relevant taxes for changes in the economy were those referring to consumption and work. Lower taxes in this sense simultaneously contribute to an increase in savings in the hands of families, who participate more strongly in the real estate market and thus boost the economy.

Finally, another indication of the sensitivity analysis is that the speed with which construction firms incorporate real estate sales values seems to be relevant when this period for receiving values is small. The built-in mechanisms imply that the firm spends its own capital to maintain workers' wages when there is no receipt of sales figures. As a result, there is a greater redistribution of capital from construction firms, which generates large savings for families, encouraging their participation in the goods and real estate markets.

In the analysis of policy alternatives, the simulation of *PolicySpace2* suggests that the housing policy for the provision of 24-month rent vouchers for families brings greater social benefits to the economy as a whole, in terms of boosting the economy and reducing inequality, when compared to the policy of purchasing and distributing real estate to families. By way of illustration, the non-housing policy of offering monetary assistance to a much larger number of families (with a lower value per family, given that the resources used are the same for the alternative policies) seems to be even more beneficial than the rental policy.

In terms of future work, it is our intention to investigate whether there is a combination of policies that produces more satisfactory results than any one alone. An analysis will also be carried out using resources external to the metropolitan region – simulating the effects of federal investments or other financing entities.

Regarding the platform, several other additional analyses are possible. In particular, the plan is to link household investment in education, household ownership of firms, perhaps through quotas and shares, and credit market sophistication, also including access to firms.

Among the limitations of the model, by way of conclusion, it seems to us that two relevant elements of the real estate market cycle were not included. On the one hand, it would be interesting to include remuneration or reinvestment of resources, or even ownership of the capital of firms. On the other hand, a better characterization of the real estate market space also seems to be absent and relevant, with the possible inclusion of urban amenities, which generate value, and the possibilities and limitations given by the regulation of urban land.

In addition to the results of the analysis of the real estate market and the identification of relevant elements for the dynamism of the economy, *PolicySpace2* can also be characterized as an analysis platform that encompasses numerous possibilities. Given its open code characteristics, its transparency in the documentation and its standard explanation of the mechanisms according to best practices and modularity, it is not expensive to adapt the model to new research questions and investigations of specific regions.

We saw that *PolicySpace2* was especially promising for analysis of inequality and the real estate market, labor qualification, sector analysis and innovation at the firm level. Additionally, analyses of urban mobility and greenhouse gas emissions can benefit from the fact that each month, the model contains the location of workers and firms, in addition to their income and family composition and qualifications.

In the near future, we imagine that it will be relatively simple to incorporate elements from the 2010 real estate market, such as replacing size and quality as intrinsic characteristics of the property with real attributes, such as number of bedrooms, bathrooms and vacancies, still relating quality to the Municipal Index of Human Development (IDHM). With this, the initial configuration of the property stock will be more similar to the real one, making it possible to obtain simulated results that are not exclusively endogenous.

It also seems easy to introduce specific analyses of greenhouse gas emissions that consider the existing differentiation in the model between public and private transport.

Finally, once the platform is built, as it stands at the moment, it is possible to make comparisons between all the metropolitan regions present and to evaluate, in a comparative and relative way, different results for each of them, given the same parameters and mechanisms.

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APPENDIX A

TABLE A.1
Default model parameters

Parameter	Comment	Default value	Tested range
pop	Population percentage	0.010	[0.005, 0.030]
α	Productivity exponent	0.6	[0, 1]
β	Size of productivity divider	10	[1, 36]
ι	Labor market	0.75	[0, 1]
η	Hiring percentage by distance	0.3	[0, 1]
φ	Percentage of entry into the real estate market	0.0045	[0, 0.05]
σ	Size of hiring sample	20	[1, 100]
ς	Market size	5	[1, 20]
$\rho+$	Maximum upper value	1.3	[1, 1.5]
$\rho-$	Maximum lower value	0.7	[0.5, 1]
τ	Neighborhood effect	3	[0, 5]
γ	Lower limit of maximum discount	0.6	[0.5, 1]
κ	Decay factor in the market	-0.01	[0, -0.05]
π	Markup	0.15	[0, 0.30]
ψ	Municipal efficiency	0.00007	[0.00001, 0.00010]
ν	Maximum bank loan percentage	0.7	[0, 1]
χ	Monthly payment in relation to income	0.5	[0, 1]
ν	Number of months of construction budget	24	[1, 36]
υ	Lot cost	0.15	[0.01, 0.30]
ζ	Slow price adjustment	0.7	[0.1, 0.9]
δ	Policy coefficient	0.2	[0, 0.3]
θ	Policy quantile	0.1	[0.1, 0.3]

Author's elaboration.

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