An applied spatial agent-based model of administrative boundaries using SEAL

Bernardo Alves Furtado¹,² and Isaque Daniel Eberhardt Rocha¹

¹ Institute of Applied Economic Research, Brazil
bernardo.furtado@ipea.gov.br
² National Council of Research, CNPq

Abstract. This paper extends and adapts an existing abstract model [1] into an empirical metropolitan region in Brazil. The model - named SEAL: a Spatial Economic Agent-based Lab - comprehends a framework to enable public policy ex-ante analysis. The aim of the model is to use official data and municipalities spatial boundaries to allow for policy experimentation. The current version considers three markets: housing, labor and goods. Families' members age, consume, join the labor market and trade houses. A single consumption tax is collected by municipalities that invest back into quality of life improvements. We test whether a single metropolitan government - which is an aggregation of municipalities - would be in the best interest of its citizens. Preliminary results for 20 runs indicate that it may be the case. Future developments include improving performance to enable running of higher percentage of the population and a number of runs that make the model more robust.

Keywords: Agent-based model, Public Policy, Spatial modeling, Metropolitan regions, Public Finances

1 Introduction

Anticipating public policy effects is no simple task [2,3,4]. Once planned and put into effect, policies are subject to interested actors reaction, learning, chance and emergent behavior [5]. That is why planned actions by governments and institutions are closely monitored and adapted through time. Or at least, they should be. Public institutions observe in-course changing less often, being the ex-post evaluation (if any) the rule [5].

However, recent developments in agent-based modeling, especially for economic [7,8] and urban analysis [9], have been shown to contribute to the debate and enlighten future prospects of policy analysis.

In this paper, we depart from an abstract previous model [1], turn the model into an empirical one and test a specific policy, i.e., whether bounded municipalities, with a single metropolitan government are more beneficial to the average citizen. Such a policy test is provided as an illustration of ex-ante policy analysis. Other alternatives are also discussed in [1].

³ For some data, non-parametric methodologies, see [6].
Besides this introduction, section 2 presents and details the model and the agents' behavior. Section 3 presents the preliminary results and pinpoints the limitations of this version. The closing section 4 develops the scope of the model as a framework and details possibilities of further development.

2 Model and processes

The model in [1] is based on [10] and [11]. However, the original abstract model [1] is built upon seven, squared and fictitious regions with 1,000 agents in total.

The model presented in this paper is based on actual municipal boundaries of the metropolitan region of Brasília, in Brazil. The model also uses census population from the year 2000 [12], following age group proportions. The agents are then bounded into families and they age according to official mortality data. Female agents give birth according to their fertility rates by age and state. Number of firms and urban rural proportions also follow actual numbers and spatial coordinates (see Fig. 1).

A detailed description of the model is available in [13].

2.1 Scheduling and multiple runs

The model is structured so that a single or multiple runs can be made automatically. Agents are generated and saved for a given sample of population. In a single run, the model first saves or loads the agents (2.2). Then actions are implemented in a day, month, quarter and year pattern. The only activities that happen in business days (set to 21) are daily production and commuting.

Monthly activities concentrate the core of the model and happen in the following order:

1. Process demographics (aging, births, deaths).
2. Firms make payments.
3. Families redistribute their own cash within members.
4. Family members consume (goods market).
5. Governments collect taxes.
6. Governments spend the collected taxes on life quality improvement.
7. Firms calculate profits and update prices.
8. Labor market is processed.
9. Real estate market is processed.
10. Statistics and output are processed.

The model is run in a Python 3.4.4 environment.

---

4 See ftp://ftp.ibge.gov.br/Projecao_da_Populacao/Projecao_da_Populacao_2013/tabuas_de_mortalidade.xls.zip
5 See ftp://ftp.ibge.gov.br/Projecao_da_Populacao/Projecao_da_Populacao_2013/projecoes_2013_indicadores.xls.zip
6 See http://dataviva.info/pt/data/
7 Library requirements include: pandas, numpy, geopandas and ggplot.
Fig. 1: Case study: Brasilia. The 10 municipalities in orange officially constitute the metropolitan region (RIDE). The run of the individual municipalities are compared with the run of the model considering the full RIDE as one single government entity. Urban areas, in black, are proportionately more populated. Commuting (Euclidean distance) is considered among households and firms in both labor and goods market.

2.2 Agents

Citizens, families and households. Citizens are bounded into families and are distinguished by gender, age and qualification. Families consolidate every working members’ income and make spending decisions together. They also move and participate in the housing market as a single entity.

Houses are fixed and can be either empty or occupied although they always have a single owner. Household addresses are the reference for all members of the family. They are relevant when searching for a job, to compute commuting statistics for those employed and when choosing firms to buy goods. Citizens, families and households each have their own class instances.

Children are born and remain in their mothers’ families. The model does not contemplate neither new families nor marriage at this time.

Firms and government. Firms participate in the labor market and maintain a labor force that varies in size according to sales performance. Firms are fixed in space and pay taxes according to the government they belong to, given their location.
Production is proportional to labor force and its qualification. Productivity is adjusted by an $\alpha$ parameter. Technology is fixed, products are homogeneous and prices depend on the level of the firms’ stock.

Governments - as municipalities or as a single metropolitan region - simply collect consumption taxes at the moment of the sales at the location of the firm. Then, they improve Quality of Life within their borders, proportionally to the amount of taxes collected.

2.3 Markets

Goods market. Families consume a given probabilistic share of their current available cash depending on a propensity to consume $\beta$ parameter. Families then search either for closest firm or the cheapest price in a parameter-defined sample of the market.

Once selected the firm, the family will spend all the designated money for consumption, given that the firm has enough product to supply. Otherwise, the family consumes whatever quantity is available. The money not set to consume plus any amount not spent is saved by the family. Such saved money is afterwards reserved for use in the housing market. Taxes are paid to the local government of the firm when the family makes the purchase.

Housing market. The housing market follows empirical results for the Brazilian case which suggest that there are always a percentage of unoccupied houses. The model contains a parameter for vacant housing set to 11% in this simulation. Every month a percentage of the families enter the housing market. All vacant houses are also available for purchasing.

Both families and houses are sorted. Cheaper houses and families with less savings rank first. If the family has enough savings to purchase a house, the transaction happens. If not, the savings of the next family are checked. When there are no more families with enough funds or available houses, the market closes.

House prices are given by a fixed size and quality and the Quality of Life Index (QLI) of their region. The QLI represents the amenities of the municipality. That implies that a municipality with a more active goods market collects higher taxes and can increase QLI faster. Note, however, that the invested money is weighted by current population every month.

Every time a family buys a new house, they will evaluate their option of actually moving to the new house. If the family lives in their best house, but all adults are unemployed, they move to the second best house. On the contrary, if the family does not live in the best house and at least one adult is employed, they move into the best house the family owns. In all other cases, the family does not move.

---

8 In this simulation $\alpha$ is set to 0.3.
9 In this simulation tax rate is set to 25%.
10 In this simulation $\beta$ is set to 0.94.
11 Set to 0.4% in this simulation.
Labor market. All agents that are not employed and are over 15 or below 70 enter the labor market every month. Firms evaluate a number of strategies. They quantify a ‘cash reserve’ value which enables them to pay out employees before laying them off. If the firm’s available cash is above such cash reserve threshold, the firm enters the labor market hiring.

Further, if the firm is currently with no employees but either their stock of products or available cash is positive, they also enter the market. When the firms’ current cash drops below the monthly payroll, they start firing employees, one at a time.

Once offering firms and applicants are defined, the labor market operates under two alternatives: half the applicants are chosen according to their qualification and half given their proximity to the firms’ address.

Firms that had profit in the last quarter and have available cash above their ‘cash reserve’ level distribute such surpluses to their employees proportionally to their qualification level. Thus, firms are sorted according to their current calculated paying wages. Firms paying higher salaries choose first and get employees with better qualification or who live closer to their firms.

Spatial and markets dynamics. Those rules provide a very dynamically spatial model with families moving within and across municipalities. Firms getting varying demand and labor offers and municipalities collecting ever-changing taxes which affect their QLI at different speeds. When QLI increases too much, houses get more expensive and less families can afford to move in. Less populated municipalities then may sell less which in turn decreases tax collection.

3 Results

In order to evaluate the results, the same model was run 10 times with the municipalities being considered independent entities just as they are today (Fig 1). Another ten runs were made as if all municipalities were one single government entity.

Preliminary results indicate that, given the variability implicit in the model, QLI for both runs, together or separated entities, do not follow a single better or worse trajectory (Fig. 2). Although the weighted QLI average is slightly superior for the runs in which the municipalities are together, we are unable to state that such result hold for other samples of the population or other combination of chosen parameters. Nevertheless, previous simulations and sensitivity analysis for the abstract model [1] suggest that the model is robust to the parameters variation.

It is also worth mentioning that such results consider the population weighted average QLI of the region. That is, we are evaluating whether the increase in QLI has homogeneously affected all citizens from all regions.

\[ \text{t test could not reject the hypothesis of identical averages at 5% (t-statistic= -1.742).} \]
Fig. 2: Results of mean weighted Quality of Life Index (QLI) for Brasília, 20 runs. Blue lines represent runs with one government entity. Red lines boundaries are as currently: 10 individual municipalities. Solid lines are mean values. QLI increases according to government revenue collected for a given municipality. Housing prices are influenced by QLI at their locations.

Instead, if we focus on the individual poorer municipalities, with lower values for QLI, we can tell that a distributive effect is actually in play. On figure 3a, Brasília, the rich capital, keeps increasing its QLI as a result of the intense activities of its firms. The other municipalities observe erratic evolution with a flat pattern. By construction, figure 3b shows all municipalities see a growth of their QLIs. Of course, such growth is in detriment of the main city and, as seen, the weighed value is small and only significant at 10%.

Limitations. The results presented here are only illustrative. In order to make them more robust, it is necessary to run a higher number of times with varying samples of the population. Further, hitherto we have been unable to implement multiprocessing and parallel programming while maintaining an object oriented programing paradigm and intense agents interaction. Consequently, given the need of repeated runs with large number of agents, simulations are taking unreasonably long.

Considering the content and the investigation of administrative boundaries, we believe we would have to expand the tax systems in order to make it more similar to observed taxes. That is especially relevant because of the regressive tax system in Brazil that tends to favor metropolitan capitals.
Fig. 3: QLI evolution of each municipality. On the left-hand side, municipalities collect taxes as individual entities and invest in their own territory. On the right-hand side, all taxes collected in the region are distributed homogeneously as if they were a single government entity.

Once a full tax system is implemented, the current model needs to be validated against observed data. As it is, unemployment remains between 0 and 5% of the working force from the 5th year onwards. GINI coefficient levels are a bit below Brazilian standards at 0.28 on average. GDP per capita growth varies around 0.7%.

Finally, this model, like the abstract one, do not contain a credit market.

4 The framework and final considerations

Turning a simple abstract model into an empirical one has presented some challenges. Firstly, implementing demographics dynamics meant reading age group, gender and location of population size, aging all the agents and allowing for fecundity while controlling for mortality by region.

Secondly, another difficult task is the need to maintain a system in which firms keep a permanent working force, but have to face very dynamic and erratic sales. Additionally, keeping the system on a growth path means avoiding generalized shut down of firms, constant consumption of families and an active labor market.

Thirdly, given the nature of agent-based models and its intrinsic stochasticity, every test should include repeated simulations so that the conclusions are based on most likely scenarios. However, running simulations with a 10% of the sample for the case of Brasília would mean 273,000 agents and such simulation would need to be run at least 100 in order to guarantee robust results. Finally, a sensitivity analysis with six main parameters and ten interval tests varying one parameter per time only as the others remain fixed would imply 60 runs.

This paper illustrates ex-ante policy analysis with a case of administrative change, i.e, a fusion of 10 municipalities. However, SEAL’s framework enables a large number of policy analysis. Those could include, at least:
Transportation and commuting studies, given that firms and households are known and dynamic in the case of the latter,
– Commuting time correlated to the housing market,
– Price and wage strategies at the level of the firm specifically, or firm product and innovation in general,
– Labor market rules and relevance of workers’ qualification,
– Efficiency of municipalities’ public investments,
– And, obviously, public finances on a spatial, administratively real setting.

References

1. Furtado, B.A., Eberhardt, I.D.R.: A Simple Agent-Based Spatial Model of the Economy: Tools for Policy. JASSS. 19, 12 (2016).
2. Colander, D., Kupers, R.: Complexity and the Art of Public Policy: Solving Society’s Problems from the Bottom Up. Princeton University Press (2014).
3. Geyer, R., Cairney, P.: Handbook on complexity and public policy. Edward Elgar Publishing (2015).
4. Furtado, B.A., Sakowski, P.A.M., T’ovolli, M.H.: Modeling complex systems for public policies. IPEA, Instituto de Pesquisa Econômica Aplicada, Brasília (2015).
5. Miller, J.H., Page, S.E.: Complex adaptive systems. Princeton University Press (2007).
6. Bogetoft, P., Otto, L.: Benchmarking with DEA, SFA, and R. Springer, New York (2011).
7. Dawid, H., Gemkow, S., Harting, P., Van der Hoog, S., Neugart, M.: Agent-based macroeconomic modeling and policy analysis: the Eurace@ Unibi model. Bielefeld Working Papers in Economics and Management. (2014).
8. Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A.: Income Distribution, Credit and Fiscal Policies in an Agent-Based Keynesian Model. SSRN eLibrary. (2012).
9. Filatova, T., Parker, D., Van der Veen, A.: Agent-Based Urban Land Markets: Agents Pricing Behavior, Land Prices and Urban Land Use Change. Journal of Artificial Societies and Social Simulation. 12, (2009).
10. Lengnick, M.: Agent-based macroeconomics: A baseline model. Journal of Economic Behavior and Organization. 86, 102-120 (2013).
11. Gaffeo, E., Gatti, D.D., Desiderio, S., Gallegati, M.: Adaptive microfoundations for emergent macroeconomics. Eastern Economic Journal. 34, 441-463 (2008).
12. Brazil: Censo demográfico 2000: agregado por setores censitários dos resultados do universo. Instituto Brasileiro de Geografia e Estatística (IBGE) (2003).
13. Furtado, B.A., Eberhardt, I.D.R., Messa, A.: SEAL’s operating manual: a Spatially-bounded Economic Agent-based Lab. arXiv:1609.03996 [cs, q-fin]. (2016).
14. Nadalin, V., Igliori, D.: Empty spaces in the crowd. Residential vacancy in São Paulo city centre. Urban Studies. 0042098016666498 (2016).
15. Furtado, B.A., Mation, L., Monasterio, L.: Fatos estilizados das finanças públicas municipais metropolitanas brasileiras entre 2000-2010. In: Território metropolitano, políticas municipais. pp. 291-312. Bernardo Alves Furtado; Cleandro Krause; Karla França, Brasília (2013).