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A spatial interaction model with land use and land value

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1. Introduction

Cities seem to be living organisms without perceivable brain. The idea that some smart brain would be able to address the sustainable development of cities and territories is as old as the humanity. Nevertheless, the possibility that ICT can gather enough data and produce useful and trustable indicators (Ben Sta, 2017) for innovative urban management is just appearing, arguably as a conjunction of four forces (Angelidou, 2015): smart government, smart transport, smart buildings and smart utilities. The problem is that those indicators mostly address central managers and not to normal citizens that, as common stakeholders, base their decisions on market prices and institutional, environmental and infrastructural constraints.

The purpose of this paper is to show that, with models for complex systems applied to cities and its environments, technologies and institutions, it is possible to estimate shadow prices that reveal the scarcities that can inform central managers of governments, transport systems, major buildings and large scale utility providers. More than that, they could provide prices for decentralized decision makers addressing the problem of market failures on common laws, resources and infrastructures, while not putting all the cards and information on central managers supposedly immune to policy failures.

This exercise focus on land use and land value that are the result of the interactions between ecosystems and civilizations through technologies and institutions (Bowler et al., 2003; Pinto-Correia & Kristensen, 2013; Taylor, 1988). Technologies and institutions mirrored in the two backbones of smart cities: ICTs and Innovative Governance. The proposal is to calibrate a model of complex systems of city to evaluate the effect on employment, land use and land and real estate values (wealth) that result from changes in the environment (Climate Change), in the economy (External Relations), in the technology (accessibility) or in the institutions (Land Use Planning).

Various approaches try to explain changes in and land use patterns. Some assume that demand for land result from culture, preferences and motivations (Antrop, 2005; van Berkel & Verburg, 2011). Others focus the attention on markets, accessibilities and population (Alonso, 1964; Glaeser, 2005; O'Sullivan, 2009; von Thünen, 1826). Van Schrojenstein Lantman, Verburg, Bregt, & Geertman (2011) take into account technological and environmental constraints.

Gravity models of spatial interaction, for a long time reported in the well rooted in economics, geography and statistical theory are able to describe and predict the flow of people, goods and information across space (Roy & Thill, 2004; Wilson, 2010). With gravity models of spatial interaction, it is possible to enlarge the knowledge and expertise on transports (Earlander & Stewart, 1990; Evans, 1976; Hyman, 1969), commerce and marketing (Bergstrand, 1985; Deardorff, 1998; Huff, 1964) and demography migration (Plane, 1984). Finally, when activities have a footprint, these approaches can also be associated to land use (Anderson, 1979; Batty, 1976; Haynes & Fotheringham, 1984; Isard, 1975; Millonen & Luoma, 1999). Spatial Interaction Models can act as decision support systems (Irwin & Geoghegan, 2001) based on cost benefit analysis based on hedonic prices associated to the calibrated attraction factors of the gravity-based spatial interaction model that are closely related to the bid-rents of land constraints (Borba & Dentinho, 2016).

The aim of this paper is to develop for an urban system and its surroundings a spatial interaction model with land use to understand how regulatory, technological and environmental constraints plus basic employment and accessibility, influence employment, population, commuting, land use, land values. The application of the model to Terceira Island in the Azores for climate change and economic scenarios demonstrates its capacity to generated systemic cost benefit analysis of external shocks adding to the existing literature on urban integrated models and cost-benefit analysis in urban systems. Research questions are mainly operational. What model can interconnect the economy and the environment at an urban scale? What tool can serve to accomplish cost benefit evaluation of urban systems? Does the model apply to different urban areas? Does the system provide useful information for decentralized decision makers?

The development of the work involved different phases. Section 2, proposes a reformulation of former models (Borba & Dentinho, 2016; Gonçalves & Dentinho, 2007; Silveira & Dentinho, 2010) to include the relation between bid-rents and land prices for urban and rural areas. Section 3 refers to data collection and the calibration of the model that explains land use patterns and bid rents as a function of the basic employment, accessibilities and land aptitudes. Section 4 presented a hedonic regression relating the values of land and property with the bid-rents estimated by the Spatial Interaction Model with Land Use. Section 5 presents the estimates of land uses and land values associated to climate change scenarios. Section 6 advances the conclusions and

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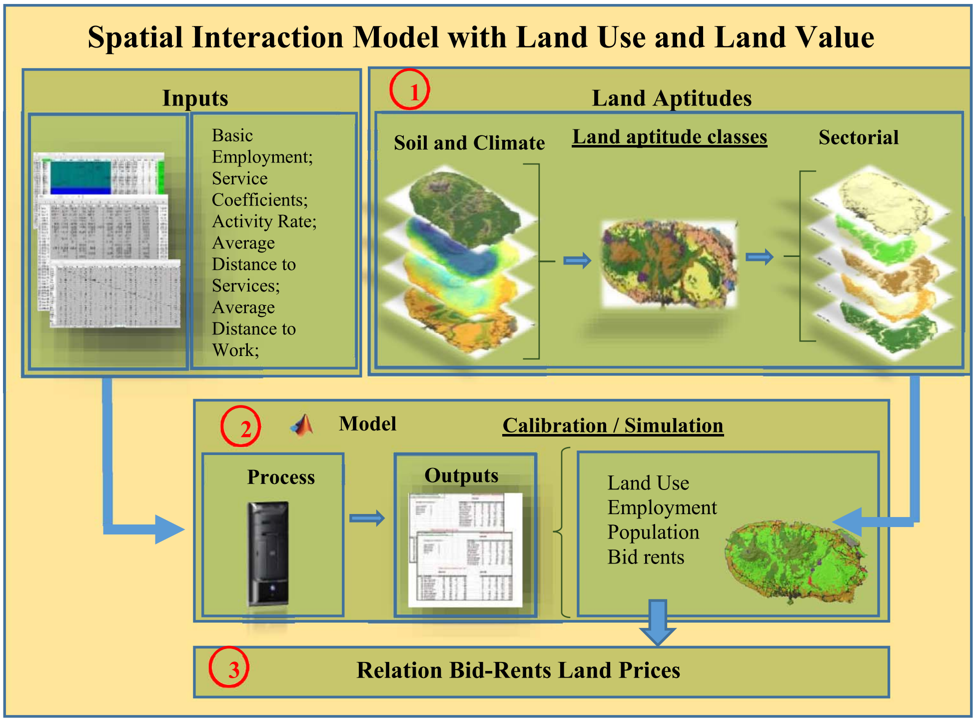

Fig. 1. Spatial interaction model with land use and land value.

prospects for future work.

2. Spatial interaction model with land use and land values

The spatial interaction model with land use and land values is a gravity-based Garin/Lowry-type model (Garin, 1966; Lowry, 1964) with footprints for each activity and land use constraints. The model generates residents, employment per sector, land use and land value by zones and land aptitude classes resulting from exogenous variable such as the basic employment per sector and zone, resident and employment footprints, land availability by class aptitude, accessibility, average residence-employment per sector and residence-services per sector distances.

As presented in Fig. 1 the Spatial Interaction Model with Land Use and Land Value. In Module 1 environmental data is treated using a GIS framework to get land aptitudes for the various sectors. Module 2 includes the model described above and programmed in MATLAB. Module 3 is an econometric hedonic price model that related land prices with the bid-rents of the Spatial Interaction Model with Land calibrated in Module 2.

The Design of Land Classes results from combining land aptitudes for different sectors generating classes of land aptitude with similar capabilities to receive the various sectors and design them in a map.

The model to calibrate and simulate assumes that the spatial interaction of activity in one sector located in one origin i and which employees reside in one destination j is positively related with the attraction on destination j (V_j/W_j) and negatively related to the distance between origin and destination (d_{ij}) controlled by the impedance coefficient α. A higher value W_j on a specified zone signifies that the attraction (V_j/W_j) must be reduced to guarantee that all demand on that zone/land class fits into the available land; W_j reflects ultimately higher real estate values and are related to the value of the bid-rent of land availability of land class/zone (j). V_j provides scale to (land class/zones) with different dimensions. Summing up all the commuting movements from employment to residence for each residence and multiplying by the inverse of the activity rate (r) we obtain the Population in each land class/zone.

On the other hand, the activities generated for each sector (k) in zone/land class (i) serves the population that lives in the various zones/land classes positively related with the attraction on destination j (V_j/W_j) and negatively related to the distance between origin and destination (d_{ij}) controlled by the impedance coefficients per sector $\beta(k)$. Summing all the shopping movements from residence to services for each residence and multiplying by the various service coefficient (s_k) we obtain the employment in each land class/zone.

Defining the elements of the matrices $[A]$ and $[B]$ as:

$$[A_{i(kj)}] = \frac{r.\ V_j/W_j.\ e^{-\alpha d_{ij}}}{\sum_{j=1}^{m} r.\ V_j/W_j.\ \ e^{-\alpha d_{ij}}} \text{ for all } k \tag{1}$$

$$[B_{(jk)i}] = \frac{s_k.\ V_i/W_i.\ e^{-\beta(k)d_{ij}}}{\sum_{i=1}^{m} s_k.\ V_i/W_i.\ \ e^{-\beta(k)d_{ij}}} \tag{2}$$

The endogenous variables (P_j and E_i) result from the exogenous variable E_b, using matrices $[A]$, $[B]$ and the identity matrix I_M:

$$[E] = \{I_M - [A][B]\}^{-1}.\ \ [E_b] \tag{3}$$

$$[P] = \{I_M - [A][B]\}^{-1}.\ \ [E_b]\,[A] \tag{4}$$

To secure that the residence-employment commuting costs and residence-services shopping costs from the model are equal to the real average costs, the model is iteratively calibrated for parameters α and $\beta(k)$ until the model average costs are similar to the real average costs. V_i/W_i values are also iteratively calibrated to guarantee the accomplishment of constraints that the demand for space in each zone/class is lower or equal than the space available. The V_i/W_i calibrated attraction values can also be interpreted as bid rents (ω_i) (Roy & Thill, 2004; Wilson, 2010). The bid-rent is complementary to the transportation costs and is given by the formula:

$$\omega_i = -\left(ln\, \frac{1}{\left(\frac{V_i}{W_i}\right)}\right) \tag{5}$$

The model code is in MATLAB 2013a (Mathworks, Natick, United States). The attrition parameters α and β (k) and the bid-rents are adjusted by Hyman's calibration method (Hyman, 1969).