TITLE OF THE DOCTORAL THESIS

Dynamic model of urban systems considering the phenomena emerging from the behavior and constrains of the system, using the approach of multiple spatial-temporal scales.

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1. CENTRAL RESEARCH QUESTION

- How does urban equilibrium affect, interact and change in different space and time scales?
- How does land use and transport equilibrium depend of the decisions and dynamics of the different agents of the urban system in several time and space scales?

2. HYPOTHESIS

Microeconomic models of urban equilibrium can be extended to dynamic models, based on the structure of complex system, typical of the urban system by its hierarchical organization, with a large number and variety of agents (individuals, firms, schools, etc.) with independent choice and interactions that inducing nonlinear relationships. The urban system is also a large scale problem because of the large number of spatial options that make choice alternatives differentiable generating a large set where options are feasible. The number of consumption goods and services is also large and diverse, which can be consumed as activities. Additionally, this system is characterized by variables that stochastic changes at a very different speed, from the slow change on residential and job choices to the fast change on transport route or modes. All these elements are common to other ecological systems from where the system dynamic literature has built tools to model the long term path of the system.

3. BACKGROUND AND CONTEXT (LITERATURE REVIEW)

3.1. Static equilibrium:

In economics literature there are static equilibrium of urban models, which are previously defined independently of land use and transport (Alonso 1964, Martinez and Henriquez 2007, Martinez and Araya 2000, Martinez 1992, Beckmann at. Al, 1956) or integrated to these factors of the urban system (Briceño et. al 2008, Bravo et. Al. 2007, Nagurney A, and Dong J, 2002, Chang and JS Mackett R, 2005, JS Chang, 2006). On the other hand, most land use works calculate equilibrium in short term, where consumers make the where to be located decision, while the offer is a fixed real estate. In the long term, the supply and demand are variable, so that the positions of households and firms affect the decisions to produce goods from the real estate companies and vice versa (F Martinez, Hurtubia F 2006). In general, the long-term models do not analyze non-linear dynamics generated by the interaction of agents but, through discount rates, it can find the benefits associated with the different activities of the urban system.

3.2. The Dynamics of Urban Systems

There are various methodologies that seek to explore the dynamics of land use and transportation in an integrated way, including in some cases basic analysis of sustainability. A major failure of these techniques is the poor analysis of the economic equilibrium conditions in each instant of the time horizon studied (Andersson 2008). Some activities were done between August and November 2008 including the revision of some works about the dynamics and interaction among the different actors of the urban system.

First, this report will provide the definition of urban dynamics and spatial interaction. According to Michael Batty (International Encyclopedia of Human Geography. Editors: Rob Kitchin and Nigel Thrift 2004), spatial interaction space is defined by the movement of goods, people and information between different locations (origins and destinations). Some mathematical models used to represent these movements are based on physical laws and these are useful to describe the interactions between travel and migration into the cities.

On the other hand, the urban dynamic is the set of processes and spatial-temporal changes in the structure of urban system. These changes are represented by a large number of processes of social, cultural, economic, commercial and political dimensions that occur simultaneously within an urban space geographical, which generally are intertwined in time scales such as the buildings and people cycle life, movements in space and time.

An urban actor or agent is a person or group of people acting in a particular field of urban economics (Aguilera 2000), with their individual incentives to interact with other actors. Urban phenomena (social, economic, cultural, political) is included in the study of complex systems (Cecchihi, 1996, Epstein and Axtell, 1996; Allen, 1997; Allen et al, 2005; Aguilera, 2000;

Albeverio et al, 2008). The essence of a complex system is the high dynamics and interaction, so changes or perturbations in some of their variables, generate changes and variations in others. In addition, another important feature is the self-organization, as in the urban system (Allen, 1983, 1997b).

As the most relevant aspects of the complexity of urban systems can be found:

- Evolution of the urban structure: spatial distribution of actors and activities. Formation of the spatial profile of the city (Aguilera, 2000; Batty and Longley, 1994).
- Activities of human beings: flows of vehicles, pedestrians behavior patterns (Helbing and Molnár, 1997)

Various authors have based their work on different methodologies and modeling techniques to analyze urban dynamics, such as systems dynamics, economic modeling, dynamical systems, stochastic processes and simulation, among others. An overview of some of these methods and some interesting papers are shown next.

3.2.1. System Dynamics

The system dynamics is a technique that tries to model the dynamics of complex systems such as economic systems, in which the subsystems and agents show interaction and intercommunication. It was created by Jay Forrester in the'60s with the rise of the MIT System Dynamics Group. The models generated by the system dynamics describe systems interconnected by feedback loops that expose the nonlinear nature found in many real world problems. In turn, system dynamics that allow to perform simulations to understand more clearly the behavior of the system analyzed. This methodology has been used by different authors to model urban systems. The same Forrester developed the theory of dynamic systems based on urban problems, the paper Urban Dynamics Model (Forrester, J., 1969, Urban Dynamics, MIT Press, Cambridge, MA) is a first approach to urban modeling where the dynamic impacts of three major urban areas (population, industry and households) in an imaginary town are analyzed. In (Sang 2001) a model of dynamic systems based on the functions of causality and feedback from a large number of variables physical, socio-economic and political, was designed. The model is divided into seven ub-models: population, migration of population, households, growth of labor-employment-availability of land, housing development, travel demand and level of traffic congestion. It´s simulated in DYNAMO and is tested with data from a particular town. This article is a result of the doctoral thesis of Lee Sang in 1995 entitled "An Integrated Model of

Land Use / Transportation System Performance: System Dynamics Modeling Approach." In the paper (Pfaffenbichler and Shepherd, 2002.) is combined mathematical modeling techniques and system dynamics. In addition, it is sought to define the dynamic interaction between land use and transportation. The main goal is found sustainable policies in areas such as environment, safety, health, land use and congestion. The objective functions are optimized to assess the impact of strategies in different scenarios. For solving the optimization models the amoeba method is applied (Nelder, JA and R. Mead (1965). Computer Journal 7, p.308.) A problem of the system dynamics is the less economic link with the models proposed.

3.2.2. Spatial or Geographic Economy

The spatial economics is concerned with the allocation of (scarce) resources over space and the location of economic activity. Moreover, it studies the reasons and factors that affect the location of the population, economic activities in cities or regions and the agglomeration phenomenon (Fujita et al 1999). The questions which their answer where sought are: why are there cities? Why do some regions prosper while others do not? Why do we observe residential segregation? Why do firms from the same industry cluster get together? How do they affect the transport costs in the locality? (Duranton 2005)

One of the spatial economy areas research is the evolution of urban systems in a hierarchical form. Item of special interest to our study.

This topic is sought to determine the reasons of the difference between cities size and various types of economic activities done in them. This means, the urban hierarchy is the result of an economic integration process in the space, where it is examined the growth of different groups of companies and its evolution in different orders of time (Fujita et al, 1999, and Thisse Tabuchi, 2006).

Spatial economy is characterized by the behavior of interaction and economic decisions of individuals and firms that generate concentration of the economic activities in a specific area (spatial agglomeration), creating incentives (centripetal forces) on different agents for grouping in a city or region. At the same time, the agents are affected by dispersal forces such as congestion cost in the city, immobile factor, high rents, life or pollution cost or quality (centrifugal forces).

The balance in these models derives from balance between agglomeration and dispersal forces. In addition, these forces or stochastic shocks generate randomness on the analysis of the spatial distribution and the urban system activities.

In their article of 2003, Duranton and Puga review the theoretical works about agglomeration. These are based in microeconomic concepts and divided in three types: sharing (the relationship between suppliers of intermediate goods and suppliers of final goods), matching (interactions in the labor market) and learning. In addition, they describe the growth and co-evolution of the cities by the following considerations: the specialized and diversified cities co-exist; the large cities tend to be more diversified; the distribution of relative sizes of cities, the ranks of individual size cities and degrees of expertise are stable over time; the growth of each city is related to their specialization and diversification, and its relative location. Also, there is a high turnover rate of producing plants. Most of the innovations and new plants are created in diverse cities.

In this way, we can use some developed ideas for the analysis of the regional hierarchy (various cities and various roles), for complementing the concept of micro and macro scales space at the urban level. Other interesting works about the spatial economy are the study of urban evolution through networks of interaction between activities or agents. In these works concepts of economic growth with cellular automata theory and stochastic processes are combined. There are some models where stationary properties are analyzed in aggregate form of economic geography (Andersson et al. 2002, 2003, 2005, 2006). Those models only explain in an aggregated form some features of the urban system, but it is interesting to notice by the probability rules used to generate the grouping homes, agents or activities. According Andersson et.al 2005, the proposed of such models is: “to address the problem of how empirically observed hierarchical structure of settlements can be explained as a stationary property of a stochastic evolutionary process rather than as equilibrium points in a dynamics, and to improve the prediction quality of applied urban modeling”.

The fundamental logic of this model is the same as multiplicative growth models, Simon´s model (Simon 1955). Which it may be applicable if the system has parallel growth of similar components.

These models have a problem that is its less micro-economic analysis. Also, these models do not include sustainability analysis, sustainability and resilience. Others applications of cellular automata in land modeling and urban dynamic are described in Aguilera, et al 2001, such as urban growth and urban morphology (Couclelis, 1985, 1989, 1996), real estate market dynamic (Sichirollo, 1996), land use dynamics (White and Engelen 1993, 1994, 1997), modeling the micro-dynamics of urban system (Vancheri et. al. 2008), etc.

3.3. Panarchy Methodology

Finally, an important work is the study of the methodology of system dynamics, described in the book Panarchy (Gunderson and Holling 2002). This methodology do not seek to study urban dynamics in a direct way, but it can be an interesting reference for understanding the dynamics and evolution of complex systems, where a large number of factors and agents in hierarchical form interact.

According to Resilience Alliance, “The purpose for writing the book Panarchy, was to develop an integrative theory to help us understand the source and role of change in systems- particularly kinds of changes that are transforming and take place in systems that are adaptive. Such changes comprise economic, ecological, and social systems, and they are evolutionary. They concern rapidly unfolding processes and slowly changing ones; gradual change and episodic change; and they take place and interact at many scales from local to global”.

Panarchy´s goal is to show up the interaction between change and persistence, between the predictable and unpredictable, noting that changes in ecosystems generate changes to society and economic conditions (the intersection of extreme weather, poor land use, political instability). In addition, Panarchy analyzes and develops concepts such as sustainability, resilience, persistence, adaptation, hierarchies, cycles of growth, liberation, reorganization, accumulation of information and balances of nature, within the framework of various complex systems. It is possible that some factors not taken into account in models of urban dynamics can be analyzed through the dynamics of the systems studied by this methodology. Otherwise, Panarchy can serve as a complementary tool for the development of economic models of the urban evolution.

4. METHODOLOGY

The doctoral research consists on developing any dynamic equilibrium urban models, based in the integrated equilibrium static model and the role of the market of the land use and transport, using the body of tool developed in system dynamics literature. The principal goal is to innovate on the capability of urban models to analyze the long term sustainability of the public policies in the urban context, specially about limited and non-renewable resources (space, air, energy, time, etc.). Current models don't work adequately the non-linearity that is obtained by the consideration of all constrains in the long term, since they only estimate the equilibrium associated with future scenarios and then social benefits/costs according to the long term social rate are discounted. One of the most interesting and challenging issues in developing research to make static models into a dynamic form is to understand complex process as the spatial segregation of groups (economics, socials, religious, etc.). We produced a first outline of the restrictions and requirements of the dynamic models as described below.

1. Analysis of time and space scales. Micro and macro scales. Hierarchies: The agents or activities of the urban system have different scales of time or space (Example: slow changes in the choice of housing or space, choice of routes or means of transport), so it's necessary to describe and analyze the influence of various levels in temporary stability and sustainability. Therefore, It is important to review the different ways to group similar agents and define the relationship of similarity between them. In addition, it must be defined scales between the actors (population, households, firms), where it is required to simulate behavior categories whose members are homogeneous. Also, it is necessary to introduce the concept and level of hierarchy between the scales.

2. Dynamic between the levels of the same scale. Dynamics between different scales: Some decisions or activities made in the same level (temporal, spatial or agents) affect the urban system configuration and create patterns of behavior. These dynamics admit nonlinear relationships between agents and the subsystems of the same hierarchy that must be modeled. In addition, The decisions and actions are taken at each level (micro or macro), can affected or redistributed to other levels.

3. Randomness inherent in each scale (shocks and random behavior) : At all levels occur stochastic shocks or perturbations, both internal and external that may temporarily change the equilibrium of the system to an unstable situation. In this case, it may be that there are no changes in the balance over the long term (equilibrium balanced) or generate new structures. In addition, we may suppose a random behavior in the agents of the urban system.

4. Memory : The urban system should be taken as a value-added memory and learning pass experiences. In addition, urban infrastructure imposes strong restrictions for planning. A decision or action of an agent, at a given time scale, influences the decisions that some other agents would be taken in the future (for example, location externalities).

5. Inter-temporal equilibrium: the equilibrium of agents and balances system: The models, that analyze urban dynamics in the long term (from an economic perspective), should ensure that there is equilibrium to the agents, each subsystem and the total equilibrium in the whole system at every instant of time horizon of study.

6. Other features: Other features of the urban system that must be considered are: Factors that contribute to the long-term sustainability and its evaluation on the proposed models. Influence of regulations and policies. Dynamic interaction between societies and ecosystems. Changes of complex adaptive systems.

5. FIRST RESULTS:

A HIERARCHICAL MICROECONOMIC MODEL OF ACTIVITIES CHOICES

In recent years a number of microeconomic models attempt to explain the consumers' behavior regarding consumption of goods, choice of activities and the use of time. Under the common utility maximization paradigm constrained by time and income budgets, several authors have made contributions, for example DeSerpa (1971) considers technical relations between goods' consumption and the minimum time to consume, and introduce leisure activities; Train and McFadden (1978), Jara-Díaz and Guevara (2003) and Jara-Díaz y Guerra (2003) analyze the interaction between the transport mode choice and the choice of activities to perform. In all these papers the assumption is that the consumers attain a long term equilibrium adjusting working and leisure hours, as well as travel choices to an optimum. Jara-Díaz et al (2008) and Munizaga et al (2008) show some recent empirical evidence on time assignment to activities and travel, which leads to the estimation of activity based choice models from which they derive values of time on different contexts.

This first model explores a theoretical model specified under a similar utility maximization paradigm but differs from previous ones in that the time scale is considered explicitly in the model, such that some choices involve a long term commitment, like jobs or education, and other are defined in the short term, like leisure and shopping. The time adjustment of these choices occurs in different scales and the resources involved on activities are also of different magnitude. We specify a stylized model with two time levels, the macro and micro level, to study what optimality conditions arise on these setting, what theoretical arguments support previous studies on the value of time and the behavior on activities choices, and what lessons can we derive from two analyze the empirical evidence.

In the macro scale the variables of the optimization problem adjust at slow speed, while in the micro level they change and adjust to changes in the system much faster but conditioned by the long term choices. This defines a multi-scale dynamic of the consumers' behavior which is simulated.

We demonstrate that value of the time resource can be generalized to all activities, including those that do not produce income, and we show that observations at micro level, like transport mode choice, are strongly conditioned by prevalent choices in the macro scale.

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