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Gravitational forces in the spatial impacts of urban sprawl: An investigation of the region of Veneto, Italy

Eric Vaz [a,*], Peter Nijkamp [b]

[a] Ryerson University, Department of Geography, Toronto, ON, Canada
[b] Vrije Universiteit Amsterdam, Faculty of Business and Economics, Amsterdam, The Netherlands

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ABSTRACT

Urban sprawl has become an increasing concern in Europe, given the abandonment of rural areas and loss of natural landscapes. In southern Europe remarkable changes have been witnessed in the last few decades concerning land-use and socio-economic growth. Much of this change has had an impact on the morphology of urban footprints. While urban growth and sprawl are conceptually very different, the latter has had an unprecedented impact on the landscape and on the existing environmental systems. This paper sets out to analyse urban sprawl on the basis of the concepts of gravitational theory. This paper brings about a convergence of the spatial sciences within the scope of analysis of theoretical physics, offering a definition of urban sprawl applied in a novel context to assess urban sprawl. Methodologically, we propose to measure acceleration a as the amount of urban change witnessed in urban land-use during a given time t, affecting the regional dynamic of intra-city growth. The concept of a gravitational force F is then discussed in function of its relation to the spatial proximity of the main cities in Veneto in Italy. We provide a novel approach, which improves our quantitative understanding of urbanization between city cores, and offers a gravitational regional system, driven by laws of acceleration and forces governing the structure of urban change. This approach allows us to calculate a city mass m, which permits us to identify, using the dataset of CORINE Land Cover Survey between 2000 and 2006, the cities which will be responsible for future urban sprawl, and to quantify this phenomenon. Our results show that Verona, Padua and Trevisso generate per mass the urban sprawl, which is then validated by defining a buffer that assesses this change. In this sense, we offer a new interpretation of urban regional change in land use, and a spatial model which can efficiently assess urban areas with regard to urban sprawl, by adding geographical capabilities to regional science and classical mechanics. In addition, our work introduces a new process in describing regional urban interactions from a spatial perspective.

Introduction

City landscapes have been rapidly changing in the last few decades in response to accelerated population growth and the increasing transition from rural to urban areas (Jenerette & Potere, 2010; Vaz, Noronha & Nijkamp, 2014). Urban sprawl, which results mainly from population dynamics and the accumulation of economic activity in cities, has become a serious cause for concern, as it brings in its wake loss of natural land and environmental resources (DeFries, Rudel, Uriarte, & Hansen, 2010). As a caveat to economic growth, sustainable development has predominantly addressed the consequences of the loss of ecosystems (Costanza et al., 1987; Vaz, 2014), biodiversity (McKinney, 2002), and both natural and historical heritage (Vaz, Cabral, Caetano, Painho, and Nijkamp, 2012). The combined effects are unprecedented, and the discussion on growth within the context of the current economic crisis has now dominated the issue. Within this context, leapfrogging, where developers 'skip over' high value city-centre locations in order to obtain a more competitive land price (Heim, 2001), questions further the role of the best long-term practices for economic development, environmental sustainability and urbanization processes. Leapfrogging has a direct connection to the periphery of built environments, where prices are more affordable, and which is thus prone to be chosen as a suitable place for investment in construction. These developments, however, contribute directly to sprawl rather than growth. Such processes may be represented on a geographical scale with fractality, as proposed by Benguigui and Czamanski (2004), whereby the spatial dimension of urban land use becomes detectable, and the changes over time possible to

* Corresponding author.
E-mail addresses: evaz@ryerson.ca (E. Vaz), p.nijkamp@vu.feweb.nl (P. Nijkamp).

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assess. Recently, the European Environmental Agency (EEA) released a report entitled *The Changing Face of Europe's Coastal Areas*, (EEA, 2006a), which questioned with increasing concern the human impact on the environment, and on coastal areas, where most of the population resides. That report was followed by a further EEA (EEA, 2006b) report in 2006, *Urban Sprawl in Europe — The Ignored Challenge*, which identified the concerns about urban sprawl, resulting from population dynamics and with a direct impact on land use. These dynamics that result in urban sprawl are somewhat vaguely defined, as they are the result of a combination of dynamics, metrics, and extent over time (Sudhira, Ramachandra, & Jagadish, 2004). One may consider sprawl to be the result of excessive city growth (Brueckner, 2000). However it also occurs because of a combination of: a) population dispersion b) the disconnection between infrastructures and buildings; and c) the creation of new core developments in the suburban regions of cities — especially when these factors arise in an uncoordinated way (Ewing, Pendall, & Chen, 2002). Current urban growth models however, fail in understanding the dimension of disconnection and interaction between new urban areas within the same region. This is the result of two underlying assumptions found in the urban growth model rationale: i) centricity: that is, from a geographical modelling perspective, urbanization follows the role of distance decay where the allocation of urbanization is led by proximity of previously constructed areas; and ii) cellular neighbourhoods: the weights calculated for future urbanization for urban growth models are the result of the neighbouring cell, and not the result of an entire system of regional dynamics, that is, the reality of an urban spatial structure, which is by far more complex (Anas, Arnott, & Small, 1998). An intercity gravitational model could help to better understand urban sprawl at the regional level. Such a model offers an understanding of changes between all urban footprints in the region, as they respond to change according to the force of a gravitational pull, a process previously not considered in urban and geographical literature as an independent force, which exerts pressure over the entire regional environment rather than being limited just to the city fringe. The model of intra-city gravitation force proposed is, therefore an elegant solution for urban sprawl, which considers the new form and shape that urban areas are currently adopting (Kourtit, Nijkamp, & Partridge, 2013), and is a response to the interaction between urban areas at the regional level. It does not intend to look at the complexity of the urbanization processes from a local perspective, but rather interprets a regional systemic perspective of urban change given laws of gravitational forces and constants of acceleration and mass. The model, therefore, provides a vision of areas which are very likely to witness future urban sprawl, but does not respond to local dynamic influences by variables relating to geophysical constraints. Rather, it interprets the nature of the urban footprint through gravitational forces. The difficulties in fully understanding, and the concern for, the phenomenon of sprawl have led to a growing literature in the fields of urban sprawl, urban growth, and sustainable development, this clearly shows the need for structural research to understand the imbalances brought by urban growth to regions with changing landscapes (Vaz, Noronha, Galindo, & Nijkamp, 2014). Needless to say, what we want to bequeath to future generations will be undermined by the problems we leave unsolved. This has an effect on spatial interactions, where dynamic modelling approaches, on the spatial level, relate particularly to gravity models (Nijkamp & Reggiani, 1988). Understanding the anthroposphere in the context of city landscapes and their changing metabolism, which is dependent on the interaction of urban regions and hinterlands (Kennedy, John, & Engel-Yan, 2007), and being aware of the vulnerability of areas at major risk, is thus the next step for the purpose of better planning the changing environments and setting the limits of carrying capacity driven by economic demand. Although urban growth modelling has been a long tradition in human geography, and is formalized in the First Law of Geography (Tobler, 1970), little attention has been given to the regional dynamics of urban change. Most of the literature assesses the urban and suburban regions (White & Engelen, 2000), offers simulation outcomes through non-linear modelling (Barredo, Kasanko, McCormick, & Lavalle, 2003; Clarke & Gaydos, 1998) and has even expanded the modelling framework to different land-use types (Pontius, Shusas, & McEachern, 2004). However, the impacts of the rate of different cities growth in the same region, and the resulting impacts on urban sprawl given their regional interactions, have not yet been explored. Land-use comparison at multiple points in time by means of regional land use inventories could enable us to make a better assessment of these urban interactions. The output of such combined approaches is led by the current state-of-the-art technologies and methods, which allow us to look at wider areas of study and interpret large data sets. Urban growth models have developed elaborate prediction methodologies which allow complex interactions of probabilistic changes in types of land use, and are of the utmost importance for decision making (Patino & Duque, 2013). Markov transition chains combined with Cellular Automata (CA), for instance, are an increasingly interesting and pervasive way of modelling trends of future urban growth and sprawl (Kamusoko, Aniya, Adi, & Manjoro, 2009; Vaz, Nijkamp, et al., 2012), where CA provides a non-linear analysis of the interactions and predictions of future land use. The integration of these types of models with Geographic Information Systems (GIS) allows these models to assess combined data on a multi-temporal basis, and relate these data to other issues of importance, such as coastal erosion and degradation of inland areas (Vaz and Bowman, 2013; Vaz, Walczynska and Nijkamp, 2013). This expands on the possibility to model the complex interaction of land-use change, as well as making available of accounting matrices of spatial change dynamics on the regional level. Ultimately, a predictive combined model may be built to understand the interactions, and thus better inform decision makers about the best strategies to cope with land-use change, and about fragile regions at a regional scale. However, and largely influenced by the available computing power, urban growth models are traditionally not ubiquitous, are hard to calibrate, and are more of local interest than regional models. A systemic approach to a region shows the city to be a very complex dynamic, where urban interactions do not occur in a single specific region, but rather develop over time, and often over a larger area. This larger area is often the region itself, where complex interactions drive city growth. These complex relationships of city and region have been little studied, as scientific methodologies of urban growth models have usually focused on understanding the dynamics of a single city core. Novel methodologies at a larger scale are therefore an important tool to understand regional dynamics more efficiently. Spatial sciences, as such, call for the combined application of different scientific fields, where physics, together with economics, geography, and complex systems science, might have a crucial role, both in analysing the regional dynamics and in monitoring current practices. This paper is structured in four sections: The first section presents the concept of the law of universal gravitation for regions, and defines the critical elements at a spatial-region scale for Force F, mass m and acceleration a. These concepts are explored in a second section, where the reader is offered a vision of a gravitational city, i.e. an urban-regional system that interacts between these forces. The third section presents an application to the urban footprint of the Veneto region, and how the different cities interact in consequences of their mass m. Finally, the fourth section draws conclusions about the regional dynamics by measuring the different factors for each city, and indicates which cities are more prone to generate higher urban sprawl in their urban–rural interaction patterns.