Land Use Policy 43 (2015) 15–27

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Modelling urban networks at mega-regional scale: Are increasingly complex urban systems sustainable?

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ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 10 October 2014
Accepted 20 October 2014

Keywords:
Mega-region
Urban system
Network modelling
Complexity
Polycentricity
Efficiency

ABSTRACT

Are the dynamics of mega-regions sustainable or not? We explore the hypothesis that increasing complexity in mega-regions implies less demands on resources needed to generate organized information, thereby making the systems more efficient and stable. This article aims to identify structural indicators for measuring urban networks at the mega-regional scale. We use night-time light data from the broad band near-visible infrared channel of the DMSP-OLS to monitor the dynamics of urbanization. We study the urban networks as graphs, where nodes are cities, and the main road and railway infrastructures represent the edges. We propose four indicators for measuring the complexity, polycentricity, efficiency and stability of networks of cities. These indicators are derived from studies and approaches such as the use of graphs and small-world networks that other authors have carried out to explain similar structures. In the article we apply the structural indicators to 12 European mega-regions. The main conclusion is that mega-regional urban systems respond to increasing complexity by adapting their relational structures to become more efficient and stable, and become more sustainable forms of organization. Consequently, it could be necessary to re-direct land use policies towards improving sustainability at the level of the mega-region.

Introduction

Over the last two centuries the boundaries of the city have been constantly redefined. Trullén et al. (2013) recently explained that the real force behind the city's change of scale has been the liberating effect of so called "spatially mobile external economies" which are not constrained to a single place by agglomeration forces and which are able to create what Lang and Nelson (2009) call "large-scale trans-metropolitan urban structures", such as mega-regions. The development of the mega-region is cause and consequence of the densification and acceleration of socio-economic processes, resulting in increasing levels of complexity. From an economic point of view, the mega-region scale of organization appears to be accelerating global change (Grazi et al., 2008), concentrating a huge amount of world production and innovation, and is associated with higher levels of per capita income and creativity (Florida et al., 2008; Ross, 2009; Marull et al., 2013). However, an issue that has received less attention in the literature (exceptions are Wheeler, 2009 and Campbell, 2009) is that once formed mega-regions also become huge consumers of resources.

The question we raise is whether, once formed, the subsequent dynamics of mega-regions are sustainable or not. This question is relevant. A positive expectation of the sustainability of existing mega-regions is a reason to facilitate the conditions for the formation of new ones. On the other hand, evidence that existing mega-regions are evolving towards positions of reduced sustainability provides arguments for preventing new ones being formed, while for existing mega-regions although it could be difficult to dissolve them there could nevertheless be attempts to manage them through pro-active policy.

To shed some light on this question, we propose an isomorphism, where mega-regions are defined as "complex open systems" made of "urban networks" (Wilson, 2009; Changizi and Destefano, 2009). This isomorphism brings together two approaches: network theory and thermodynamics. The metaphors of "system", "network" and "assemblage" (Dematteis, 1991; Camagi and Salone, 1993; De Landa, 2006) can be drawn on to facilitate a conceptual transition across several scales of "the city": from the idea of "the nodal city" to that of "the local labour market"; then from this to the notion of "the metropolitan area"; and finally thereon to trans-metropolitan scales such as "the mega-region" (Florida et al., 2007,

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http://dx.doi.org/10.1016/j.landusepol.2014.10.014
0264-8377/

2008; Trullén et al., 2013). All of them can be considered as particular cases of a general theory of urban networks. By means of network theory we can:

a) move from an "areal" to a "systemic" vision of mega-regions. In the areal notion (i.e., Gottman, 1969) the mega-region is thought of as a new geographically bounded area formed by the aggregation of neighbouring metropolitan areas. In the systemic vision, in contrast, the mega-region is conceived as a macropolitan network of cities forming a spatial and socio-economic continuum;
b) analyze the mega-region as a "complex graph" or "complex system". In this point of view, the mega-region is seen as having three characteristics. First, it is a real network with non-trivial features. Second, it can be defined not only at the macro level, but also in terms of meso and micro levels within it. Third, it can be defined as a "small-world network", since despite containing a large number of nodes the number of degrees of separation between them is small (Rozenblat and Melançon, 2009).

Complex systems are usually open systems since they exist by dissipating energy in a thermodynamic gradient. In thermodynamics, "complex open systems" are systems within which occur internal exchanges of energy flows (as well as of materials and information), and in which the assemblage of the parts results in a collective behaviour (the mega-region) that interacts (exchanges flows) with the environment. Following Morowitz (2002), energy flows are "autocatalytic", which means that they generate a process whereby the flows induce effects which react back; this process serves to organize the system, all the while changing the properties of the system. Energetic inputs help the order or "functional organization" (Corning, 2002) to evolve into an open system, producing perturbations that induce greater complexity (Pulselli et al., 2006; Kondepudi and Prigogine, 1998). However, an open system cannot absorb an unlimited amount of energy; rather, through a process of increasing complexity the system is able to generate, and take control over, the information needed to reduce internal entropy and limit energy consumption, and to increase the system's efficiency and stability (Margalef, 1968). The isomorphism provides a simple explanation for changes of scale of urban networks into more complex structures, and why some of them form mega-regions. It also provides an operative hypothesis. This is that contrary to what might be first assumed, the increasing complexity of the mega-region in fact requires a lesser use of resources for generating and organizing information, and because of this the system is more efficient and stable.

In order to provide evidence for the hypothesis, this article focuses on the study of transport network infrastructures inside 12 European mega-regions between 1991 and 2007. The article is structured as following. After the introduction, section two provides an introduction to the notion of mega-region and the procedures to be followed for identifying mega-regions. Section three introduces mega-regions as a particular case of small-world graphs, and describes indicators for measuring complexity, polycentricity, efficiency and stability. Section four presents a characterization of mega-regions according to the chosen indicators. Section five focuses on testing the hypothesis. Finally, section six presents concluding remarks and discusses the implications of the research.

Mega-regions: origins, notion and identification

The idea of a *large-scale, trans-metropolitan urban structure* can be dated back to the first half of the twentieth century to a debate between Thomas Adams and Luis Mumford. Adams considered that cities would maintain their nineteenth-century form even if they grew to 10 or 20 million residents and extended 50 or more miles from the centre. In contrast, Mumford foresaw a radical shift in metropolitan structure, away from a monocentric metropolis form and towards a more dispersed network of cities and villages arranged in a vast but integrated space that he called an "urban region".

The first evidence on this issue appeared a few years later when Gottman (1969) noticed the growth of the interconnection between the urban agglomerations of Boston and Washington, the whole forming a cluster of metropolitan areas he named a megalopolis. Gottman defined a megalopolis as an agglomeration and density of different activities, settlements and landscapes, reaching a much larger size than that which typically characterizes urban agglomerations. During the same period, the Regional Planning Association (RPA) produced a series of reports on growth patterns in the New York metropolitan area and in the process identified what it called an "Atlantic Urban Region", a concept which essentially coincided with Gottman's notion of megalopolis. The RPA considered that the main difference between an urban area on the scale of the Atlantic Urban Region and a traditional metropolitan sized phenomenon was that the former was composed of a multitude of major urban nodes which were likely to be largely autonomous but at the same time benefit from a proximity to one another which increased their mutual integration (Lang and Dhavale, 2005). Also, Doxiadis (1968) predicted that the continued growth of cities would result in the interconnection of many cities into broad urban complexes. He identified three forces that would shape the future development of cities: the attraction of existing urban centres; the attraction of major transportation links; and the aesthetic attractions for people of proximity to seas, lakes, rivers and other places of scenic beauty. Dioxiadis envisaged a future where urban complexes would grow as a continuous network of interconnected cities, forming an overarching city he termed *ecumenopolis*.

In 1993, Ohmae published a paper introducing a similar concept but his approach was from a completely different perspective. His focus was on the units where managers or officials in the private or public sectors necessarily made decisions. In his opinion, the nation state "has become an unnatural, even dysfunctional, unit for organizing human activity and managing economic endeavour in a borderless world" and it should be replaced, in the global economic map, with what he called "region states" (Ohmae, 1993, p. 93). Region states were conceived as natural economic zones which could fall within or without national borders. In his conception, a region state must be large enough to provide an attractive market, and to warrant the communication and transportation infrastructures and quality professional services necessary for economic participation on a global scale.

In more recent years, a growing awareness of the interdependency of social and economic networks has resulted in a growing importance being given to the notion of the "mega-region." Mega-regions have been defined as "agglomerations of contiguous cities and their suburbs, [that] extend far beyond individual cities and their hinterlands" (Florida et al., 2008, p. 44), or as "networks of metropolitan centres and their surrounding areas, connected by existing environmental, economic, cultural, and infrastructure relationships" (Ross, 2009, p. 1). In essence, a mega-region is *a macropolitan network of cities forming a spatial and socio-economic continuum.* It is a new natural economic unit in which metropolitan regions not only grow internally and become denser, but also grow outwardly, encompassing one another. They are not formed as a result of the imposition of artificial political boundaries, but thanks to increasing interaction between centres of innovation, production and consumption. Therefore, two types of economies can be achieved: the typical urban agglomeration type and also that resulting from the relationships developed in the network of clusters that are part of the mega-region (network economies).