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Evolving rank-size distributions of intra-metropolitan urban clusters in South China

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ABSTRACT

Cities are the dominant form of human settlements and their interaction with the global environment presents great challenges for sustainability. This paper analyzes the evolution of urban form in three rapidly-growing Chinese metropolitan areas in the Pearl River Delta: Shenzhen, Foshan and Guangzhou. It is the first study to utilize a combination of time-series satellite imagery, GIS, and a time-series of spatial pattern statistics based on rank-size distributions to evaluate the evolving nature of urban clusters in Chinese cities. Defining the urban clusters – contiguous urban built-up areas – as the unit of our analysis, we estimate exponents of rank-size distributions for each city's clusters for the years between 1988 and 1999. We observe substantial variation in the evolution of urban form across time. For all three metropolitan areas, the rank-size distribution exponents evolve in an oscillatory fashion within the 11-year period as the metropolitan areas grow through a process of cluster birth and coalescence. The analysis sheds light on the evolving nature of urban clusters that can help us better understand urban phenomena, and make inferences on how socioeconomic processes influence urban form which in turn has considerable effects on the ecology of the urban system and the local and regional environment. We show that a time-series analysis of rank-size distributions of urban clusters reveals trends in spatial patterns of urban form that can aid in the design of cities and help achieve more sustainable land-uses.

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1. Introduction

The beginning of the 21st century marked a milestone in human existence: half of the world's population now resides in urban areas. Regardless of world region, cities are the dominant form of human settlement worldwide. Asia and Africa will experience the most dramatic levels and rates of urbanization this century, respectively. By 2030, China and India will house almost one-third of the world's urban population (UN, 2008). Both countries view urbanization as a critical component of their development strategies and have ambitious goals to develop a vast network of modern cities.

The spatial structure of urban areas has significant and far-reaching socioeconomic and environmental impacts. The impact on the environment comes at multiple scales including regional precipitation patterns (Kaufmann, Seto, Schneider, Zhou, & Liu, 2007), loss of wildlife habitat and biodiversity (McKinney, 2002), conversion of agricultural land (Seto, Kaufmann, & Woodcock, 2000), increase in air pollution coupled with increased automobile dependency and congestion (Boarnet & Crane, 2001), and greater demand for water, energy, and agricultural resources (Johnson, 2001; Bockstael & Irwin, 2000). A better understanding of urban growth processes and urban morphology is critical, as both have significant impacts on and are impacted by global environmental change.

While urban growth has been significant worldwide, it has been exceptionally dynamic in China over the last two decades. Local, regional and global forces have led to unique and rapidly changing urban configurations across the country. For example, similarly to other socialist and formerly socialist countries, central and other forms of planning in China contributes to urban land-use patterns that differ significantly from those in market economies (Lin, 2002; Scarpaci, 2000). It is now expected that the urban population of China will grow by an estimated 261 million between 2007 and 2025 (UN, 2008).

This paper reports findings on the rank-size distribution of urban clusters in selected Pearl River Delta metropolitan areas, namely Shenzhen, Foshan and Guangzhou. We build on the literature that examines the form of the rank-size distributions of urban clusters across time and report our findings on the hypothesized presence of a power-law (Pareto) distribution or even, a Zipf-type rank-size rule (Schweitzer, 1997). We focus on cluster area rank-size distributions. We define an urban cluster system as a central urban agglomeration with suburbs, exurbs, peripheral towns and villages, rather than city population rank-sizes distributions within

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a national or a regional system. Since its origins in urban analysis (Schweitzer, 1997), the examination of the distribution of urban clusters has been performed in a few cases primarily for urban growth model validation purposes, the testing power-laws and/or describing the evolution of urban form in cities (Benguigui, Blumenfeld-Lieberthal, & Czamanksi, 2006; Makse, Andrade, Batty, Havlin, & Stanley, 1998; Makse, Havlin, & Stanley, 1995). In this paper, we identify urban clusters through an algorithm created for the purposes of solving complex percolation problems (Hoshen & Kopelman, 1976). After calculating areas and ranks of clusters in the system, we draw double-logarithmic plots of the ranking of the cluster versus the size of the area of the cluster (similarly to the rank-size rule for cities and their populations) and produce estimates of the fit of the hypothesized Pareto distribution. Changes through time are reported and discussed.

Our goal is to present a quantitative time-series view of the spatial patterns of urban land-use change in three coastal cities in China using the urban cluster as the primary unit of analysis. Apart from the paucity of studies on urban Asia, the cities in question have been growing at astonishing rates during the years examined in this study (Seto & Fragkias, 2005). Thus, we address the following questions: What is the spatiotemporal path of the distribution of urban clusters in the evolving metropolitan systems under study? Can a time-series of an urban cluster distribution parameter capture particularities of urban morphology and is it a useful dynamic intra-metropolitan urban form descriptor? Are there similarities in the distribution of urban clusters at different stages of economic development of the Pearl River Delta cities? Does the spatial configuration of intra-metropolitan urban clusters converge to a standard form? What can we infer regarding the relationship between the pattern and trajectory of spatiotemporal distribution of urban clusters and social processes?

2. Evolving intra-metropolitan urban systems

2.1. The evolution of urban form and rank-size distributions

Urban areas, and their form and function, have been the focus of urban planners, economists, geographers, and sociologists for more than 100 years with deep foundations in spatial land-use theory (Alonso, 1964; Muth, 1961; von Thünen, 1875). More recently, there have been contributions in the study of urban growth and morphology (Anas, Arnott, & Small, 1998; Batty, Longley, & Fotheringham, 1989; Batty & Longley, 1986, 1988; Clawson, 1962; Harvey & Clark, 1965; Sinclair, 1967). We now have a better understanding of urban growth drivers that range from global factors such as the emerging global economy and world cities (Beaverstock, Smith, Taylor, Walker, & Lorimer, 2000; Sassen, 1994), to international capital and policy reforms (Seto & Kaufmann, 2003) and local socioeconomic and political factors (Beauregard, 1995). However, the physical process of urban land-use change at the level of the urban cluster and underlying socioeconomic processes that drive particular spatial configurations are relatively understudied; a large body of spatially-explicit theory of urban morphology at the intra-city level is still in development (Batty, 2008).

Spatially-explicit models of urban morphology are primarily mechanistic, derived from modeling traditions in mathematics and statistical physics; these include cellular automata (CA), diffusion-limited aggregation (DLA) and correlated percolation models (Batty & Longley, 1986; Makse et al., 1995). Cellular automata models have been an important tool in the analysis of urban morphology and the growth/formation of urban clusters - although not explicitly adopting an urban cluster-centric approach (Benguigui et al., 2006) while characterizations of the fractal nature of cities and detailed work on the connections of urban form and cellular automata through GIS technology – and more recently agent-based modeling - originated in the early 1990s (Batty, 1997; Batty et al., 1989; Batty & Longley, 1986, 1988; Batty, Xie, & Sun, 1999; White & Engelen, 1997). During the same period, physicists developed models based on the correlated percolation modeling techniques (Makse et al., 1995).

The beginning of the 20th century brought about the first pieces of evidence suggesting that the size distribution of cities follows a Pareto distribution of the form $y \sim Ax^{-\alpha}$ where x is the city population size, y is the number of cities with populations greater than x, A is a constant that corresponds to the size of the largest city in the system and α is the Pareto distribution exponent (Auerbach, 1913). The existence of power-laws in social systems is an idea related to social complex systems theory and directly associated to, among others, the system property of non-ergodicity that occurs when conditional probability statements for the system do not uniquely characterize its average or long-run behavior and a temporary shock affect the long-run state of the system (Brock, 1999; Durlauf, 2005). Testing such power and scaling laws can be thought of as complexity empirics.

By the middle of the century, Zipf made the observation that the frequency of some event (P) – and in the case of urban systems, the frequency of cities of different size – and its rank (i) (where the rank is determined by the frequency of occurrence), are connected through a power-law function $P_i \sim 1/i^{\alpha}$ with the exponent α close to unity giving rise to the so-called Zipf Law (Zipf, 1949). Essentially, Zipf proposed that the distribution of city sizes take a special form of the Pareto distribution with an exponent equal to 1. There exist numerous empirical studies on rank-size distributions of systems of cities (Batty et al., 1989; Benguigui & Blumenfeld-Lieberthal, 2007; Garmestani, Allen, & Bessey, 2005; Soo, 2005) as well as ones specific to the case of China (Andersen & Ge, 2005; Song & Zhang, 2002).

2.2. A conceptual framework for urban cluster growth and formation

Simple measures of the change in the absolute area of urban space or the rate at which non-urban land is converted to urban uses have been utilized in the past to describe description of the physical process of urban growth or urban land-use change. But it is now widely understood that these metrics give limited information on the spatial patterns of urbanization or the underlying processes that shape urban areas (Seto & Fragkias, 2005). A spatially and temporally explicit consideration of changes in urban form is necessary in order to capture more important information related to potential social and environmental impacts of urban growth, such as the relation among commute patterns, transportation infrastructure, energy consumption, and carbon emissions. Evaluating those changes explicitly can also give us insight into the underlying socioeconomic and political processes that create observed landscape patterns.

As a tool for understanding the spatial and temporal patterns of urban land-use change, we employ a simple stylized dynamic scenario depicting a hypothetical landscape at different stages of urban development and report the different ways the landscape changes can be quantified. The scenario is a controlled environment that allows us to form hypotheses regarding the behavior of quantifiable spatial pattern. The scenario exhibits the standard dynamic properties of evolving urban systems, namely spontaneous, adjacent growth and coalescence. In period one, the landscape consists of one major urban cluster (e.g. a central city), a, and two smaller clusters (e.g. towns), b and c (Fig. 1). In the second period, three new clusters emerge (d, e ,f) while clusters a and b expand in size. In periods three and four, two additional clusters develop near cluster e and all three become a contiguous metropolitan region.