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# Discontinuities in the evolution of the city system in Texas from 1850 to 2010

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ABSTRACT

We report the results of a historical investigation and quantification of discontinuous evolution, and a gap statistic analysis of discontinuities, on city size distributions of the city system in Texas, USA, over a 160-year period from 1850 to 2010. The growth of the city system exhibits four stages that are evident from our quantitative analysis of the convergence of population in large cities and qualitative analysis of historical socioeconomic and technological developments. The decadal city size distributions in the aggregate evolve with a persistent pattern while individual cities over time shift positions in the urban hierarchy as the result of adapting or passing growth opportunities in infrastructure innovations, economic change, and industrial transformations. These decadal city size distributions exhibit persistent discontinuities that mainly occur in the upper and lower tails. The observed patterns and discontinuities are indicative of the stability and resilience of a complex adaptive system of cities.



## 1. Introduction

Human population has increasingly concentrated in cities, and the pace and extent of this process in many countries will continue at unprecedented rates in the decades to come (Kasarda & Crenshaw, 1991; van Ginkel, 2008). As the size and number of cities increase, they are increasingly interdependent and interconnected forming city systems that are emerging all over the world. Understanding the structural properties of city systems is crucial to advancing our understanding of how city systems evolve and individual cities flourish or fail (Batty, 2008). The structural properties of city systems includes not only the persistent scaling regularities, such as the rank size rule or Zipf's law (Zipf, 1949), but also patterns of discontinuities. In this paper we integrate qualitative and quantitative analyses to investigate the persistent patterns and discontinuities at both longitudinal and cross-sectional dimensions in the evolution of the city system in Texas, USA over a 160-year period from 1850 to 2010. Texas is selected as a case study due to its long record of population of cities and towns, its well documented history of urban and transportation developments, as well as its relative independence in terms of geography and size.

The city size distribution implicates the structural properties of a system of cities in terms of both the overall scaling patterns and the discontinuities that are significant deviances of individual cities from the overall scaling patterns. The most well-known scaling pattern suggests that the city size distribution of a city system follows a persistent scaling law, i.e., the rank size rule or Zipf's law (Batty, 2006; Berry, 1964; Zipf, 1949), especially when the cities are properly defined (Berry & Okulicz-Kozaryn, 2012; Jiang & Tao, 2011). Moreover, this scaling law is further substantiated by being derived from a scale-free random growth process or the Gibrat's law of proportionate effect (Gabaix, 1999a, 1999b). Xu and Harriss (2010) suggest a spatially and temporally autocorrelated growth process can better approximate the empirical city size distributions. This scaling law is a well-known regularity for not only city systems but also a wide variety of complex systems elsewhere, such as the power law distributions (Barabasi & Albert, 1999) and the body mass distributions in ecosystems (Holling et al., 1996). It implies a continuous pattern exists across multiple scales, and that common processes, rules, or mechanisms propagate across a wide range of temporal and spatial scales (Stanley et al., 1996).

However, voluminous socio-economic and ecological research suggests that there are processes operating at distinct temporal and spatial scales, and that these processes create scale-specific patterns deviating from the general scaling patterns (Allen & Holling, 2008; Batty, 2003, 2007, 2008; Garmestani, Allen, & Bessey, 2008; González-Val, 2011; Henderson, 1974; Henderson, 1988, 1997; Henderson & Becker, 2000; Krugman, 1992, 1993; Levin, 1992; Rossi-Hansberg, 2007). Persistent discontinuities (or lumpy patterns) have been found in body mass distributions of biological species and they are considered to reflect the structural properties and processes of the ecosystems, such as

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the discontinuous pattern of resources (Holling, 1992), competitive interactions among species (Scheffer & van Nes, 2006), or external shocks from the introduction of invasive species (Allen, 2006). City systems are much more complex but they are similar to ecosystems and other social-economic complex systems in ways of transporting, consuming, and competing for energy and resources, and producing services, information, and artifacts (Batty, 2008; Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007). Additionally, city systems have been found to have characteristic patterns of discontinuities. It is well-known that city systems evolve in a discontinuous matter. The qualitative interpretations of discontinuities by Borchert (1967, 1983) are interpreted as an evolutionary process determined by the different economic and social epochs in U.S. metropolitan history. It has been found that integrating the discontinuous growth impulses associated with different innovation cycles improves the modeling of the growth of systems of cities (Bretagnolle & Pumain, 2010; Favaro & Pumain 2011). In addition, the discontinuous city size distribution has been found a persistent feature of city systems (Garmestani, Allen, & Bessey, 2005; Garmestani, Allen, Gallagher, & Mittelstaedt, 2007; Garmestani et al., 2008). Among the numerous studies that attribute empirical city size distributions to the Zipf's law, Berry and Okulicz-Kozaryn (2012) find that the upper most tail of city size distribution is discontinuous from the Zipf's law.

In fact, many empirical city size distributions have demonstrated discontinuities or lumpy patterns in which population of some cities significantly deviate from the Zipf's law, especially when the city size distributions include cities of all sizes (Benguigui & Blumenfeld-Lieberthal, 2011; González-Val, 2011; Nitsch, 2005; Rosen & Resnick, 1980; Rossi-Hansberg, 2007). These discontinuities have usually been ignored when studies on city size distributions only pursue the overall scaling pattern; nevertheless, they do represent a kind of information city size distributions have for the structural properties of city systems. The discontinuities and their patterns are in need of better understanding on how they inform the patterns of city systems. In this study, we aim to fill this void by examining the discontinuities at both longitudinal and cross-sectional dimensions of the evolution of the regional city system in Texas. We examine the discontinuous evolution of the system of cities in Texas by integrating a qualitative analysis of historical urban growth with a quantitative analysis of population convergence in large cities. The discontinuities in the decadal city size distributions are analyzed using a modified gap statistic method (Restrepo, Renjifo, & Marples, 1997).

In the reminder of this paper, the context of each section is as follows. Section 2 introduces major events as the historical context of the urbanization process of Texas, USA; Section 3 describes the dataset and methods used in analyzing the discontinuities of city size distributions; Section 4 presents the results of our analyses, and Section 5 summarizes and concludes this study.

## 2. A brief history of Texas urbanization

We briefly sketch a narrative history of major events that influenced urbanization in Texas. Our history of Texas urbanization is primarily based on an interpretation of maps presented in *The Historical Atlas of Texas* (Stephens & Holmes, 1990), various articles from the Handbook of Texas Online, and a study of the establishment and growth of Texas cities and towns beginning in the early nineteenth century based on the work of Harris (1971). Our qualitative study of the narrative history of Texas urbanization complements our quantitative analysis that revealed four distinct stages of city and town growth.

Early settlements prior to the establishment of Texas as a U.S. state were inhabited by indigenous Native Americans and early Spanish colonists. These settlements were sited along rivers and on coastal embayments to meet basic human needs for a reliable water supply, food resources, and transportation between coastal and inland settlements. Spanish Texas was known as New Spain from 1690–1821. San Antonio de Bexar was the largest Spanish settlement in provincial Texas, with a population estimated at 2,500 in the early 1800s (McComb, 2013). Coastal settlements in areas that would later become large cities like Galveston and Corpus Christi provided Native Americans and early sailing ships with access to safe protected harbors and a diversity of freshwater and marine resources.

The expansion of farming and ranching in Texas occurred rapidly between 1836 and the beginning of the U.S. Civil War in 1861. The Republic of Texas existed during the period of 1836 through 1845 following the defeat of the Mexican army. In 1850, Galveston was ranked first in population followed by San Antonio and Houston (McComb, 2013). Mail service between Texas and the far west started in 1853 with the San Antonio-San Diego mail line, followed soon by a second overland route across Texas connecting to St. Louis and onto San Francisco. These rail and dirt roads required a diversity of settlements and towns at intervals of approximately thirty miles to provide food, forage, animals, and equipment repairs. Numerous towns such as Van Horn, Ft. Davis, Sherman, and El Paso that were located on routes continue today.

The demand for red meat in the North resulted in a network of cattle trails and urban stockyards in Texas and the Great Plains. In the mid-1880s, the open range system ended with the development of barbed-wire fences, windmill-driven water wells, and imported British cattle (Stephens & Holmes, 1990). Subsequently, highways, railroads, and towns adapted to a system of regionally enclosed ranches that required long-distance transportation to deliver beef to northern urban markets. The number of farms rose from 61,000 in 1870 to 350,000 by 1900 (Dethloff & Nall, 2013), reflecting a transition from subsistence to commercial production for national and international markets. This first phase of growth in the number of settlements and towns transitioned emerging frontier areas into early networks of transportation infrastructures and regional economies. The demand for labor attracted a significant migration of Europeans to the Texas frontier.

In 1900, when Texas became the sixth most populous state, the urban population was 17.1%, compared to the national urban population average of 39.6% (McComb, 2013). The discovery of the Spindletop oil field near Beaumont in 1901 resulted in an oil and gas economy that further stimulated the urban landscape of East Texas. Oil fields spread across East Texas during the period of 1901 through 1930. Discoveries of oil in West Texas began in 1923, with major oil fields found in 1926 (Smith, 2013). Pipelines, railroads, and highways were necessary to transport crude oil to refinery towns and cities. The major petrochemical refinery complexes were located in the areas of Houston-Texas City, Beaumont-Orange-Port Arthur, and Corpus Christi, taking advantage of connections with rail and ocean transportation systems. The railroads established in this era of urban expansion would also have a profound influence on the future pattern of highway infrastructure and the patterns of growth of urban populations in Texas.

Agriculture expanded in the Rio Grande Valley with a large-scale citrus industry in place by 1929. The adoption of the tractor and combine resulted in a major expansion of cotton and grain production in the High Plains of Texas during the same time period. This agricultural revolution also contributed to the growth of rural populations in small towns and cities leading to an increased unevenness in town size distributions. The Great Depression in the U.S. started in 1929 and lasted until the late 1930s. This tumultuous second era of urban growth and decline from 1900 through1930 was characterized by the growing population concentration in cities and towns in response to a variety of urban economic opportunities.