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González-Val, Rafael and Lanaspa, Luis

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# Patterns in US Urban Growth (1790–2000)

Rafael González-Val\*, Universitat de Barcelona & IEB  
Luis Lanaspa, Universidad de Zaragoza

## Abstract

This paper reconsiders the evolution of the growth of American cities since 1790 in light of new theories of urban growth. Our null hypothesis for long-term growth is random growth. We obtain evidence supporting random growth against the alternative of mean reversion (convergence) in city sizes using panel unit root tests. We also examine mobility within the distribution to try to extract growth patterns different from the general unit root trend detected. We find evidence of high mobility when we model growth as a first-order Markov process. Finally, using a cluster procedure we find strong evidence in favor of conditional convergence in city growth rates within convergence clubs, which we interpret as “local” mean-reverting behaviors. We interpret the high mobility and the results of the clustering analysis as signs of a sequential city growth pattern.

**Key words:** city size, urban growth, random growth, sequential city growth, transition matrices, club convergence

**JEL Classification:** C12, O18, R11, R12

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\*Corresponding Author: Rafael González-Val. E-mail: r.gonzalez-v@ub.edu. The authors acknowledge financial support from the Spanish Ministerio de Educación y Ciencia (ECO2009-09332 and ECO2010-16934 projects), the DGA (ADETRE research group) and FEDER. We have benefited from the helpful comments of David Cuberes. Suggestions from Fernando Sanz also contributed to improving the paper. We are also grateful to seminar participants at the IEB seminar (Barcelona, 2011) and to participants at the XIV Encuentro de Economía Aplicada (Huelva, 2011). All remaining errors are ours.

# 1 Introduction

This paper reconsiders the evolution of the growth of American cities since 1790 in light of new theories of urban growth, paying special attention to sequential city growth theories. The urban system of the United States (US) has often been studied because of its special characteristics. First, it is a relatively young system (the first census by the US Census Bureau dates from 1790) characterized by the entry of new cities (Dobkins and Ioannides, 2000). In addition, its inhabitants present very high mobility; Cheshire and Magrini (2006) estimate that mobility in the US is 15 times higher than that in Europe. Both characteristics, high mobility and the entry of new cities, should reduce the time transition to spatial equilibrium between cities. In line with this, González-Val (2010) finds that the final decades of the twentieth century are characterized by stability in the number of cities and the percentage of the US total population they represent, indicating a shift to a stable city size distribution and a more consolidated urban landscape. Finally, industry cycles have an important effect on the growth rates of American cities (Duranton, 2007). Thus, in the second half of the nineteenth century and the early twentieth century, the growing urban population was concentrated in the north-eastern region known as the manufacturing belt, while in the second half of the twentieth century the rise of the Sun Belt (a phenomenon known as regional inversion; Lanaspá-Santolaria et al., 2002) attracted population to the West Coast area.

Many papers study the long-term evolution of American city growth. These include Dobkins and Ioannides (2000, 2001), Kim (2000), Beeson et al. (2001), Overman and Ioannides (2001), Black and Henderson (2003), Ioannides and Overman (2003), Kim and Margo (2004), González-Val (2010) and Michaels et al. (2010). The spatial units (states, counties, minor civil divisions, metropolitan areas, incorporated places, etc.) and time periods studied and the statistical and econometrics methods used in the literature vary widely.

Our aim is to analyze the evolution of the largest American cities from the beginning of

the urban system in 1790. Such a wide time horizon enables us, first, to consider the effect of the entry of new cities (most of them during the nineteenth century), and second, to look for different patterns of city growth. New theories have recently emerged that examine both aspects, concluding that historically city growth may have been sequential. Sequential city growth means that cities have early periods of fast growth (from their date of entry as a city) followed by slow growth and/or stagnation. The idea is that during some periods, the largest cities that entered the distribution first are the ones that grow most. Later, their growth slows, and the smaller cities that entered later are the ones that grow most. When these reach a certain size, their growth rates slow again and other smaller cities are the ones that grow fastest, and so on. It should be noted that the result is convergence among cities. This convergence is not in size, as final city size is determined by other factors such as amenities, city productivity, land availability, etc., but in the growth rates at the steady state.

Only two papers model sequential city growth: Henderson and Venables (2009) and Cuberes (2009). The model developed by Henderson and Venables (2009) examines city formation in a country whose urban population is growing steadily over time, with new cities required to accommodate this growth. It yields the sequential formation of cities, where new cities grow from scratch to a stationary size. The basic assumptions are that city formation requires investment in fixed capital in the form of housing and urban infrastructure and that agents are forward-looking. Cuberes (2009) presents another model of sequential city growth; the key to generating sequential growth is the assumption of irreversible investment in physical capital. The predictions of this second model are empirically tested by Cuberes (2011), who finds strong support for sequential city growth using two comprehensive data sets on populations of cities and metropolitan areas for a large set of countries.

The next section presents the data used. Our basic hypothesis for long-term growth is random growth. We use random growth as a benchmark because the effect of other factors (locational fundamentals or increasing returns) may change over time when such a

long period is considered because of the decrease in transport costs (Davis and Weinstein, 2002). Moreover, Ioannides and Overman (2003) and González-Val (2010) find that random growth is a good description of city size growth in the US during the twentieth century. Therefore, in Section 3 we test random growth versus mean reversion (convergence) in US cities using panel unit root tests. We obtain evidence supporting random growth against the alternative of mean reversion in city sizes. In Section 4, we examine mobility within the distribution to try to extract growth patterns that are different from the general unit root trend. We use two different techniques. First (Section 4.1), we calculate transition matrices, which tell us the degree of mobility in terms of probability, applying a generalized equation to enable cities to enter and leave the sample. Second (Section 4.2), we apply a cluster algorithm to identify different groups of cities that converge with each other. The results point to a certain type of sequential growth, at least within groups. We discuss the different empirical results in Section 5, and conclude in Section 6.

## 2 Data

There are various ways of defining a “city.” The evolution of the American urban structure has been analyzed using different geographical units: counties (Beeson et al., 2001), minor civil divisions (Michaels et al., 2010), metropolitan areas (Dobkins and Ioannides, 2000, 2001; Black and Henderson, 2003; Ioannides and Overman, 2003), urbanized areas (Garmestani et al., 2005; Garmestani et al., 2008) or the economic areas recently defined by Rozenfeld et al. (2011) using the city clustering algorithm. However, since our aim is to study the evolution of the urban system from its origin, we must use data from “legal” cities, which are those reported since the first census in 1790.<sup>1</sup> Units such as metropolitan

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<sup>1</sup>We talk about the “origin” of the urban system because the 1790 census is the first one, and provides data on the first 16 cities. However, these cities existed earlier. Kim (2000) gives data for four and five cities in 1690 and 1720, respectively. His data come from Bridenbaugh (1938) and the Historical Statistics of the United States. However, we prefer to use a single source of data, the US Census Bureau. In addition, the periodicity of these data would not be the same as the rest of the sample (decennial census).

areas were introduced later.<sup>2</sup> Thus, we identify cities as what the US Census Bureau denominates incorporated places. These places have also been used recently in the empirical analyses of American city size distribution (Eeckhout, 2004, 2009; Levy, 2009; Giesen et al., 2010; González-Val, 2010).

The US Census Bureau uses the generic term “incorporated place” to refer to a type of governmental unit incorporated under state law, such as a city, town (except New England states, New York and Wisconsin), borough (except in Alaska and New York) or village, with legally established limits, powers and functions. We take our data from the US Census Bureau (2004);<sup>3</sup> the sample consists of all the incorporated places with 100,000 inhabitants or more in 2000.<sup>4</sup>

Unincorporated places (concentrations of population that form no part of an incorporated place but that are locally identified with a name) are excluded because they began to be counted after 1950 (they were renamed census designated places (CDPs) in 1980). Although some of them are consolidated as incorporated places and are reported in the 2000 census as cities, we also exclude them. The only exception is Honolulu CDP, because in Hawaiian state law there are no incorporated places; they are all unincorporated.

Therefore, our final sample in 2000 is the 190 largest cities. This sample size is similar to that of other studies using Metropolitan Statistical Areas (MSAs). Black and Henderson (2003) use data from 194 (1900) to 282 (1990) MSAs, while the sample of Ioannides and Overman (2003) ranges from 112 (1900) to 334 (1990). Their samples are slightly

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<sup>2</sup>The standard definitions of the metropolitan areas were first issued in 1949 by the then Bureau of the Budget, the predecessor of the present Office of Management and Budget.

<sup>3</sup>Source: Table 32. Only 16 of all the cities (8.42%) show a significant change in their boundaries (the case of annexed areas): Anchorage, Boston, Columbus, Hampton, Honolulu CDP, Indianapolis, Jacksonville, Lexington-Fayette, Nashville-Davidson, Newport News, New York, Philadelphia, Pittsburgh, Virginia Beach, Washington and Winston-Salem. Information about entities whose names and/or boundaries have changed, entities that no longer exist, newly established entities (both legal and statistical) and changes in geographic relationships is given in the “geographic change notes” section.

<sup>4</sup>Imposing a minimum population threshold is relevant for the analysis of city size distribution (Eeckhout, 2004). However, it seems to be less decisive in the study of city growth. González-Val (2010) obtains the same conclusion, using data from all incorporated places without any size restriction, as do Ioannides and Overman (2003) with their sample of MSAs: the validity of random growth in the US city growth during the twentieth century. Cuberes (2011) carries out several robustness checks and his results for sequential city growth do not vary much with different cut-offs for selected cities.

larger because in the US to qualify as an MSA a central city of 50,000 or more inhabitants is needed (a lower minimum population threshold than ours). In fact, most of these incorporated places are the central city of an MSA.

Table 1 shows the sample sizes for each decade and the descriptive statistics. For the first decades and until the mid-nineteenth century, the number of cities is low and grows very slowly; however, these few cities represent about two-thirds of the total urban population of the period. From 1850 to 1900, the number of cities doubles (from 73 to 157). The last major entry of new cities takes place from 1900 to 1930, and from that date the number of cities remains stable. In 2000, the percentage of the urban population represented by this upper-tail distribution is much lower (31%) because of the appearance of many small and mid-sized cities (there were 19,296 incorporated places in the 2000 census, with an average population of 8,968.44 inhabitants) and because a change had taken place to a more consolidated urban landscape.

The size of our sample is an advantage from a methodological point of view because the techniques we apply are specially designed for small samples. However, the sample is defined according to the largest cities in the latest period, which might imply a slight bias because these are the “winning” cities, namely those that have presented the highest growth rates over time. We deal with this problem in Sections 3 and 4.2 where this possible bias could have an influence.

### **3 Testing long-term trends: random growth versus mean reversion**

#### **Description**

Random growth theories are based on stochastic growth processes and probabilistic models. The most important models are those of Champernowne (1953), Simon (1955) and more recently Gabaix (1999) or Córdoba (2008). In the case of population growth,

these models are able to reproduce two empirical regularities that are well known in urban economics: Zipf's and Gibrat's laws (or the rank-size rule and the law of proportionate growth).

Random growth theory is especially important from our long-term perspective, because the influence of other factors such as locational fundamentals or increasing returns may change (or even disappear) over time. Locational fundamentals are exogenous factors linked to the physical landscape, such as temperature, rainfall, access to the sea, the presence of natural resources or the availability of arable land. These characteristics are randomly distributed across space, and although they may have played a crucial role in early settlements, one would expect their influence to decrease over time.<sup>5</sup> By contrast, urban increasing returns, also known as agglomeration economies, appear later as a consequence of industrial development. The empirical literature on agglomeration economies and their positive effects on urban growth is wide, although there is a great deal of variability in the results reported in the literature; see the meta-analysis by Melo et al. (2009).

Therefore, our basic hypothesis for long-term growth is random growth (or Gibrat's law<sup>6</sup>). We follow the methodology proposed by Clark and Stabler (1991), who suggested that testing for random growth is equivalent to testing for the presence of a unit root. They built on the Vining model of city growth with autocorrelated errors (Vining, 1976). Let  $S_{it}$  be the size (population) of city  $i$  at time  $t$ . Starting from a simple AR growth model, they assume that the relationship between the size of a city in time period  $t$  and  $t - 1$  is  $S_{it} = \rho_{it}S_{it-1}$ , where  $\rho_{it}$  is the growth rate of city  $i$  over the period  $t - 1$  to  $t$ . This growth rate can be decomposed into two (Clark and Stabler, 1991) or three components (Bosker et al., 2008): a random component, a non-stochastic component relating the current growth rate to a (possibly time-varying) constant and past growth rates, and initial city size. Then,

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<sup>5</sup>However, empirical studies demonstrate that in some cases their influence in determining agglomeration remains important; see Ellison and Glaeser (1999) or Davis and Weinstein (2002).

<sup>6</sup>According to Gabaix and Ioannides (2004), "Gibrat's Law states that the growth rate of an economic entity (firm, mutual fund, city) of size  $S$  has a distribution function with mean and variance that are independent of  $S$ ."



after some algebra Clark and Stabler (1991) get the following expression:

$$\Delta \ln S_{it} = c_i + \Theta_i \ln S_{it-1} + \sum_{j=1}^n \beta_{ij} \Delta \ln S_{it-j} + u_{it}, \quad (1)$$

where  $c_i$  is a constant,  $\beta_{ij}$  is a parameter measuring the influence of past growth rates on current city growth and  $u_{it}$  is a random error term.  $\Theta_i$  is the key parameter that captures the effect of initial city size on growth. Random growth would imply  $\Theta_i = 0$ , meaning that the growth of a particular city does not depend on the initial city size. This shows that testing for random growth (Gibrat's law) is equivalent to testing for a unit root in city sizes. Evidence supporting a unit root (if  $\Theta_i$  is not significantly different from zero) means that city  $i$ 's growth rate is independent of initial size. By contrast, when  $\Theta_i < 0$  the evolution of city  $i$  will be a stationary process (mean reversion).<sup>7</sup> Using Eq. (1), Clark and Stabler (1991) apply the standard Dickey–Fuller (1979) t-statistic, not rejecting random growth for the seven largest cities in Canada from 1975 to 1984.

## Results

Gabaix and Ioannides (2004) emphasize “that the next generation of city evolution empirics could draw from the sophisticated econometric literature on unit roots.” According to this suggestion, most recent studies apply unit root tests: Black and Henderson (2003), Sharma (2003), Resende (2004), Henderson and Wang (2007) and Bosker et al. (2008).

Some authors (Black and Henderson, 2003; Henderson and Wang, 2007; Soo, 2007) propose a growth equation to test the presence of a unit root, which they estimate using panel data. However, there are problems with this methodology (Gabaix and Ioannides, 2004; Bosker et al., 2008; González-Val et al., 2010). First, data availability; we have only 22 temporal observations as the periodicity of our data is by decades (decade-by-decade city sizes over a total period of 210 years), when the ideal would be to have at least annual data (as Clark and Stabler, 1991, or Bosker et al., 2008). Most studies use data from

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<sup>7</sup>A consequence of an estimated  $\Theta_i < 0$  is that any shock will dissipate over time; see Davis and Weinstein (2002).

the decennial census, so this limitation is a common problem in the literature. Second, an econometric issue; the presence of cross-sectional dependence across the cities in the panel can give rise to estimations that are not very robust. Econometric literature clearly establishes that panel unit root and stationarity tests that do not explicitly allow for this feature among individuals present size distortions (Banerjee et al., 2005).

For this reason, as in González-Val et al. (2010), we use one of the most recent tests especially created to deal with this question, namely Pesaran’s (2007) test for unit roots in heterogeneous panels with cross-section dependence. The test of the unit root hypothesis is based on the t-ratio of the OLS estimate of  $b_i$  in the following cross-sectional augmented Dickey–Fuller (denoted by CADF) regression:

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it}, \quad (2)$$

where  $y_{it} = \ln S_{it}$ ,  $a_i$  is the individual city-specific average growth rate and  $\bar{y}_t$  is the cross-section mean of  $y_{it}$ ,  $\bar{y}_t = N^{-1} \sum_{j=1}^N y_{jt}$ . To eliminate cross-dependence, the standard Dickey–Fuller (or augmented Dickey–Fuller) regressions are augmented with the cross-section averages of lagged levels and first differences of the individual series, such that the influence of the unobservable common factor is asymptotically filtered. The null hypothesis assumes that all series are non-stationary, and Pesaran’s CADF is consistent under the alternative that only a fraction of the series is stationary.

Another advantage of Pesaran’s CADF test over other recently developed unit root tests (Levin et al., 2002) is that it is suitable for unbalanced panels, as is the case with our city sample<sup>8</sup>. New cities appear over time, from 16 in 1790 to 190 in 2000. However, owing to limitations in the data (the CADF test works with unbalanced panels but if we consider the complete sample it is a strongly unbalanced panel; there is an excessive amount of missing

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<sup>8</sup>Another panel test that deals with cross-section dependence and that is suitable for unbalanced panels is Im, Pesaran and Shin (2003) test (IPS test). We also calculated this test and the results lead to more rejections of the unit root null hypothesis. However, we do not show these results because as Baltagi (2008, p. 280) points out the IPS test has size distortions when, as in our sample,  $N$  is large relative to  $T$ . In the related literature, Breitung (2000) finds that the IPS test suffers from a dramatic loss of power if individual specific trends are included.

data) we must restrict our analysis to a maximum of 150 cities. These 150 cities are a fixed sample for the entire period, and correspond to the largest cities (upper-tail distribution) in the year of reference. We consider three different periods: 1790–1900, 1900–2000 and 1790–2000. In the 1790–1900 period, the year of reference is 1860 while in 1900–2000 and 1790–2000 it is 1900 (we cannot use always the same year of reference owing to data limitations). In this way, we can control the possible bias mentioned in Section 2, because not all the largest cities of 1860 or 1900 would have maintained their positions a century later. Therefore, the samples defined according to 1860 or 1900 ranks contain “winning” and “losing” cities.<sup>9</sup>

Table 2 shows the results of the standardized  $Z_{tbar}$  statistic of the CADF test,  $Z [t]$ , and the corresponding p-value for four sample groups (top 10, 75, 100 and 150 largest cities in the year of reference), different specifications:  $AR(p)$  with  $p = 1, 2, 3$  including a constant or constant and trend, and three different periods.<sup>10</sup> In Panel A (1790–1900), we must restrict the analysis to top 10 and 75 owing to data limitations; the results show that we cannot reject the unit root in any case. Support for the unit root hypothesis is also strong in Panel B (1900–2000), as we can only reject the null hypothesis in one case: the model with one lag and no trend for the top 150 cities. Finally, Panel C, which considers the entire period 1790–2000, shows less unanimous evidence. In this panel, the results are similar for the four sample sizes. When only one lag is included, the null hypothesis of

<sup>9</sup>Moreover, 1900 is when our sample exceeds 150 cities (see Table 1).

<sup>10</sup>The estimations were made with the `pscadf` Stata package, developed by Piotr Lewandowski. The number of cities in each panel in Table 2 is fixed, although some of the cities did not exist in all periods (that is why Panels A and C are unbalanced panels). To clarify this point, these are the number of time observations for each city in the panels:

Panel A: 1790–1900. Year of reference for Top cities: 1860. Top 75 (N=75): (N, T1-T75) = (75, 11 11 11 11 9 9 7 6 9 7 11 10 5 11 10 7 8 6 8 11 11 7 7 6 5 11 11 11 5 10 11 9 6 6 7 10 11 11 6 5 6 11 6 9 5 5 4 6 5 6 10 11 6 5 6 4 5 4 5 7 4 5 6 4 5 10 4 4 5 4 5 5 4 5 5). Top 10 is the subsample with the first 10 elements (N=10, T1-T10).

Panel B: 1900–2000. Year of reference for Top cities: 1900. This is a balanced panel; there are 11 temporal observations for each city.

Panel C: 1790–2000. Year of reference for Top cities: 1900. Top 150 (N=150): (N, T1-T150) = (150, 22 17 22 18 22 22 19 20 16 20 21 20 19 17 21 18 17 22 15 22 17 15 16 18 15 17 18 22 16 22 17 15 16 16 18 22 15 16 16 20 22 21 14 22 17 15 15 22 16 22 17 21 15 16 21 20 13 15 22 15 16 16 16 13 13 12 18 13 16 12 12 16 18 17 15 16 15 17 14 16 16 13 15 22 13 16 16 14 13 14 12 16 16 15 17 15 17 15 16 13 13 14 22 15 14 21 15 12 15 13 17 12 14 12 12 16 12 13 16 14 15 13 15 12 13 14 12 12 12 12 15 14 14 12 12 14 17 12 12 12 12 14 11 12 14 12 11 14 13 12). Top 10, Top 75 and Top 100 are the subsamples with the first 10 (N=10, T1-T10), 75 (N=75, T1-T75) and 100 (N=100, T1-T100) elements, respectively.

a unit root is rejected for any specification. However, as the number of lags in the model increases we soon find evidence in favor of our null hypothesis: in the model with two lags when a trend is included, and in the model with three lags with any specification. This last result is especially relevant, as Said and Dickey's (1984)  $T^{1/3}$  rule would establish the lag choice  $p = 3$  in that case ( $22^{1/3} = 2.8$ ).

This evidence in favor of a unit root indicates that city growth during the 1790–2000 period was independent of initial size, supporting our hypothesis of random growth. The evidence is even stronger when we consider subperiods (1790–1900 and 1900–2000). We carried out several robustness checks with the Panel C sample (the whole 1790–2000 period).<sup>11</sup> First, we defined the sample according to the largest cities in 2000, the latest period for which we have data. The results of the test, when it could be carried out,<sup>12</sup> were similar: with two lags or more, we could not reject the unit root for any specification of the model. We also tried defining the group of cities randomly, and again we obtained the result that the null hypothesis of a unit root could not be rejected (in this case, the only model with which it could be rejected was with  $p = 1$  and without trend). Finally, we estimated separately a panel for the sample of 16 cities that are present in all periods. In this case, as we considered a balanced panel we were also able to run the tests of Levin et al. (2002) and Im et al. (2003). The results for this group of the oldest cities were similar; we could not reject the null hypothesis from two lags onward with any specification of the model and with any of the three tests.

## **4 What lies beneath the random growth? Intra-distribution mobility**

In Section 3, we found evidence supporting random growth against the alternative of mean reversion (convergence) in American cities during the 1790–2000 period. This type of

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<sup>11</sup>The specific values of the tests are available from the authors on request.

<sup>12</sup>In this case, owing to data limitations, we could only carry out the test for the top 75 cities.

growth pattern implies that cities evolve according to a stochastic process in which the growth rate does not depend on the initial size, so that the differences in the final sizes of the cities depend on exogenously distributed characteristics (locational fundamentals theory) or random shocks. In this case, under certain conditions the limit distribution of city size must converge to a Pareto distribution that obeys Zipf’s law (Gabaix, 1999).

In this section, we take a different perspective. Our intention is to examine mobility within the distribution, trying to extract growth patterns different from the general unit root trend detected in the previous section. To do this, we use two different techniques. First, we calculate transition matrices, which tell us the degree of mobility in terms of probability. Second, we apply a cluster algorithm to identify different groups of cities that converge with each other. Both approaches are complementary; while the transition matrices define some groups in relative terms and the movements of cities between these groups are examined, with the second method we use the algorithm to identify endogenously the groups of cities that converge over time, looking for evidence of some type of “local” mean-reverting behavior.

## 4.1 Transition matrices

### Description

Eaton and Eckstein (1997) were the first to apply Quah’s (1993) transition matrices to city size evolution. Let  $F_t$  be the vector representing the city size distribution at instant  $t$ , relative to the average size. We can say that this distribution follows a stochastic process defined by a Markov chain if the transition from one period to the next is given by:

$$F_{t+1} = M_t F_t, \tag{3}$$

where  $M_t$  is the movement matrix or transition matrix defining the law of movement from one period to the next. If  $M_t$  is time-invariant, then we have a stationary process and  $M_t = M$ . A Markov chain requires discrete time and a finite space of states  $E$ , which

represents a discrete approximation to population distribution. Implicit in (3) is also what is known as the Markov property, i.e., that the future of the process depends only on its most immediate past (a homogeneous first-order stationary Markov process). Element  $p_{ij}$  of the matrix  $M$  represents the probability that a city in state  $i$  in  $t$  moves to state  $j$  in  $t + 1$ ,  $i, j \in E$ . It is evident that  $p_{ij} \geq 0$  and that  $\sum_{j \in E} p_{ij} = 1, \forall i \in E$ .

The elements of the matrix  $M$  can be estimated by maximum likelihood (Hamilton, 1994; Bosker et al., 2008) applying:

$$\hat{p}_{ij} = \frac{\sum_{t=1}^{T-1} n_{it,jt+1}}{\sum_{t=1}^{T-1} n_{it}}, \quad (4)$$

where  $n_{it,jt+1}$  is the number of cities moving from state  $i$  in year  $t$  to state  $j$  in year  $t + 1$  and  $n_{it}$  the number of cities in state  $i$  in year  $t$ .

The general expression (3) is valid for the case in which no cities enter or leave the sample from one year to the next. This is not our case, and thus we need to apply an extended equation, which describes the evolution of a distribution that allows cities to enter or leave.

In the case of a sample that grows over time, in which from one period to the next cities only enter, Dobkins and Ioannides (2000) and Black and Henderson (2003) show that the correct equation is:

$$F_{t+1} = (1 - i_t) M F_t + i_t Z_t, \quad (5)$$

where  $i_t$  is a scalar denoting the percentage of new cities in  $t + 1$  over the total existing cities in  $t + 1$  and  $Z_t$  is the vector of relative frequencies of the cities that enter.

In our case, where cities enter and leave the sample from one period to the next, Lanaspá et al. (2011) propose the next equation:

$$F_{t+1} = M F_t - n_t M X_t + n_t Z_t, \quad (6)$$

where  $n_t = \frac{N_t}{N}$  with  $N$  denoting the constant number of cities in each period and  $N_t$  representing the number of cities entering or leaving from  $t$  to  $t + 1$ ,  $Z_t(X_t)$  is the vector of relative frequencies of the cities that enter (leave) the sample and  $M$  is the transition matrix from  $t$  to  $t + 1$  but only of the  $N - N_t$  cities that are in the sample both in  $t$  and in  $t + 1$ . The difference between Eq. (6) and Black and Henderson's (2003) expression (Eq. 5) is the term  $n_t M X_t$ , which represents the distribution of cities that leave the sample.

## Results

Table 3 shows the  $M$  matrices for three different periods (again 1790–1900, 1900–2000 and 1790–2000) and three sample sizes (75, 100 and 150 cities). This methodology always takes into account the largest cities at each moment in time, allowing these largest cities to change, enter or leave the sample, or remain in it from one period to the next.<sup>13</sup> Five states are considered; a larger number would increase the mobility artificially and a smaller number would provide little information on intra-distribution mobility. The upper limits for each state are 0.4, 0.7, 1, 2 and  $\infty$  times the average for each year.<sup>14</sup> The thresholds of the different categories are not exactly the same, but they are very similar to those used by Eaton and Eckstein (1997), Dobkins and Ioannides (2000) and Bosker et al. (2008). In any case, one of the criteria used to define them is that the number of cities in each of the categories should not be different. As is already known, the major problem with this approach is that any choice of states inevitably involves a certain amount of arbitrariness. With this in mind, we explored alternative cut-off points, although these are not very different from the states finally chosen, and the qualitative results remain the same. The relative frequencies are also shown of the cities that enter ( $Z_t$ ) and leave the sample ( $X_t$ ) throughout the period, as defined above.

Several conclusions emerge from Table 3. The first and most important is that we find intense mobility in the distribution of cities; persistence is not high. This is especially true

<sup>13</sup>But to define the largest cities in each period, entry and exit, we use all the cities available each year.

<sup>14</sup>The average is not calculated for all the cities, but for those that remain in the sample for two consecutive periods (see the definition of the matrix  $M$ ).

for Panel A (1790–1900), which captures the creation of cities in the nineteenth century, and Panel C (1790–2000), which represents the aggregate period. In fact, many of the elements in the diagonal of the matrices in Panel A, which correspond to the cities that belong to the same state for two consecutive periods, are below 0.7, thus indicating high mobility in that period. Panel B shows less mobility, as most of the elements in the diagonal of the matrices are greater than 0.8. These results highlight the difference between the nineteenth (high mobility) and twentieth century (a more stable urban system). The matrices in Panel B are consistent with those of Black and Henderson (2003), as the period they consider is similar (1900–1990). Focusing on the aggregate period 1790–2000 (Panel C), of the fifteen elements in the diagonals, only three are higher than 0.9, while six values are between 0.7 and 0.8, and one is below 0.7. All of them are significantly different from one (value one represents no transitions to any other states and thus absolute persistence).<sup>15</sup>

It is usual in the literature to find little mobility, as detected for the US by Black and Henderson (1999, 2003) and by Beeson et al. (2001), but those samples cover a considerably shorter time horizon than the one we consider. Our sample covers more than two centuries. By studying the urban structure from its beginning the conclusions may be different, because over these centuries, the late eighteenth, the nineteenth and the twentieth, the American urban structure was formed and built through demographic expansion (waves of immigration throughout the nineteenth century) and territorial expansion (the so-called conquest of the West and the founding of the cities of the West and Mid-West). Other works that consider the same time horizon (1790–2000) also find evidence of high mobility within the distribution (Batty, 2006; Cuberes, 2011). Thus, Batty (2006) develops rank-clocks that show how, with the exception of New York, the cities of the original 13 colonies gradually lost their positions with the entrance of new cities. Our data show the same behavior as a consequence of the mobility noted above and the entry of new cities. If we rank cities in 2000 only New York, Philadelphia, Boston and Baltimore of all the cities that existed in the first period (1790) are still among the top 20 cities (and only New York and Philadel-

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<sup>15</sup>Standard errors, not shown, are available from the authors on request.



phia remain within the top 10 cities), while the rest have lost their positions and have been overtaken by other cities that entered the system later.

Cuberes (2011) finds that the average-rank of the fastest-growing cities (not just American cities, as his sample includes data for cities in other countries) tends to increase over time, a result that he interprets as evidence in favor of sequential urban growth. If cities grow sequentially, the cities that are initially the largest must represent a large share of the total urban population of the country in the initial periods and a relatively smaller one later on (although this is a necessary but not sufficient condition). As Table 1 shows, the behavior of our sample of cities is consistent with this affirmation.

The second conclusion refers to the cities that enter ( $Z_t$ ) and leave the sample ( $X_t$ ). In the three panels, those cities that leave the sample do so almost exclusively from the fifth state, that of the smallest cities. It makes sense that large cities do not disappear suddenly. In Cuberes (2009) and Henderson and Venables (2009), the explanation is that there is irreversible investment. In Glaeser and Gyourko (2005), it happens because housing is a durable good that depreciates slowly over time. This fact is not the same for cities entering the sample; in Panels A and C they enter in all the states, except for that of the largest cities. Nevertheless, in Panel B, which we claim represents a more stable urban structure, cities only enter to the last two states (the smallest cities in the samples). From a long-term perspective (Panel C), this result indicates that cities enter the sample with a considerable size (most of them cities created in the West) and grow very quickly until they reach the sizes of the pre-existing cities (leapfrogging).

## 4.2 Convergence clubs

### Description

The results in Section 3 show that we cannot reject the random growth (unit root) hypothesis for most of the proposed specifications, against the alternative hypothesis of convergence (mean reversion). However, in the previous section we find evidence of high

mobility when we model growth as a first-order Markov process. That approach explains how cities move between the different population thresholds we defined; however, more or less movement does not automatically imply convergence or divergence. Therefore, in this section we apply a cluster algorithm to try to identify different groups of cities that converge with each other, looking for evidence of some type of “local” mean-reverting behavior. Cluster analysis has previously been used to study clusters of cities within city size distribution (Garmestani et al., 2005), but here we look for clusters in city growth rates rather than clusters in city sizes.

The cluster procedure is based on the log  $t$ -test (Phillips and Sul, 2007, 2009), which focuses on the evolution over time of the idiosyncratic transitions in relation to the common growth component. Therefore, in Section 3 we analyzed the evolution of the common growth component using panel unit root tests and now we focus on the possible differences in the idiosyncratic transitions across cities. This new approach is different from that of previous empirical studies on growth convergence clubs, such as Durlauf and Johnson (1995) and Canova (2004). The regression model of the log  $t$ -test is:

$$\log \frac{H_1}{H_t} - 2 \log (\log t) = \beta_0 + \beta_1 \log t + u_t, \quad \text{for } t = T_0, \dots, T \quad (7)$$

where  $\frac{H_1}{H_t}$  is the cross-sectional variance ratio,  $H_t$  is the transition distance,  $H_t = N^{-1} \sum_{i=1}^N (h_{it} - 1)^2$ , and  $h_{it}$  is the relative transition coefficient, defined as  $h_{it} = \frac{\log S_{it}}{N^{-1} \sum_{i=1}^N \log S_{it}}$  (again  $S_{it}$  is the size (population) of city  $i$  at time  $t$ ). These relative transition coefficients exclude the common growth component ( $\mu_t$ ) by scaling, measuring city  $i$ 's transition element relative to the cross-section average. This means that  $h_{it}$  traces out city  $i$ 's individual trajectory relative to the average, so Phillips and Sul (2009) call  $h_{it}$  the “relative transition path.” Moreover,  $h_{it}$  also measures for each city  $i$  the departure from the common growth path  $\mu_t$  in relative terms. Eq. (7) is obtained from a neoclassical growth model (see Phillips and Sul, 2007).

Eq. (7) simply represents a time series regression; the null hypothesis is growth convergence across all cities and the alternatives include no convergence and partial convergence

among subgroups of cities. As the t-statistic of the test refers to the coefficient  $\beta_1$  of the  $\log t$  regressor in Eq. (7), the test is called the ‘ $\log t$ ’ convergence test. It is important that not only the sign of the coefficient  $\beta_1$  of  $\log t$  but also its magnitude measure the speed of convergence. The interpretation of the results may change depending on whether the estimated parameter is  $2 > \beta_1 \geq 0$  or  $\beta_1 \geq 2$ . In the case that  $\beta_1 \geq 2$  and the common growth component  $\mu_t$  follows a random walk with drift or a trend stationary process,<sup>16</sup> then so large values of  $\beta_1$  will imply convergence in level city populations (cities end up with the same population). However, if  $2 > \beta_1 \geq 0$  this speed of convergence corresponds to conditional convergence, in which population growth rates converge over time across the cities within the club.<sup>17</sup>

The cluster procedure performs the  $\log t$  test for each of the groups and stops when the group of remaining cities does not satisfy the convergence test. First, it defines an initial core primary group, and other groups are formed according to certain criteria that maximize the value of the t-statistic. A much more detailed explanation of the constructive steps of the procedure can be found in Phillips and Sul (2007, 2009).

## Results

Table 4 shows the results of applying the cluster algorithm to our sample of cities.<sup>18</sup> We only consider the whole period (1790–2000); owing to data limitations, we cannot analyze subperiods as we did in the previous sections. Again, the results are reported for three sample sizes: the top 75, 100 and 150 largest cities in 1900.<sup>19</sup> In this case, the

<sup>16</sup>Note that the hypothesis of random growth in the common growth component was tested in Section 3.

<sup>17</sup>Note that this terminology is slightly different from the classical definition of conditional convergence, which depends on individuals’ structural characteristics and initial conditions (Galor, 1996). An analysis of the general characteristics of the various convergence clubs as well as the many possible determining factors and initial conditions in each case is beyond the scope of this paper.

<sup>18</sup>The estimations were performed with the Gauss code kindly provided by Donggyu Sul on his webpage. As Phillips and Sul (2007) recommend, we set  $r = 0.3$  ( $r$  is the initiating sample fraction).

<sup>19</sup>To apply the algorithm we must have a balanced panel data. Given that most of the cities appear in the sample after 1790, we must carry out a little data transformation, assigning a population of 1 to the cities that did not exist in each period. This transformation means that these cities have a zero log-population in the periods in which they did not exist. If this change affected the cluster procedure, the cities that appear in the same period would be grouped in the same club; however, Figure 1 shows how the groups are formed by cities that appear in different periods.

choice of the reference period is relevant, because the largest cities in 2000 are a sample of “winning” cities, those that since they first appeared have presented the highest growth rates.<sup>20</sup> However, some of the cities that were among the largest in 1900 have lost their positions in the ranking and they have been overtaken by other cities. Therefore, if we consider this sample of cities, we capture more heterogeneous behaviors.<sup>21</sup>

The “club” column shows the number of cities that are members of each convergence group. The results are consistent for the three sample sizes, because despite enlarging the sample the cities do not usually change groups. Only with the top 150 sample is there a small redistribution of cities, because one less convergence club is detected. The distribution of cities within groups can be consulted in the Appendix.

Given that the city distribution is fairly consistent regardless of the sample size, for clarity we will show only the graphs for the top 75. Figure 1 shows the evolution over time of the log-population of the cities in each convergence club (we show the log-population because by definition the test is performed with log-variables). Our analysis focuses on these results. Figure 2 shows the evolution of the top 75 cities, and demonstrates that it is difficult to deduce any specific type of pattern. However, some of the groups represented in the remainder of the graphs show a sequential pattern, especially in the entry of new cities. These new cities appear later in the sample, but grow at a faster rate than do the rest of the cities in their club until they reach similar growth rates to the pre-existing cities.<sup>22</sup> It is surprising that in almost all convergence clubs (groups of cities that converge in growth rates identified by the cluster procedure), the cities do not appear in the sample at the same time, but rather sequentially. This behavior is consistent with a pattern of sequential city growth, at least within groups.

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<sup>20</sup>In fact, with the largest cities in 2000 we find only four convergence clubs, because all of them are cities characterized by high growth rates. The results are available from the authors on request.

<sup>21</sup>Altogether, 31 cities (20.7%) of the top 150 cities in 2000 are not in the top 150 cities in 1900. The differences are greater still in the top 75 and 100, because there are 36 different cities (48% and 36% of the sample, respectively).

<sup>22</sup>Some of the graphs are similar to Figure 4 (a) in Henderson and Venables (2009), obtained by simulations of their theoretical model of city formation. However, these graphs should be taken with caution as they show log-population and the log-scale smoothes cross-city differences in levels. Moreover, because a city’s log population is zero before it enters the sample, graphically most (but not all) of the catch-up is the steep segment for the single decade in which the city appears.

The algorithm classifies cities into 12 groups (convergence clubs). There are four remaining cities that are not classified into any club and for which the convergence hypothesis is rejected. In each group, the estimated coefficient  $\hat{\beta}_1$  is significantly positive, strongly supporting the club classification. Furthermore, only one of the estimated coefficients is significantly greater than two (club 2), indicating that the evidence in favor of level convergence is small, while support for conditional convergence within each of the other clubs is stronger because  $\hat{\beta}_1 < 2$ . Of the four cities belonging to club 2, three are in the South Region, although the geographical distribution of cities shows no specific spatial pattern in any of the groups. Only club 11 consists of cities belonging to the same region (Northeast), although another common characteristic of these cities is that they are among the oldest. The cities that have existed since 1790 are classified into groups 10 to 12, indicating that while they present a different growth pattern from the cities that appeared later, they also differ from each other.

It should be noted that of the 12 clubs, only clubs 1 and 2 correspond to cities that rise in the ranking (on average) from 1900 to 2000. The cities within the other clubs lose positions in the ranking (on average), especially those in clubs 7, 9 and 12, confirming our idea that our sample captures more heterogeneous behaviors than does the sample of “winning” cities in 2000, especially because we also include “failing” cities that performed poorly in terms of growth over the entire time interval.

## 5 Discussion

Thus far, we found mixed evidence regarding city growth in the long-term. First, we cannot reject the random growth (unit root) hypothesis for most of the proposed specifications, against the alternative hypothesis of convergence (mean reversion). However, we find evidence of high mobility when we model growth as a first-order Markov process; this mobility is consistent with the results of other studies that consider the same 1790–2000 period (Batty, 2006; Cuberes, 2011). Finally, using a cluster procedure we find strong evidence

supporting conditional convergence in city growth rates within convergence clubs, which we can interpret as “local” mean-reverting behaviors. We interpret the high mobility and the results of clustering analysis as signs of a sequential city growth pattern.

These results raise two questions: first, whether these different empirical results are compatible and, second, whether the city size distribution has evolved according to the random growth pattern (if Zipf’s law holds) or whether, on the contrary, the trend has been convergence among cities.

The first question asks whether a random growth result is compatible with a degree of convergence in the evolution of city growth rates; in other words, whether a unit root is compatible with some kind of mean-reverting component. Gabaix and Ioannides (2004) answer this question by putting forward what they call “deviations from Gibrat’s Law (random growth) that do not affect the distribution,” starting from:

$$\ln S_{it} - \ln S_{it-1} = \mu(X_{it}, t) + \epsilon_{it}, \quad (8)$$

where  $X_{it}$  is a possibly time-varying vector of characteristics of city  $i$ ;  $\mu(X_{it}, t)$  is the expectation of city  $i$ ’s growth rate as a function of economic conditions at time  $t$ ; and  $\epsilon_{it}$  is white noise. In the simplest specification,  $\epsilon_{it}$  is independently and identically distributed over time (this means that  $\epsilon_{it}$  has a zero mean and a constant variance that is uncorrelated with  $\epsilon_{is}$  for  $t \neq s$ ) and  $\mu(X_{it}, t)$  is constant.

Gabaix and Ioannides (2004) consider two types of deviations, relaxing both assumptions. Rossi-Hansberg and Wright (2007) discuss the economic interpretations of deviations from Zipf’s and Gibrat’s laws. We are interested in the consequences of relaxing the assumption of an i.i.d.  $\epsilon_{it}$ , assuming constant  $\mu(X_{it}, t) = \mu$ . In its place, the following stochastic structure is assumed:  $\epsilon_{it} = b_{it} + \eta_{it} - \eta_{it-1}$ , where  $b_{it}$  is i.i.d. and  $\eta_{it}$  follows a stationary process. Replacing in (8) they obtain:

$$\ln S_{it} - \ln S_{i0} = \mu t + \sum_{s=1}^t b_{is} + \eta_{it} - \eta_{i0}. \quad (9)$$

The term  $\sum_{s=1}^t b_{is}$  gives a unit root in the growth process, while the term  $\eta_{it}$  can have any stationarity. According to Gabaix and Ioannides (2004), this means that “for Zipf’s law to hold, the city evolution process can contain a mean reversion component, as long as it contains a non-zero unit root component.” Therefore, our mixed empirical evidence is not contradictory, but rather compatible. In addition, our conclusion leads us directly to our second question, the behavior of city size distribution over the 1790–2000 period (and whether Zipf’s law holds).

Let us denote  $S$  as the size (population) and  $R$  as its corresponding rank (1 for the largest, 2 for the second largest and so on). A power law (Pareto distribution) links city size and rank as follows:  $R(S) = AS^{-a}$ . This expression has been used extensively in urban economics to study city size distribution (see, for example, Eeckhout (2004) and Ioannides and Overman (2003) for the US case). It is usually specified and estimated in its logarithmic version:

$$\ln R = b - a \ln S + \xi, \quad (10)$$

where  $\xi$  is the error term and  $b$  and  $a$  are the parameters that characterize the distribution. The latter is known as the Pareto exponent, and Zipf’s law is considered to hold when  $a = 1$ . This means that when ordered from largest to smallest, the size of the second city is half that of the first one, the size of the third is a third of the first one and so on. The greater the coefficient, the more homogeneous are the city sizes. In addition, an increase in the coefficient over time would mean a process of convergence in city sizes. Similarly, the smaller the coefficient, the less homogeneous are city sizes, and a decreasing evolution would mean a process of divergence.

Gabaix and Ibragimov (2011) propose specifying Equation (10) by subtracting  $1/2$  from the rank to obtain an unbiased estimation of  $a$ :

$$\ln \left( R - \frac{1}{2} \right) = b - a \ln S + \epsilon. \quad (11)$$

Equation (11) was estimated by OLS for our sample of cities in the different decades dur-

ing the 1790–2000 period. Figure 3 shows the results.<sup>23</sup> We estimated using all the cities available in each decade (from 16 in 1790 to 190 in 2000). The results show that the distribution remained stable until 1950, so the entry of new cities did not have a significant effect, although the estimated coefficients are less than one, indicating a high degree of inequality among city sizes. Therefore, during this period the stable evolution of the city size distribution reflects the random growth process, even though the resulting Pareto exponent of the distribution is lower than one, rejecting Zipf’s law for this group of the largest cities.<sup>24</sup>

From 1950 the estimated Pareto coefficient grows to reach (and exceed) the value of one. Note that from 1950 to 2000 only 11 cities enter the sample, so that the evolution of the exponent reacts only to the city growth process. The increasing trend of the exponents indicates a process of convergence among cities. We also estimated the Gini coefficients for each period. The Gini coefficients have the advantage of not imposing a specific size distribution (Pareto for rank-size coefficients). The results are similar; from 1790 to 1950, the Gini coefficient rose from 0.65 to 0.68,<sup>25</sup> while in 2000 it was 0.50. Therefore, during this period the evolution of the distribution clearly corresponds to a convergence phase. The explanation for this convergence process is well known in the literature (post-war suburbanization). During the second half of the twentieth century, mid-sized and small American cities grew much more than did the largest cities in the same metropolitan areas.<sup>26</sup> Glaeser et al. (2011) claim that some of the impact of sprawl and the role that the automobile played in dispersing the American population can explain some of these patterns. The effect that we capture from this process is that the cities of the upper-tail distribution became more homogeneous in size because of the larger growth of mid-sized cities, thereby bringing them closer to the largest ones.

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<sup>23</sup>The Pareto exponent is estimated using Gabaix and Ibragimov’s Rank-1/2 estimator. Dashed lines represent the standard errors calculated applying Gabaix and Ioannides’s (2004) corrected standard errors:  $GI\ s.e. = \hat{a} \cdot (2/N)^{1/2}$ , where  $N$  is the sample size.

<sup>24</sup>Except in 1830 and 1840, for which the confidence intervals indicate that we cannot reject the fact that the coefficient is significantly different from one.

<sup>25</sup>However, the evolution of the Gini coefficient is not as stable as that of the Pareto exponent, because within this period it does reflect changes in the inequality of the distribution in some decades.

<sup>26</sup>Several works have studied the causes of this process. For example, Margo (1992) examines the role of income.



## 6 Conclusions

In this paper, we study the growth pattern of the system of cities in the United States from its origin. We obtain several conclusions. First, we find evidence supporting random growth in American cities during the 1790–2000 period, indicating that the growth rate does not depend on initial size. Second, we find evidence of high intra-distribution mobility when we consider growth as a first-order Markov process. Third, using a cluster procedure we find evidence in favor of the conditional convergence of city growth rates within convergence clubs, allowing us to conclude that “local” mean-reverting behaviors exist. Our results lend support to recent theories of sequential city growth.

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Table 1: NUMBER OF CITIES AND DESCRIPTIVE STATISTICS BY YEAR

Year	Cities	Mean	Standard deviation	Minimum	Maximum	US urban population (UP)	% of UP
1790	16	8,746.50	13,313.13	200	49,401	201,655	69.40%
1800	22	10,255.00	18,565.84	81	79,216	322,371	69.98%
1810	25	14,278.04	26,052.55	383	119,734	525,459	67.93%
1820	28	16,832.07	31,499.38	606	152,056	693,255	67.98%
1830	36	20,631.19	43,079.73	877	242,278	1,127,247	65.89%
1840	50	24,502.46	58,753.40	1,222	391,114	1,845,055	66.40%
1850	73	30,220.67	85,663.40	415	696,115	3,574,496	61.72%
1860	94	44,193.24	136,697.40	175	1,174,779	6,216,518	66.82%
1870	110	55,417.75	160,729.66	155	1,478,103	9,902,361	61.56%
1880	125	65,037.17	197,482.93	556	1,911,698	14,129,735	57.54%
1890	149	77,799.07	232,080.75	273	2,507,414	22,106,265	52.44%
1900	157	108,432.39	329,863.51	202	3,437,202	30,214,832	56.34%
1910	165	142,935.56	433,335.63	297	4,766,883	42,064,001	56.07%
1920	171	176,340.04	509,938.16	326	5,620,048	54,253,282	55.58%
1930	179	211,572.36	614,701.55	515	6,930,446	69,160,599	54.76%
1940	179	224,762.88	651,013.99	582	7,454,995	74,705,338	53.85%
1950	179	260,994.59	695,986.21	727	7,891,957	96,846,817	48.24%
1960	182	290,794.10	683,649.24	3,695	7,781,984	125,268,750	42.25%
1970	187	308,875.27	679,828.20	14,089	7,895,563	149,646,617	38.60%
1980	188	311,706.85	617,176.35	62,134	7,071,639	167,050,992	35.08%
1990	190	332,701.32	635,704.55	95,802	7,322,564	187,053,487	33.79%
2000	190	364,890.56	690,433.95	100,565	8,008,278	222,360,539	31.18%

*Note:* US urban population data are taken from US Census Bureau.

Source: <http://www.census.gov/population/censusdata/table-4.pdf>

Table 2: PANEL UNIT ROOT TESTS, PESARAN'S CADF STATISTIC

Panel A: 1790-1900. Year of reference for Top cities: 1860						
Sample Size	Augmenting lag (1)		Augmenting lags (2)		Augmenting lags (3)	
	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
Top 10	4.448 (1.000)	4.522 (1.000)	10.877 (1.000)	8.882 (1.000)	10.877 (1.000)	8.882 (1.000)
Top 75	18.021 (1.000)	15.331 (1.000)				
Panel B: 1900-2000. Year of reference for Top cities: 1900						
Sample Size	Augmenting lag (1)		Augmenting lags (2)		Augmenting lags (3)	
	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
Top 10	2.673 (0.996)	0.374 (0.646)	12.533 (1.000)	11.253 (1.000)	12.533 (1.000)	11.253 (1.000)
Top 75	5.152 (1.000)	1.049 (0.853)	34.011 (1.000)	30.349 (1.000)	34.011 (1.000)	30.349 (1.000)
Top 100	-0.799 (0.212)	2.250 (0.988)	39.273 (1.000)	35.044 (1.000)	39.273 (1.000)	35.044 (1.000)
Top 150	-5.100 (0.000)	2.612 (0.995)	48.540 (1.000)	43.583 (1.000)	48.540 (1.000)	43.583 (1.000)
Panel C: 1790-2000. Year of reference for Top cities: 1900						
Sample Size	Augmenting lag (1)		Augmenting lags (2)		Augmenting lags (3)	
	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
Top 10	-4.110 (0.000)	-1.593 (0.056)	-1.394 (0.082)	-1.626 (0.052)	-3.212 (0.001)	-1.752 (0.040)
Top 75	-8.251 (0.000)	-8.067 (0.000)	-3.507 (0.000)	-0.805 (0.210)	4.165 (1.000)	12.598 (1.000)
Top 100	-5.489 (0.000)	-5.468 (0.000)	-0.071 (0.472)	1.575 (0.942)	10.535 (1.000)	18.987 (1.000)
Top 150	-7.645 (0.000)	-1.397 (0.081)	-2.471 (0.007)	9.946 (1.000)	20.622 (1.000)	28.679 (1.000)

*Note:* Pesaran's (2007)  $Z[\bar{t}]$  test-statistic (p-value). Sample may not contain gaps; therefore, the eight gaps in the sample were filled using values calculated by linear interpolation.



Table 3: AVERAGE 10-YEAR TRANSITION MATRICES

Panel A: 1790-1900						Panel B: 1900-2000						Panel C: 1790-2000					
Sample Size: 75						Sample Size: 75						Sample Size: 75					
	$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4
$\infty$	0.933	0.067	0	0	0	$\infty$	0.922	0.078	0	0	0	$\infty$	0.928	0.072	0	0	0
2	0.082	0.755	0.163	0	0	2	0.033	0.856	0.111	0	0	2	0.050	0.820	0.130	0	0
1	0	0.279	0.512	0.209	0	1	0	0.112	0.747	0.141	0	1	0	0.162	0.676	0.162	0
0.7	0	0.011	0.080	0.670	0.239	0.7	0	0.005	0.076	0.839	0.080	0.7	0	0.006	0.077	0.792	0.125
0.4	0	0.004	0.010	0.086	0.900	0.4	0	0	0.013	0.134	0.853	0.4	0	0.002	0.012	0.106	0.880
$X_t$	0	0	0	0	0.05751	$X_t$	0	0	0	0.00135	0.07143	$X_t$	0	0	0	0.00073	0.06506
$Z_t$	0	0.00160	0.00160	0.00320	0.14537	$Z_t$	0	0	0	0.00674	0.06604	$Z_t$	0	0.00073	0.00073	0.00512	0.10234
Sample Size: 100						Sample Size: 100						Sample Size: 100					
	$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4
$\infty$	0.918	0.082	0	0	0	$\infty$	0.913	0.087	0	0	0	$\infty$	0.915	0.085	0	0	0
2	0.102	0.780	0.102	0.016	0	2	0.056	0.839	0.105	0	0	2	0.071	0.820	0.104	0.005	0
1	0	0.102	0.592	0.306	0	1	0	0.118	0.756	0.126	0	1	0	0.114	0.710	0.176	0
0.7	0	0.041	0.082	0.653	0.224	0.7	0	0.009	0.101	0.780	0.110	0.7	0	0.018	0.095	0.742	0.145
0.4	0	0.003	0.003	0.087	0.907	0.4	0	0	0.011	0.122	0.867	0.4	0	0.001	0.007	0.105	0.887
$X_t$	0	0	0	0	0.02307	$X_t$	0	0	0	0	0.06949	$X_t$	0	0	0	0	0.04971
$Z_t$	0	0.00136	0.00136	0.00407	0.13026	$Z_t$	0	0	0	0.00302	0.06647	$Z_t$	0	0.00058	0.00058	0.00347	0.09364
Sample Size: 150						Sample Size: 150						Sample Size: 150					
	$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4		$\infty$	2	1	0.7	0.4
$\infty$	0.921	0.079	0	0	0	$\infty$	0.898	0.102	0	0	0	$\infty$	0.908	0.092	0	0	0
2	0.143	0.661	0.196	0	0	2	0.068	0.837	0.095	0	0	2	0.085	0.797	0.118	0	0
1	0	0.141	0.684	0.175	0	1	0.006	0.116	0.749	0.129	0	1	0.005	0.123	0.731	0.141	0
0.7	0	0.037	0.111	0.667	0.185	0.7	0	0.018	0.078	0.806	0.098	0.7	0	0.023	0.086	0.771	0.120
0.4	0	0	0.002	0.084	0.914	0.4	0	0.002	0.003	0.125	0.870	0.4	0	0.001	0.003	0.109	0.887
$X_t$	0	0	0	0	0.00407	$X_t$	0	0	0	0	0.03928	$X_t$	0	0	0	0	0.02608
$Z_t$	0	0.00114	0.00114	0.00457	0.14400	$Z_t$	0	0	0	0.00333	0.03595	$Z_t$	0	0.00042	0.00042	0.00379	0.07783

Table 4: CONVERGENCE CLUBS, 1790-2000

Club	$\beta_1$ (t-statistic)	Club	$\beta_1$ (t-statistic)	Club	$\beta_1$ (t-statistic)
1 [7]	0.105 (0.146)	1 [12]	0.744 (2.386)	1 [26]	1.217 (6.979)
2 [4]	2.507 (3.844)	2 [7]	0.671 (4.686)	2 [17]	0.254 (3.720)
3 [6]	0.893 (2.326)	3 [6]	0.893 (2.326)	3 [9]	0.225 (2.674)
4 [5]	0.256 (3.225)	4 [7]	0.142 (0.910)	4 [15]	0.141 (1.634)
5 [6]	0.294 (1.885)	5 [12]	0.560 (2.119)	5 [20]	0.400 (1.462)
6 [8]	0.435 (5.784)	6 [12]	0.010 (0.087)	6 [23]	0.064 (0.502)
7 [14]	0.224 (2.389)	7 [18]	0.370 (4.367)	7 [21]	0.539 (4.215)
8 [6]	1.970 (1.188)	8 [6]	1.970 (1.188)	8 [3]	2.405 (2.303)
9 [4]	0.353 (0.985)	9 [5]	0.700 (2.794)	9 [6]	0.011 (0.396)
10 [5]	0.224 (4.673)	10 [5]	0.224 (4.673)	10 [3]	0.842 (6.385)
11 [3]	0.842 (6.385)	11 [3]	0.842 (6.385)	11 [3]	0.347 (0.711)
12 [3]	0.347 (0.711)	12 [3]	0.347 (0.711)		
Sample Size: Top 75		Sample Size: Top 100		Sample Size: Top 150	

*Note:* The numbers in brackets are the number of cities. Top cities are defined according to ranks in 1900. The corresponding t-statistic in the regression is constructed in the usual way using HAC standard errors. At the 5% level, for example, the null hypothesis of convergence is rejected if t-statistic < -1.65. All of the t-statistics reported are positive, indicating that we cannot reject the null hypothesis at the 5% in any case.

Figure 1: Cities' log population evolution, Top 75, 1790–2000: Convergence clubs

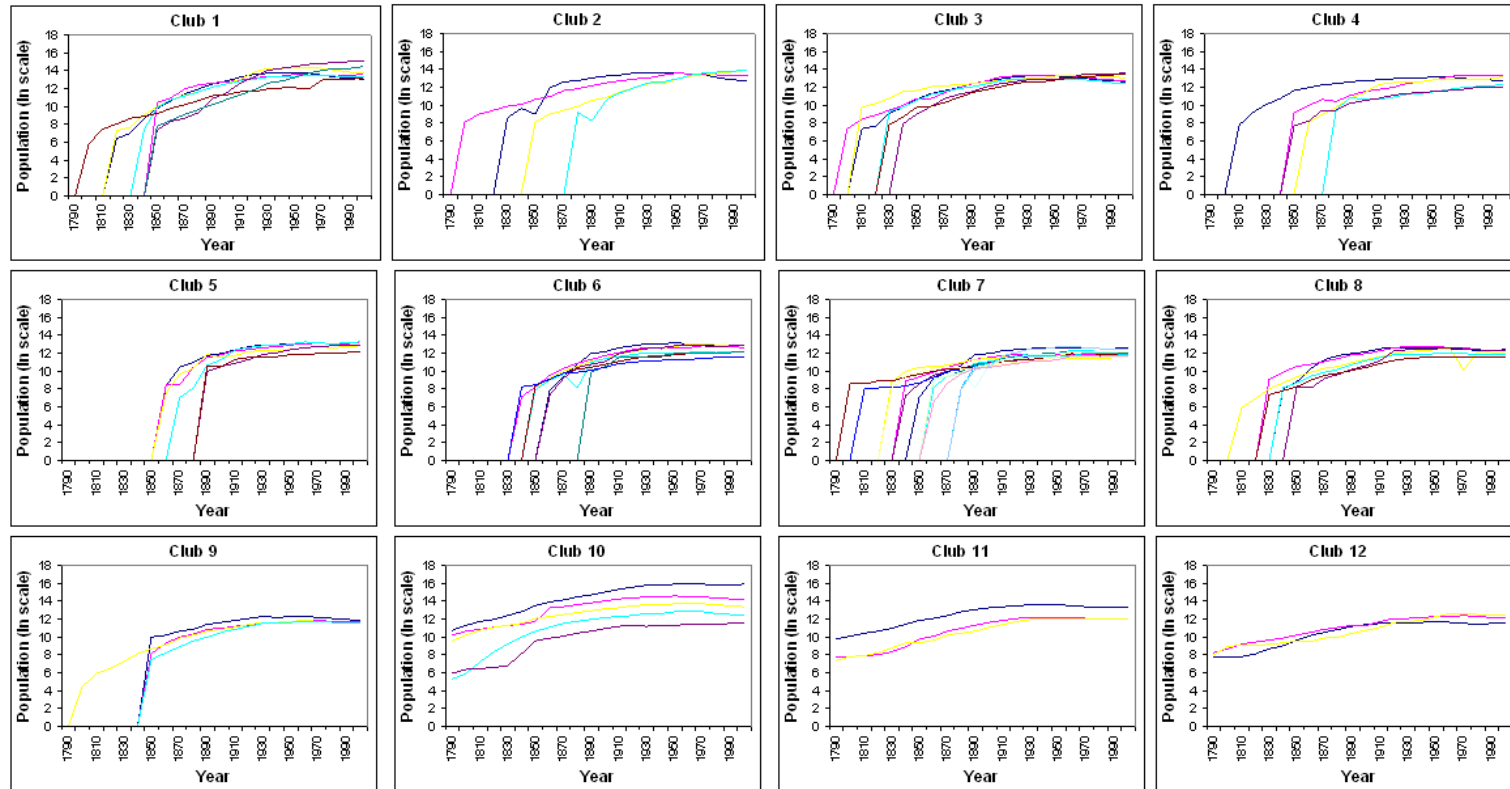


Figure 2: Cities' log population evolution, Top 75, 1790–2000

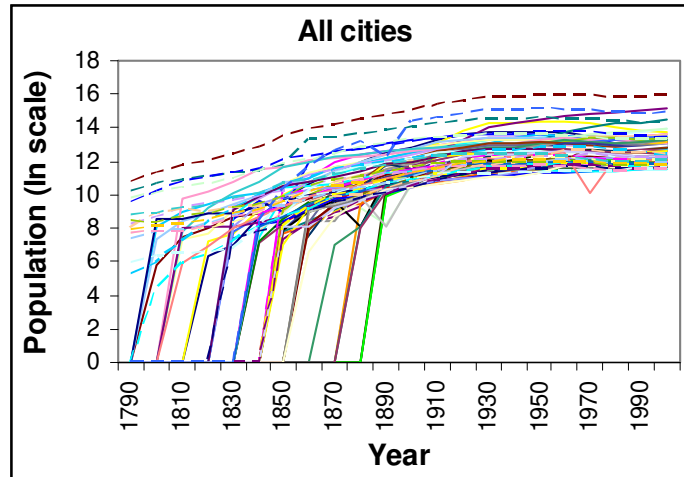
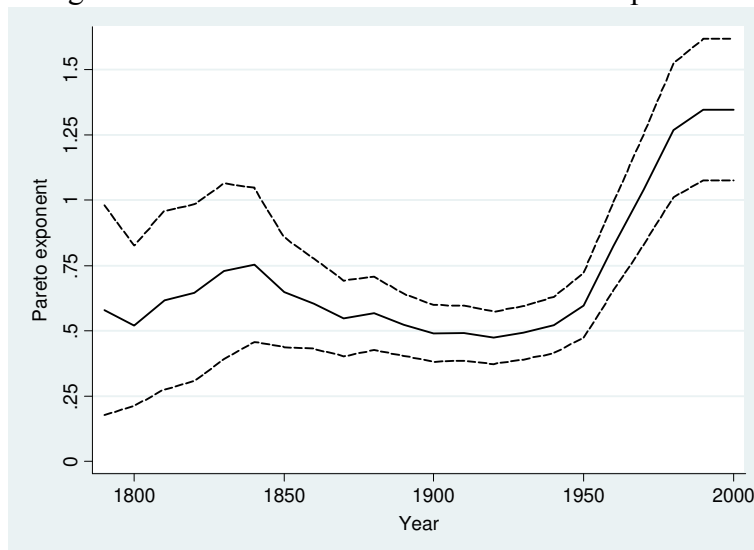


Figure 3: Evolution of the estimated Pareto exponents



# Appendix: Cities within clubs

## CITIES WITHIN CLUBS

Rank in 1900	First year in the sample	Name	Club (Sample Size: Top 75)	Club (Sample Size: Top 100)	Club (Sample Size: Top 150)
1	1790	New York	10	10	9
2	1840	Chicago			
3	1790	Philadelphia	10	10	9
4	1830	St. Louis	2	2	2
5	1790	Boston	11	11	10
6	1790	Baltimore	10	10	9
7	1820	Cleveland	1	1	1
8	1810	Buffalo	3	3	3
9	1850	San Francisco	1	1	1
10	1810	Cincinnati	4	4	4
11	1800	Pittsburgh	3	3	3
12	1810	New Orleans	3	3	3
13	1820	Detroit	1	1	1
14	1840	Milwaukee	1	1	1
15	1800	Washington	2	2	2
16	1830	Newark	3	3	3
17	1840	Jersey	8	8	7
18	1790	Louisville	10	10	9
19	1860	Minneapolis	6	6	6
20	1790	Providence			
21	1840	Indianapolis	3	3	3
22	1860	Kansas	5	5	5
23	1850	St. Paul	7	7	6
24	1830	Rochester	8	8	7
25	1860	Denver	5	5	5
26	1840	Toledo	6	6	6
27	1830	Columbus	3	3	3
28	1790	Worcester	11	11	10
29	1850	Syracuse	9	9	7
30	1790	New Haven			
31	1840	Paterson	7	7	7
32	1860	Omaha	5	5	5
33	1850	Los Angeles	1	1	1
34	1850	Memphis	4	4	4
35	1830	Lowell	7	7	7
36	1790	Cambridge	12	12	11
37	1860	Portland	4	4	4
38	1850	Atlanta	6	6	6
39	1850	Grand Rapids	6	6	6
40	1810	Dayton	8	8	6
41	1790	Richmond	12	12	11
42	1800	Nashville-Davidson	1	1	1
43	1870	Seattle	5	5	5
44	1790	Hartford			
45	1840	Bridgeport	8	8	7
46	1860	Oakland	6	6	6
47	1860	Des Moines	7	7	7
48	1790	Springfield	11	11	10
49	1850	Evansville	9	9	7
50	1790	Manchester	10	10	9
51	1840	Peoria	7	7	7
52	1800	Savannah	7	7	7
53	1860	Salt Lake	7	7	7

Rank in 1900	First year in the sample	Name	Club (Sample Size: Top 75)	Club (Sample Size: Top 100)	Club (Sample Size: Top 150)
54	1850	San Antonio	2	2	2
55	1800	Erie	9	9	8
56	1810	Elizabeth	7	7	7
57	1880	Kansas	7	7	6
58	1860	Yonkers	7	7	6
59	1790	Norfolk	12	12	11
60	1860	Waterbury	7	7	7
61	1850	Fort Wayne	6	6	6
62	1850	Houston	1	1	1
63	1850	Akron	8	8	7
64	1880	Dallas	2	2	2
65	1880	Lincoln	4	4	4
66	1890	Honolulu CDP	5	5	5
67	1830	Mobile	7	7	6
68	1880	Birmingham	7	7	7
69	1850	Little Rock	4	4	4
70	1890	Tacoma	5	5	5
71	1890	Spokane	6	6	6
72	1850	South Bend	9	9	8
73	1830	Allentown	8	8	7
74	1840	Springfield	6	6	6
75	1860	Topeka	7	7	7
76	1850	Knoxville		5	5
77	1860	Rockford		7	6
78	1840	Montgomery		4	4
79	1870	Chattanooga		6	6
80	1850	Sacramento		2	2
81	1850	Jacksonville		1	1
82	1880	Fort Worth		4	4
83	1860	Cedar Rapids		6	6
84	1790	Lexington-Fayette		6	6
85	1880	Wichita		5	5
86	1850	Springfield		5	5
87	1850	Austin		1	1
88	1870	San Jose		1	1
89	1880	Colorado Springs		1	1
90	1870	Waco		7	6
91	1890	Newport News		5	5
92	1850	Madison		5	5
93	1850	Charlotte		2	2
94	1860	San Diego		1	1
95	1840	Columbus		5	5
96	1860	Stockton		2	2
97	1840	Portsmouth		9	7
98	1860	Lansing		7	7
99	1850	Shreveport		6	6
100	1880	Stamford		7	6
101	1880	El Paso			2
102	1870	Tampa			6
103	1790	Alexandria			9
104	1860	Ann Arbor			5
105	1870	Winston-Salem			5
106	1800	Raleigh			2
107	1860	Laredo			2
108	1890	Berkeley			7
109	1860	Flint			8
110	1880	Fresno			1
111	1840	Baton Rouge			4

Rank in 1900	First year in the sample	Name	Club (Sample Size: Top 75)	Club (Sample Size: Top 100)	Club (Sample Size: Top 150)
112	1890	Oklahoma			4
113	1870	Greensboro			4
114	1890	Beaumont			7
115	1890	Pasadena			6
116	1850	Huntsville			3
117	1890	Riverside			1
118	1880	Vallejo			4
119	1850	Jackson			5
120	1870	Tucson			2
121	1860	Independence			5
122	1880	Durham			2
123	1860	Santa Rosa			1
124	1890	Albuquerque			2
125	1880	San Bernardino			3
126	1870	Boise			1
127	1890	Phoenix			1
128	1890	Pomona			3
129	1890	Santa Ana			1
130	1890	Bakersfield			1
131	1860	Corpus Christi			4
132	1870	Reno			1
133	1870	Salem			2
134	1890	Abilene			6
135	1890	Salinas			1
136	1870	Eugene			2
137	1840	Tallahassee			2
138	1890	Hampton			5
139	1890	Orlando			2
140	1890	Long Beach			4
141	1890	Modesto			1
142	1870	Hayward			4
143	1900	Miami			5
144	1890	St. Petersburg			5
145	1870	Anaheim			1
146	1890	Amarillo			5
147	1900	Tulsa			4
148	1870	Plano			1
149	1880	Orange			1
150	1890	Arlington			1