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**Cities and Innovation**

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## HISTORICAL URBAN GROWTH IN EUROPE (1300–1800)

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ABSTRACT: This paper analyses the evolution of the European urban system from a long-term perspective (from 1300 to 1800) considering the historical data set of Bairoch et al. (1988). Using the method recently proposed by Clauset et al. (2009), a Pareto-type city size distribution (power law) is rejected from 1300 to 1600. A power law is a plausible model for the city size distribution only in 1700 and 1800, although the log-normal distribution is another plausible alternative model that we cannot reject. Moreover, random growth of cities is rejected using parametric and non-parametric methods. The results reveal a clear pattern of convergent growth in all periods.

JEL Codes: C12, C14, 018, R11, R12

Keywords: City size distribution, power law, Pareto distribution, Zipf's law, Gibrat's law

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## 1. Introduction

European cities date from ancient times (Medieval ages, Roman Empire or even before). Their importance increased or decreased over time depending on geographical, economical and historical forces. Literature usually distinguishes between first- and second-nature forces in determining city size and city growth. The former are characteristics related to the physical landscape of a given location, such as temperature, rainfall, access to the sea, the presence of natural resources or the availability of arable land, while the latter refer to factors relating to human actions and economic incentives, such as economies of scale or knowledge spillovers. A number of recent empirical papers have considered the importance of natural amenities in explaining city creation and city growth. For instance, Fernihough and O'Rourke (2014) find that geographical proximity to coal had a strong influence on city population; according to their estimates, being close to coal mines explains at least 60% of the growth in European city populations from 1750 to 1900.

As Gabaix and Ioannides (2004) point out, historians have produced fascinating series of urban populations that have not been fully explored yet. Most of the literature on historical city growth has focused on the United States (US) case (Kim, 2000; Kim and Margo, 2004; González-Val, 2010; Michaels et al., 2012), while evidence on the European case is more scarce. Nevertheless, there are significant differences between the urbanization processes in Europe and the US. First, in many cases European cities have hundred of years of existence, while the US urban system is relatively young (the first census by the US Census Bureau dates from 1790). Second, European inhabitants usually present low mobility compared to US citizens; Cheshire and Magrini (2006) estimate that mobility in the US is 15 times higher than that in Europe. Finally, the growth rates of American cities strongly react to industry cycles. 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 attracted population to the West Coast area.

Bairoch et al. (1988) and de Vries (1984) report comprehensive historical data sets or European cities for several centuries. To date, just a few studies have used these data to analyse urban growth in Europe, focusing on different factors influencing population growth. De Long and Shleifer (1993) examine the relationship between political regimes and historical city growth in the largest European cities. Acemoglu et al. (2005) use the European city-level data from Bairoch et al. (1988) to investigate which urban centres were driving demographic and economic growth, and also to contrast the growth of Atlantic ports with other ports and with inland cities. Bosker et al. (2013) analyse why, between 800 and 1800, the urban centre of gravity moved from the Islamic world to Europe, unravelling the role of geography and institutions in determining long-run city development in the two regions. Finally, Dittmar (2011) studies the evolution of European city size distribution from 1300 to 1800. He considers Zipf's law (a Pareto distribution whose exponent is equal to one) as the benchmark for city size distribution, concluding that Zipf's law only emerged in Europe after 1500.

There has been a revival of interest in city size distributions and Zipf's law in the last few decades from urban economists, especially after the New Economic Geography by Krugman. Zipf's law has been extensively studied in many countries and periods. Starting from the wide empirical literature, some theoretical models have been proposed recently to explain the law, with different economic foundations: productivity or technology shocks (Duranton, 2007; Rossi-Hansberg and Wright, 2007) or local random amenity shocks (Gabaix, 1999). These models justify Zipf's law analytically, associate it directly with an equilibrium situation and connect it to proportionate city growth (Gibrat's law), another well-known empirical regularity which postulates that the growth rates of cities tend to be independent of their initial sizes. In both the theoretical and empirical literature, Zipf's law is seen as a reflection of a steady-state situation.

The aim of this paper is to analyse historical urban growth in Europe focusing on these two empirical regularities. However, we adopt a broader view than Dittmar (2011). Thus, we are not interested in whether Zipf's law exactly holds (although there exist statistical tests to address this issue; Urzúa (2000) and Gabaix (2009)). By using a new methodology, our approach is to let the data speak for themselves and test whether the Pareto distribution (for which Zipf's law is a particular case) is a good description of the European city data, no matter the particular value of the Pareto exponent. In cases where we reject the Pareto distribution, we will also consequently be rejecting Zipf's law.

The paper is organized as follows. Section 2 introduces the database that we use. Section 3 contains the statistical analysis of the distribution of city sizes and their evolution over time, and Section 4 concludes.

## 2. Data

We use the historical data set of European cities collected by Bairoch et al. (1988). They provide information by century on a large set of cities (2,135) from many countries from 800 to 1800. We focus only on Western European cities, from the current Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden and Switzerland. Bairoch et al. (1988) emphasize that data before 1300 are less reliable (they even skip the year 1100 due to lack of information), so we only consider data from 1300 to 1800. Moreover, in many cases observations are missing in some years; like Voigtländer and Voth (2013), we fill these gaps using linear interpolated values.[1] This way we increase the number of observations, obtaining a better fit of the models. However, we repeat all the analysis using the raw Bairoch et al. (1988) data set and results do not change (see the Appendix).

Some authors criticize the Bairoch et al. (1988) data because of some of their unrealistic values. In particular, the population estimate for Cordoba (Spain) in 1000 is usually considered to be excessively large.[2] Nevertheless, Dittmar (2011) compares the Bairoch et al. (1988) data to the database of de Vries (1984), concluding that there is no evidence of systematic shortfalls in the populations that the Bairoch et al. (1988) data record for large cities.

Table 1 shows the number of cities for each century and the descriptive statistics. The table also reports the difference between raw data and data filled with interpolations. Bairoch et al. (1988) include in their database all cities with a population over 1,000. Some authors (Dittmar, 2011; Bosker et al., 2013) impose a fixed minimum population threshold (5,000 and 10,000 inhabitants, respectively). Nevertheless, our methodology here selects a different threshold by period to obtain the best fit to the empirical data. The sample reflects the urbanization process that took place over time in Europe. From the first period there was a rapid increase in the number of cities, while the average size of cities remains stable at around 10,000 inhabitants.

[1] Values interpolated using the ipolate command in Stata.
[2] We repeat all the analysis excluding Cordoba and results do not change.

## 3. City size distribution

Let $S$ denote the city size (measured by the population); if this is distributed according to a power law, also known as a Pareto distribution, the density function is $p(S) = \frac{a-1}{\underline{S}}\left(\frac{S}{\underline{S}}\right)^{-a}$ $\forall S \geq \underline{S}$ and the complementary cumulative density function $P(S)$ is $P(S) = \left(\frac{S}{\underline{S}}\right)^{-a+1}$ $\forall S \geq \underline{S}$, where $a > 0$ is the Pareto exponent (or the scaling parameter) and $\underline{S}$ is the population of the city at the truncation point, which is the lower bound to the power law behaviour. It is easy to obtain the expression $R = A \cdot S^{-a}$, which relates the empirically observed rank $R$ (1 for the largest city, 2 for the second largest, and so on) to the city size. Zipf's law is an empirical regularity, which appears when Pareto's exponent of the distribution is equal to the unit ($a = 1$). This means that, when ordered from largest to smallest, the population of the second city is half that of the first, the size of the third is a third of the first, and so on.

This expression is applied to the study of very varied phenomena, such as the distribution of the number of times that different words appear in a book (Zipf, 1949), the intensity of earthquakes (Kagan, 1997), and the losses caused by floods (Pisarenko, 1998) or forest fires (Roberts and Turcotte, 1998). It has been used extensively in urban economics to study city size distribution (see the excellent surveys of Cheshire, 1999, and Gabaix and Ioannides, 2004).

Taking natural logarithms, we obtain the linear specification that is usually estimated:

$$\ln R = \ln A - a \ln S + u, \qquad (1)$$

where $u$ represents a standard random error ($E(u) = 0$ and $Var(u) = \sigma^2$) and $\ln A$ is a constant. The greater the coefficient $\hat{a}$, the more homogeneous are the city sizes. Similarly, a small coefficient (less than 1) indicates a heavy-tailed distribution. However, this regression analysis, which is commonly used in the literature, presents some drawbacks that have been recently highlighted by Clauset et al. (2009); of these, the main one is that the estimates of the Pareto exponent are subject to systematic and potentially large errors.

Therefore, to estimate the power laws, we use the innovative method proposed by Clauset et al. (2009). The maximum likelihood (ML) estimator of the Pareto exponent is:

$$\hat{a} = 1 + n\left(\sum_{i=1}^{n} \ln \frac{S_i}{\underline{S}}\right), \ \forall S_i \geq \underline{S}.$$

The ML estimator is more efficient than the usual OLS line regression if the underlying stochastic process is really a Pareto distribution (Gabaix and Ioannides, 2004; Goldstein et al., 2004). Clauset et al. (2009) propose an iterative method to estimate the adequate truncation point ($\underline{S}$). The exponent $a$ is estimated for each $S_i \geq \underline{S}$ using the ML estimator (bootstrapped standard errors are calculated with 500 replications), and then the Kolmogorov–Smirnov (KS) statistic is computed for the data and the fitted model. The $\underline{S}$ lower bound that is finally chosen corresponds to the value of $S_i$ for which the KS statistic is the smallest.[3]

Figure 1 shows the results from 1300 to 1800. The data, plotted as a complementary cumulative distribution function (CCDF), are fitted by a power law, and its exponent is estimated using the ML estimator. For illustrative purposes, a log-normal distribution is also fitted to the data by maximum likelihood (the blue dotted line). The optimal lower bound for both distributions is estimated using Clauset et al.'s (2009) method; the estimated values are reported in Table 2. The black line shows the power law behaviour of the upper tail distribution. Estimated Pareto exponents are also shown in Table 2, but remember that we are interested in the fit of the distribution, rather than in the particular value of the parameter. Thus, important deviations between empirical data and the fitted power law can be observed in the first centuries (1300–1500), especially for the largest cities. Nevertheless, in the last periods (1600–1800) the fit improves and the power law appears to provide a good description of the behaviour of the distribution. In a similar fashion, the fit of the log-normal distribution also improves over time.

However, visual methods can lead to inaccurate conclusions (González-Val et al., 2013), especially at the upper tail, because of large fluctuations in the empirical

[3] The power laws and the statistical tests are estimated using the poweRlaw R package developed by Colin S. Gillespie (based on the R code of Laurent Dubroca and Cosma Shalizi and the Matlab code of Aaron Clauset) and the Stata codes developed by Michal Brzezinski, which are all freely available on their web pages.

distribution, so next we conduct statistical tests on the goodness of fit. Clauset et al. (2009) propose several goodness-of-fit tests. We use a semi-parametric bootstrap approach. The procedure is based on the iterative calculation of the KS statistic for 500 bootstrap data set replications. This method samples from observed data and checks how often the resulting synthetic distributions fit the actual data as poorly as the ML-estimated power law. Thus, the null hypothesis is the power law behaviour of the original sample for $S_i \geq \underline{S}$. Nevertheless, this test has an unusual interpretation because, regardless of the true distribution from which our data were drawn, we can always fit a power law. Clauset et al. (2009) recommend the conservative choice that the power law is ruled out if the p-value is below 0.1. Therefore, this procedure only allows us to conclude whether the power law is a plausible fit to the data. Table 2 shows the results of the tests; the p-values of the test for periods from 1300 to 1600 are lower than 0.1, rejecting the power law behaviour of data in these centuries. Only in the last two periods, 1700 and 1800, are p-values clearly higher than 0.1, indicating that the power law is a plausible approximation to the real behaviour of the data.

Finally, we also compare the linear power law fit with the fit provided by the log-normal distribution (a non-linear distribution), using Vuong's model selection test to compare the power law with the log-normal.[4] The test is based on the normalized log-likelihood ratio; the null hypothesis is that the two distributions are equally far from the true distribution, while the alternative is that one of the test distributions is closer to the true distribution.[5] High p-values indicate that one model cannot be favoured over the other, and this is the conclusion reached in all the periods. Therefore, even for the last two centuries in which we obtain moderate support for the power law behaviour, the power law is a plausible fit but there is a plausible alternative as well.

According to these results, support for a Pareto distribution (and thus for Zipf's law) is weaker than other studies previously found. By using the test developed in Gabaix (2009), Dittmar (2011) rejects Zipf's law in Western Europe up to 1500, but he

[4] In Figure 1, the lower bound for both distributions (log-normal and power law) is calculated using Clauset et al.'s (2009) method. The lower bounds can be different, but to compare the distributions the threshold must be the same for both distributions, so to run the test we use the same lower bound, the estimated value corresponding to the power law.

[5] This procedure is different from the approach used by Giesen et al. (2010) and González-Val et al. (2015). These authors use information criteria to discriminate between different statistical city size distributions. Thus, they can conclude which distribution best fits their data (although the information criteria penalize the distribution with more parameters). Here, we only test whether the two distributions that we consider are equally far from the true distribution.

cannot reject Zipf's Law from 1600 onwards. However, it is true that the fit provided by the Pareto distribution improves over time, indicating a transition over time to a more stable city size distribution.

Remember that Zipf's law is considered as a steady-state situation. The rejection of a Pareto distribution (and Zipf's law) for the first periods (1300 to 1600) for this pool of European cities from different countries indicates that the European urban system was not integrated in those early times. Moreover, the shape of the overall city size distribution also has implications for the city size distributions at the national level. Recent works relate the fulfilment of Zipf's law in city size distributions at the regional and national level. Gabaix (1999) shows that if urban growth in all regions follows Gibrat's law we should observe the Zipfian upper-tail distribution both at the regional and national level (in our case, at the national and supranational level). Giesen and Südekum (2011) test this hypothesis for the German case, finding that Zipf's law is not only satisfied for Germany's national urban hierarchy, but also in single German regions. However, here we reject the power law behaviour of city size distribution at the European level; thus, this would indicate that Zipf's law did not hold at the national level either.[6] Therefore, the national urban systems of those countries were not integrated. Several studies provide evidence of the internal process of economic integration of European countries, which in some cases finished at the eighteenth or nineteenth century. For instance, Bosker et al. (2008) study the evolution of Italian cities over the period 1300–1861, finding significant differences between the north and south of Italy in the century-specific effects on city growth. As a consequence, the city size distribution of the northern part of Italy is relatively more stable than that of the southern part. González-Val et al. (2016) analyse the growth of Spanish cities during the period 1860–1960. They find that only changes in the market potential from 1900 have a significant effect on population growth, linking this to the advances in the economic integration of the national market together with an intense process of industrialization. All in all, each individual European country consolidated its national economy and urban system around the end of our period (1800), which is in line with the improvement in the fit of the Pareto for the pool of European cities in the last periods in our sample.

[6] A national analysis country by country is beyond the scope of this paper. Russell (1972) shows that Zipf's law did not hold at the local level in the high middle ages.

## 4. Urban growth

The previous results show what we consider to be a snapshot of the city size distribution from 1300 to 1800. For each period, we conduct a goodness-of-fit test that indicates the plausibility of the power law model only in the last two centuries. For the remaining periods the Pareto distribution (and thus Zipf's law) is rejected. The literature that studies the distribution of city sizes usually concludes that a Pareto-type distribution is generated by a random growth process (Gabaix, 1999; Gabaix and Ioannides, 2004). Furthermore, there is another plausible alternative model that we could not reject in the previous empirical analysis, the log-normal distribution. Random growth rates of cities could generate both types of distribution – log-normal and Pareto – if there is a lower bound to the distribution (which can be very low) (see Gabaix, 1999).[7] The hypothesis usually tested is that the growth of the variable is independent of its initial size (the underlying growth model is a multiplicative process), which is known as Gibrat's law. To check whether this is true for our sample of European cities, we carry out a dynamic analysis of growth rates using parametric and non-parametric tools.

### *4.1 Parametric analysis*

Let $S_{it}$ be the population of city $i$ at the time $t$ and let $g$ be its logarithmic growth rate, then $g_{it} = ln\, S_{it} - ln\, S_{it-1}$. We consider the following general expression of the growth equation:

$$g_{it} = \mu + \beta \ln S_{it-1} + \varphi_j + \delta_t + u_{it}, \qquad (2)$$

where $\varphi_j$ are country fixed effects, $\delta_t$ are time fixed effects and $u_{it}$ is a random variable representing the random shocks that the growth rate may suffer, which we shall suppose to be identically and independently distributed for all cities, with $E(u_{it}) = 0$ and $Var(u_{it}) = \sigma^2 \; \forall i, t$. If $\beta = 0$, Gibrat's law holds and we find that growth is independent of the initial size with an average growth rate $\mu$. Thus, if the estimation of $\beta$ is significantly different from zero we will reject the fulfilment of Gibrat's law. In the case of it being lower than zero, we will have convergent growth, because there

[7] Only a small change from the log-normal generative process yields a generative process with a power law distribution, that is, a bounded minimum that acts as a lower reflective barrier to the multiplicative model (Gabaix, 1999).

would be a significant negative relationship between growth and initial size.[8] Moreover, the log-log specification simplifies the interpretation of the coefficient (elasticity).

We expect to find that, at least in the periods in which the power law is rejected, random growth is rejected. Table 3 shows the OLS results. We run the regression for each century and for a pool 1300–1800 including all the observations. Estimates by century include country fixed effects, while the pool estimate also includes time fixed effects and a time trend. All the estimations show a significant negative coefficient for the initial population, indicating a convergent growth pattern in all periods. Thus, the greater the initial city size, the lower the population growth. Furthermore, the value of the estimated coefficient is similar in all the periods, with an average value of -0.2. This means that a 1% increase in the initial population implied an average 0.2% decrease in the growth rate of the city.

Finally, we adopt an alternative definition of city size. A common approach in the literature consists of taking a distance-weighted sum of the population of all other existing cities as a proxy of city market potential (Black and Henderson, 2003; Ioannides and Overman, 2004; Bosker et al., 2008). Thus, following Black and Henderson (2003), we define market potential as

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$$MP_{it} = \sum_{i \neq j} \frac{S_{it}}{d_{it}}.$$

Market potential ($MP_{it}$) is the sum of the populations ($S_{it}$) of all cities weighted by physical distances ($d_{it}$), calculated using the geographical coordinates.[9] Moreover, the cross-sectional measure of market potential is normalized by the contemporaneous average market potential to avoid effects from later periods overpowering earlier ones on account of absolute growth in market potential (Black and Henderson, 2003). Relative market potential ($mp_{it}$) can therefore be defined as:

$$mp_{it} = \frac{MP_{it}}{\frac{1}{n_t}\sum_{1}^{n_t} MP_{jt}}.$$

[8] Actually, Equation (2) is an unconditional $\beta$-convergence regression, widely known in the economic growth literature.
[9] Latitude and longitude by city are taken from Bairoch et al. (1988).

We re-estimate Eq. (2) considering this relative market potential definition based on population to be our main explanatory variable instead of log-population and using the same set of controls as above. Table 4 shows the OLS results. Again, we obtain a negative and significant coefficient in the first periods (1300–1400, 1400–1500 and 1500–1600), indicating convergent growth. Nevertheless, the estimated coefficient for relative market potential is not significant either in the last two centuries (1600–1700 and 1700–1800) or in the pool 1300–1800.

### *4.2 Non-parametric analysis*

Ioannides and Overman (2004) have highlighted the advantages of the non-parametric approach over the standard parametric one. Mainly, non-parametric methods do not impose any structure on underlying relationships, which may be non-linear and may change over time (no need to restrict the relationship to being stationary; see Ioannides and Overman, 2004). Again, we define $g_i$ as the logarithmic growth rate $(\ln S_{it} - \ln S_{it-1})$ and normalize it (by subtracting the contemporary mean and dividing by the standard deviation in the relevant year).[10] First, we perform a non-parametric analysis using kernel regressions (Ioannides and Overman, 2003). This consists of taking the following specification:

$$g_i = m(S_i) + \varepsilon_i,$$

where $g_i$ is the normalized growth rate and $S_i$ the logarithm of the *i*th city's population.[11] Instead of making assumptions about the functional relationship $m$, $\hat{m}(S)$ is estimated as a local mean around point $S$ and is smoothed using a kernel, which is a symmetrical, weighted and continuous function in $S$. Thus, this non-parametric estimate lets growth vary with initial population over the entire distribution. We run the kernel regression for each period and for a pool 1300–1800 including 3,798 observations.

To estimate $\hat{m}(S)$, the Nadaraya–Watson method is used, as it appears in Härdle (1990, Chapter 3), based on the following expression:

[10] The growth rates need to be normalized to be able to consider growth rates from different periods jointly in a pool.

[11] The non-parametric analysis is carried out using the population. Results using a measure of market potential based on populations are similar.

$$\hat{m}(S) = \frac{n^{-1}\sum_{i=1}^{n} K_h(S - S_i)g_i}{n^{-1}\sum_{i=1}^{n} K_h(S - S_i)},$$

where $K_h$ denotes the dependence of the kernel $K$ (in this case an Epanechnikov) on the bandwidth $h$.[12] As the growth rates are normalized, if the growth was independent of the initial population, the non-parametric estimate would be a straight line on the zero value and values different from zero would involve deviations from the mean.

The results by century are shown in Figure 2. The graphs also include the 95% confidence bands. The estimates confirm the negative relationship between size and growth obtained with the growth regressions, although for the last periods (1500–1600, 1600–1700 and 1700–1800) a U-shaped pattern appears and cities in the upper-tail distribution also display high growth rates. Thus, we can reject the premise that the growth is different from zero (random growth) in all periods. The decreasing pattern is clear: the greater the initial population, the lower the growth rate. This points to a high degree of convergence (mean reversion) across cities, especially for the smallest units.

We also build a pool with all the growth rates between two consecutive periods; there are 3,798 city size–growth rate pairs in the period 1300–1800. Graph (a) in Figure 3 shows the kernel regression of growth for the pool. The estimated mean growth clearly decreases with city size, indicating a convergent growth pattern through the whole period, and rejecting random growth. Finally, we study how the distribution of growth rates is related to the distribution of the initial population (Ioannides and Overman, 2004). Graph (b) in Figure 3 shows the stochastic kernel estimation of the distribution of normalized growth rates, conditional on the distribution of the initial population at the same date for the pool 1300–1800. To make the interpretation easier, the contour plot is also shown. The plot reveals a slight negative relationship between the two distributions, although there is little variance and most of the observations are concentrated in a peak of density. Note that the conditional distribution of growth rates is equal to zero in that peak of density, indicating that both distributions are independent for many observations. Thus, although random growth is rejected for the whole period, for many middle-sized cities Gibrat's law holds.

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[12] The bandwidth is determined using Silverman's rule of thumb.

## 5. Conclusions

Zipf's and Gibrat's laws are two stylized facts in urban economics. Researchers from many fields (Urban Economics, Statistical Physics and Urban Geography) have checked these empirical regularities considering different countries and time periods. However, there is a new mainstream in the literature that argues that random growth (or Gibrat's law) and Zipf's law correspond to the steady state (a long-run average), but that to reach that situation temporal episodes of different growth patterns across some cities are possible. Quoting Gabaix and Ioannides (2004), "*the casual impression of the authors is that in some decades, large cities grow faster than small cities, but in other decades, small cities grow faster*." Therefore, the time period considered seems to be crucial. For the US case, several studies document episodes of convergence with or divergence from a long-term perspective, but both convergence and divergence dissipate over time and Zipf's and Gibrat's law gradually emerge (Giesen and Südekum, 2014; Sánchez-Vidal et al., 2014; Desmet and Rappaport, 2016).

In this paper, we study the evolution of the European city size distribution from a very long-term perspective (from 1300 to 1800) considering the historical data set of Bairoch et al. (1988). By using the method recently proposed by Clauset et al. (2009), a Pareto-type city size distribution (power law) is rejected from 1300 to 1600. A power law is a plausible model for the city size distribution only in 1700 and 1800, although the log-normal distribution is another plausible alternative model that we cannot reject. Therefore, support for a Pareto distribution (and thus for Zipf's law) is weaker than other papers previously found (Dittmar, 2011). Our explanation is that, in those early periods, neither the European nor the internal national urban systems were integrated. European countries consolidated their national economies and urban systems around the end of our period (1800), which is in line with the improvement in the fit of the Pareto for the pool of European cities in the last periods in our sample.

Finally, random growth of cities is unequivocally rejected using parametric and non-parametric methods. The results reveal a clear pattern of convergent growth in all periods, although for many middle-sized cities growth is size-independent. Thus, neither Zipf's nor Gibrat's law holds from a long-term perspective in European cities, although the last periods (1700 and 1800) show some signs of transition to a more stable city size distribution and a consolidated urban landscape.

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**Table 1. Descriptive statistics by year**

| Year | Cities | Cities (Raw Bairoch et al. (1988) data) | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| 1300 | 438 | 416 | 11,594.03 | 17,058.14 | 1,000 | 150,000 |
| 1400 | 527 | 339 | 9,879.57 | 17,596.57 | 1,000 | 275,000 |
| 1500 | 717 | 538 | 9,032.961 | 14,128.17 | 1,000 | 225,000 |
| 1600 | 952 | 762 | 10,155.5 | 19,538.77 | 1,000 | 300,000 |
| 1700 | 1,180 | 994 | 10,055.1 | 27,877.18 | 1,000 | 575,000 |
| 1800 | 1,623 | 1,623 | 12,468.88 | 33,941.05 | 1,000 | 948,000 |

Source: Bairoch et al. (1988).

**Table 2. Power law fit**

| Year | Lower bound | Observations | Pareto exponent | | Power law test | Power law vs. log-normal |
|---|---|---|---|---|---|---|
| | $\underline{S}$ | $S \geq \underline{S}$ | $\hat{a}$ | Standard error | p-value | p-value |
| 1300 | 9,000 | 163 | 2.318 | 0.103 | 0.000 | 0.101 |
| 1400 | 8,000 | 176 | 2.361 | 0.103 | 0.006 | 0.299 |
| 1500 | 12,333 | 116 | 2.533 | 0.142 | 0.084 | 0.417 |
| 1600 | 10,400 | 203 | 2.404 | 0.099 | 0.014 | 0.542 |
| 1700 | 19,000 | 106 | 2.400 | 0.136 | 0.732 | 0.856 |
| 1800 | 21,000 | 145 | 2.357 | 0.113 | 0.288 | 0.780 |

Note: The lower bound and the Pareto exponent are estimated using Clauset et al.'s (2009) methodology. The power law test is a goodness-of-fit test. $H_0$ is that there is power law behaviour for $S_i \geq \underline{S}$. The power law vs. log-normal test is Vuong's model selection test, based on the normalized log-likelihood ratio. $H_0$ is that both distributions are equally far from the true distribution while $H_A$ is that one of the test distributions is closer to the true distribution.

## Table 3. Growth and initial population

| | 1300–1400 | 1400–1500 | 1500–1600 | 1600–1700 | 1700–1800 | Pool 1300–1800 |
|---|---|---|---|---|---|---|
| ln(Population) | -0.223*** | -0.204*** | -0.127*** | -0.160*** | -0.223*** | -0.198*** |
| | (0.021) | (0.042) | (0.028) | (0.039) | (0.030) | (0.013) |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time fixed effects | No | No | No | No | No | Yes |
| Trend | No | No | No | No | No | Yes |
| Observations | 436 | 527 | 711 | 950 | 1,174 | 3,798 |
| $R^2$ | 0.223 | 0.301 | 0.104 | 0.238 | 0.337 | 0.240 |

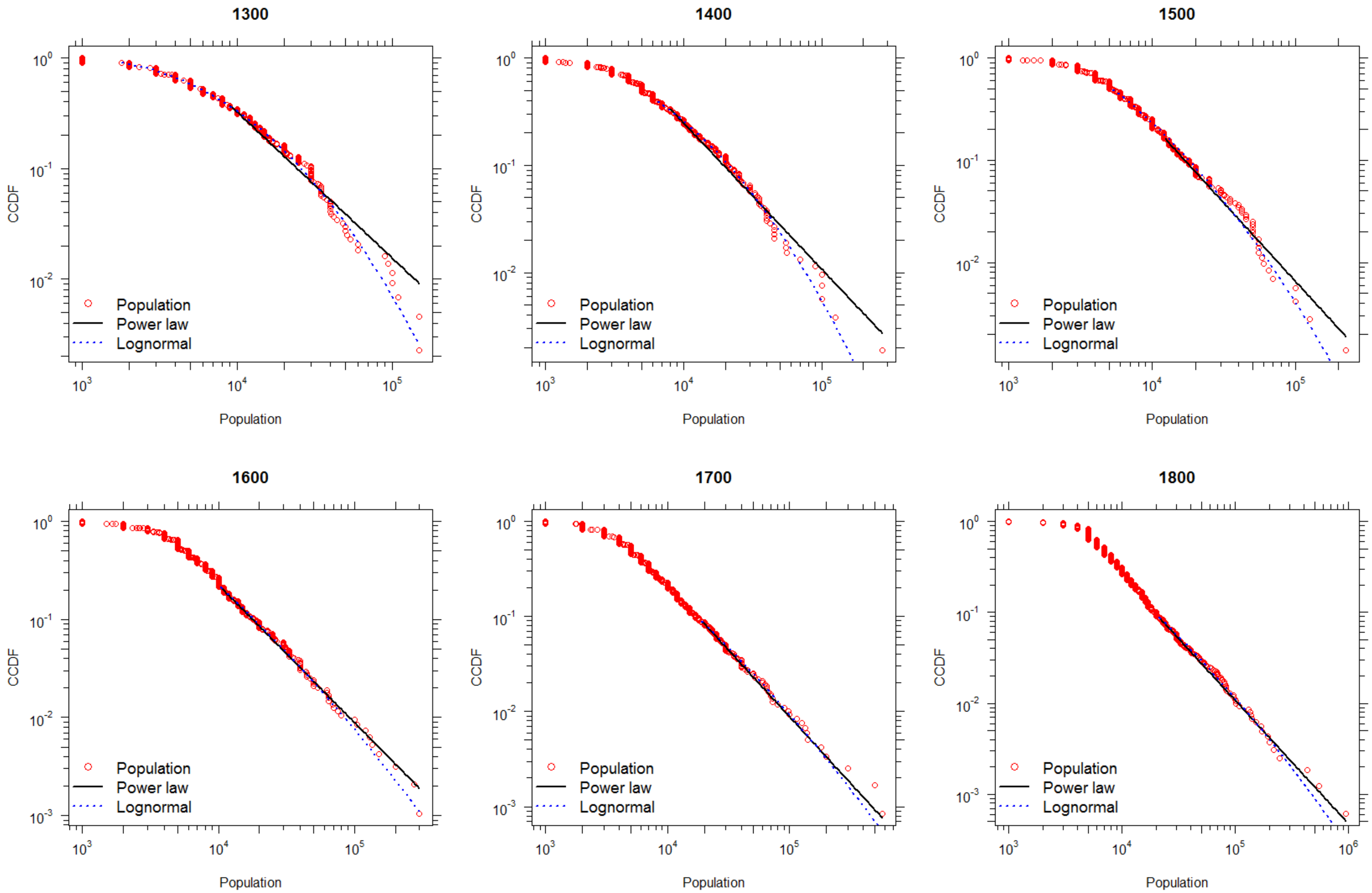
Notes: All the models include a constant. Coefficient (robust standard errors). Standard errors clustered by country. Significant at the *10%, **5%, ***1% level.

## Table 4. Growth and market potential

| | 1300–1400 | 1400–1500 | 1500–1600 | 1600–1700 | 1700–1800 | Pool 1300–1800 |
|---|---|---|---|---|---|---|
| Relative market potential | -0.485*** | -0.389*** | -0.215* | -0.189 | 0.098 | -0.110 |
| | (0.085) | (0.106) | (0.105) | (0.230) | (0.062) | (0.099) |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time fixed effects | No | No | No | No | No | Yes |
| Trend | No | No | No | No | No | Yes |
| Observations | 436 | 527 | 711 | 950 | 1,174 | 3,798 |
| $R^2$ | 0.093 | 0.169 | 0.055 | 0.181 | 0.233 | 0.143 |

Notes: All the models include a constant. Coefficient (robust standard errors). Standard errors clustered by country. Significant at the *10%, **5%, ***1% level.

**Figure 1. European city size distribution from 1300 to 1800.**




Note: The data are plotted as a complementary cumulative distribution function (CCDF), $\Pr\left(S \geq \underline{S}\right)$.

**Figure 2. Non-parametric estimates of growth by century.**

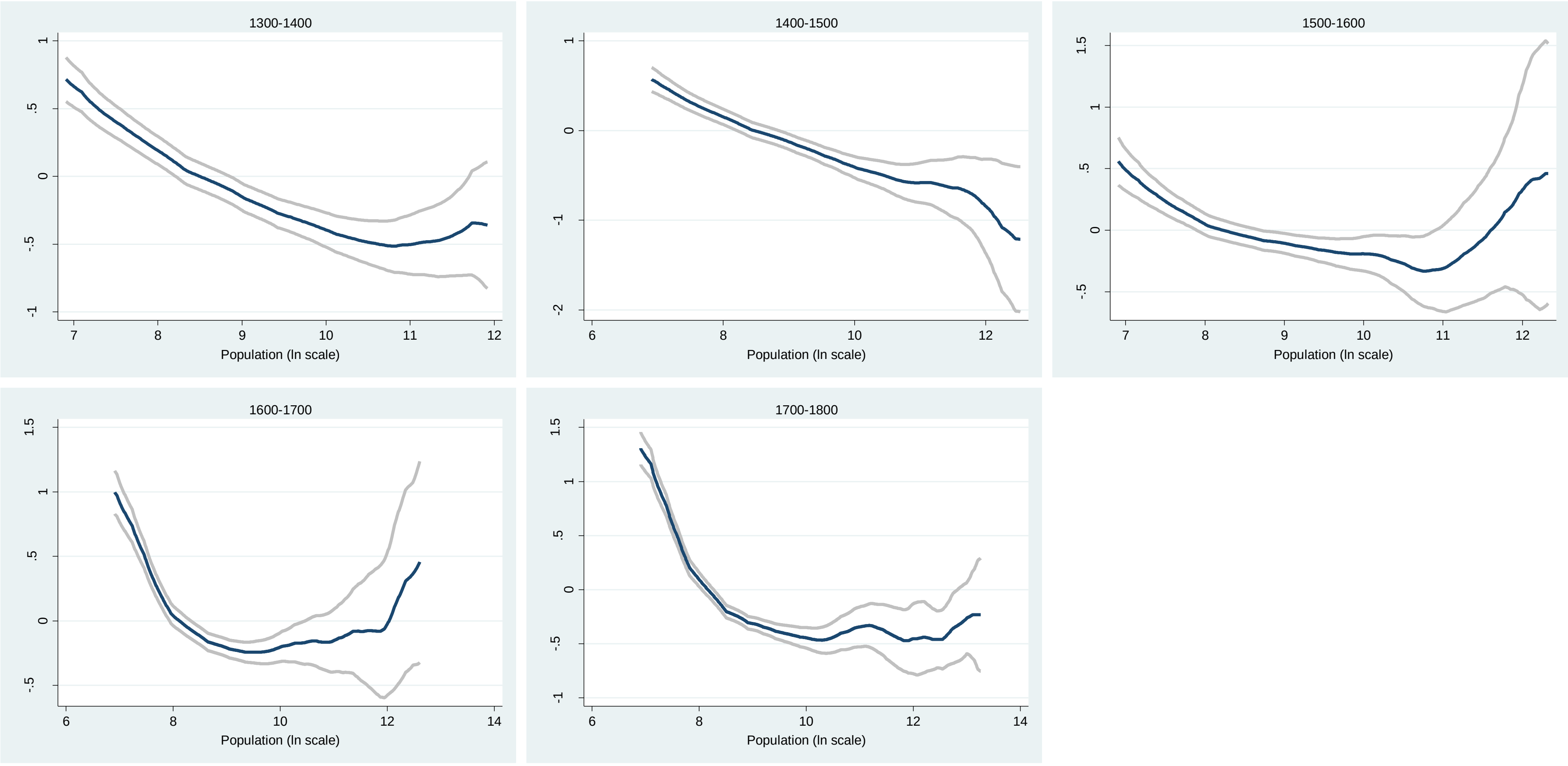
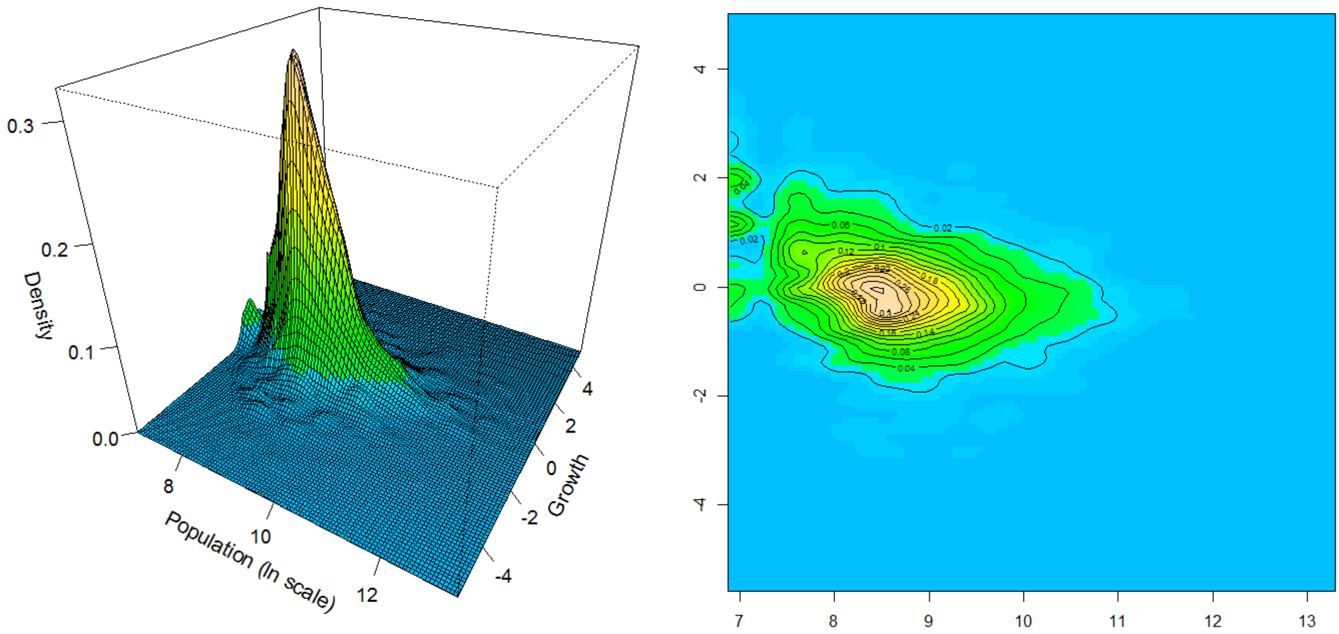


**Figure 3. Growth from 1300 to 1800, 3,798 observations.**


(a) Kernel estimate of growth




(b) Stochastic kernel

**Appendix: Raw Bairoch et al. (1988) data**

**Table A1. Descriptive statistics by year**

| Year | Cities | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| 1300 | 416 | 11,855.77 | 17,360.76 | 1,000 | 150,000 |
| 1400 | 339 | 11,646.02 | 21,464.81 | 1,000 | 275,000 |
| 1500 | 538 | 10,223.05 | 16,053.29 | 1,000 | 225,000 |
| 1600 | 762 | 11,393.70 | 21,622.67 | 1,000 | 300,000 |
| 1700 | 994 | 10,687.12 | 30,297.65 | 1,000 | 575,000 |
| 1800 | 1,623 | 12,468.88 | 33,941.05 | 1,000 | 948,000 |

Source: Bairoch et al. (1988).

**Table A2. Power law fit**

| Year | Lower bound | Observations | Pareto exponent | | Power law test | Power law vs. log-normal |
|---|---|---|---|---|---|---|
| | $\underline{S}$ | $S \geq \underline{S}$ | $\hat{a}$ | Standard error | p-value | p-value |
| 1300 | 9,000 | 160 | 2.322 | 0.105 | 0.000 | 0.117 |
| 1400 | 17,000 | 67 | 2.592 | 0.195 | 0.020 | 0.528 |
| 1500 | 11,000 | 130 | 2.463 | 0.128 | 0.034 | 0.313 |
| 1600 | 13,000 | 150 | 2.424 | 0.116 | 0.028 | 0.565 |
| 1700 | 21,000 | 93 | 2.413 | 0.147 | 0.770 | 0.906 |
| 1800 | 21,000 | 145 | 2.357 | 0.113 | 0.288 | 0.780 |

Note: The lower bound and the Pareto exponent are estimated using Clauset et al.'s (2009) methodology. The power law test is a goodness-of-fit test. $H_0$ is that there is power law behaviour for $S_i \geq \underline{S}$. The power law vs. log-normal test is Vuong's model selection test, based on the normalized log-likelihood ratio. $H_0$ is that both distributions are equally far from the true distribution while $H_A$ is that one of the test distributions is closer to the true distribution.

**Table A3. Growth and initial population**

| | 1300–1400 | 1400–1500 | 1500–1600 | 1600–1700 | 1700–1800 | Pool 1300–1800 |
|---|---|---|---|---|---|---|
| ln(Population) | -0.205*** | -0.183*** | -0.180*** | -0.155*** | -0.235*** | -0.203*** |
| | (0.034) | (0.022) | (0.042) | (0.030) | (0.024) | (0.014) |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time fixed effects | No | No | No | No | No | Yes |
| Trend | No | No | No | No | No | Yes |
| Observations | 241 | 243 | 421 | 669 | 988 | 2,562 |
| $R^2$ | 0.217 | 0.284 | 0.191 | 0.301 | 0.379 | 0.295 |

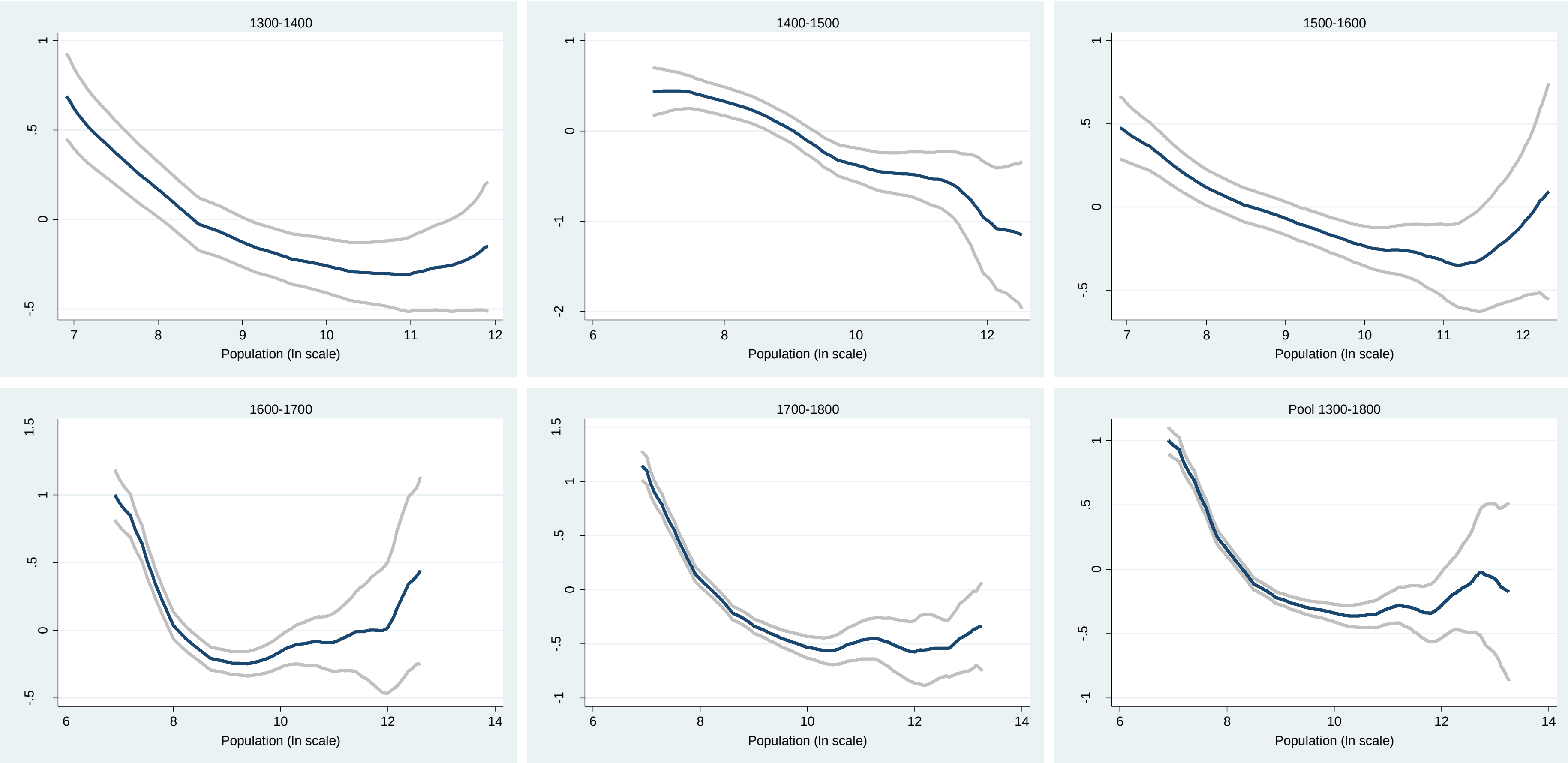
Notes: All the models include a constant. Coefficient (robust standard errors). Standard errors clustered by country. Significant at the *10%, **5%, ***1% level.

**Table A4. Growth and market potential**

| | 1300–1400 | 1400–1500 | 1500–1600 | 1600–1700 | 1700–1800 | Pool 1300–1800 |
|---|---|---|---|---|---|---|
| Relative market potential | -0.543*** | -0.266 | -0.170 | -0.246 | 0.050 | -0.107 |
| | (0.072) | (0.192) | (0.155) | (0.269) | (0.063) | (0.087) |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time fixed effects | No | No | No | No | No | Yes |
| Trend | No | No | No | No | No | Yes |
| Observations | 241 | 243 | 421 | 669 | 988 | 2,562 |
| $R^2$ | 0.147 | 0.183 | 0.055 | 0.253 | 0.255 | 0.205 |

Notes: All the models include a constant. Coefficient (robust standard errors). Standard errors clustered by country. Significant at the *10%, **5%, ***1% level.

**Figure A1. Non-parametric estimates of growth.**



**2012**

**2012/1, Montolio, D.; Trujillo, E.:** "What drives investment in telecommunications? The role of regulation, firms' internationalization and market knowledge"
**2012/2, Giesen, K.; Suedekum, J.:** "The size distribution across all "cities": a unifying approach"
**2012/3, Foremny, D.; Riedel, N.:** "Business taxes and the electoral cycle"
**2012/4, García-Estévez, J.; Duch-Brown, N.:** "Student graduation: to what extent does university expenditure matter?"
**2012/5, Durán-Cabré, J.M.; Esteller-Moré, A.; Salvadori, L.:** "Empirical evidence on horizontal competition in tax enforcement"
**2012/6, Pickering, A.C.; Rockey, J.:** "Ideology and the growth of US state government"
**2012/7, Vergolini, L.; Zanini, N.:** "How does aid matter? The effect of financial aid on university enrolment decisions"
**2012/8, Backus, P.:** "Gibrat's law and legacy for non-profit organisations: a non-parametric analysis"
**2012/9, Jofre-Monseny, J.; Marín-López, R.; Viladecans-Marsal, E.:** "What underlies localization and urbanization economies? Evidence from the location of new firms"
**2012/10, Mantovani, A.; Vandekerckhove, J.:** "The strategic interplay between bundling and merging in complementary markets"
**2012/11, Garcia-López, M.A.:** "Urban spatial structure, suburbanization and transportation in Barcelona"
**2012/12, Revelli, F.:** "Business taxation and economic performance in hierarchical government structures"
**2012/13, Arqué-Castells, P.; Mohnen, P.:** "Sunk costs, extensive R&D subsidies and permanent inducement effects"
**2012/14, Boffa, F.; Piolatto, A.; Ponzetto, G.:** "Centralization and accountability: theory and evidence from the Clean Air Act"
**2012/15, Cheshire, P.C.; Hilber, C.A.L.; Kaplanis, I.:** "Land use regulation and productivity – land matters: evidence from a UK supermarket chain"
**2012/16, Choi, A.; Calero, J.:** "The contribution of the disabled to the attainment of the Europe 2020 strategy headline targets"
**2012/17, Silva, J.I.; Vázquez-Grenno, J.:** "The ins and outs of unemployment in a two-tier labor market"
**2012/18, González-Val, R.; Lanaspa, L.; Sanz, F.:** "New evidence on Gibrat's law for cities"
**2012/19, Vázquez-Grenno, J.:** "Job search methods in times of crisis: native and immigrant strategies in Spain"
**2012/20, Lessmann, C.:** "Regional inequality and decentralization – an empirical analysis"
**2012/21, Nuevo-Chiquero, A.:** "Trends in shotgun marriages: the pill, the will or the cost?"
**2012/22, Piil Damm, A.:** "Neighborhood quality and labor market outcomes: evidence from quasi-random neighborhood assignment of immigrants"
**2012/23, Ploeckl, F.:** "Space, settlements, towns: the influence of geography and market access on settlement distribution and urbanization"
**2012/24, Algan, Y.; Hémet, C.; Laitin, D.:** "Diversity and local public goods: a natural experiment with exogenous residential allocation"
**2012/25, Martinez, D.; Sjögren, T.:** "Vertical externalities with lump-sum taxes: how much difference does unemployment make?"
**2012/26, Cubel, M.; Sanchez-Pages, S.:** "The effect of within-group inequality in a conflict against a unitary threat"
**2012/27, Andini, M.; De Blasio, G.; Duranton, G.; Strange, W.C.:** "Marshallian labor market pooling: evidence from Italy"
**2012/28, Solé-Ollé, A.; Viladecans-Marsal, E.:** "Do political parties matter for local land use policies?"
**2012/29, Buonanno, P.; Durante, R.; Prarolo, G.; Vanin, P.:** "Poor institutions, rich mines: resource curse and the origins of the Sicilian mafia"
**2012/30, Anghel, B.; Cabrales, A.; Carro, J.M.:** "Evaluating a bilingual education program in Spain: the impact beyond foreign language learning"
**2012/31, Curto-Grau, M.; Solé-Ollé, A.; Sorribas-Navarro, P.:** "Partisan targeting of inter-governmental transfers & state interference in local elections: evidence from Spain"
**2012/32, Kappeler, A.; Solé-Ollé, A.; Stephan, A.; Välilä, T.:** "Does fiscal decentralization foster regional investment in productive infrastructure?"
**2012/33, Rizzo, L.; Zanardi, A.:** "Single vs double ballot and party coalitions: the impact on fiscal policy. Evidence from Italy"
**2012/34, Ramachandran, R.:** "Language use in education and primary schooling attainment: evidence from a natural experiment in Ethiopia"
**2012/35, Rothstein, J.:** "Teacher quality policy when supply matters"
**2012/36, Ahlfeldt, G.M.:** "The hidden dimensions of urbanity"
**2012/37, Mora, T.; Gil, J.; Sicras-Mainar, A.:** "The influence of BMI, obesity and overweight on medical costs: a panel data approach"
**2012/38, Pelegrín, A.; García-Quevedo, J.:** "Which firms are involved in foreign vertical integration?"

**2012/39, Agasisti, T.; Longobardi, S.:** "Inequality in education: can Italian disadvantaged students close the gap? A focus on resilience in the Italian school system"

**2013**

**2013/1, Sánchez-Vidal, M.; González-Val, R.; Viladecans-Marsal, E.:** "Sequential city growth in the US: does age matter?"
**2013/2, Hortas Rico, M.:** "Sprawl, blight and the role of urban containment policies. Evidence from US cities"
**2013/3, Lampón, J.F.; Cabanelas-Lorenzo, P-; Lago-Peñas, S.:** "Why firms relocate their production overseas? The answer lies inside: corporate, logistic and technological determinants"
**2013/4, Montolio, D.; Planells, S.:** "Does tourism boost criminal activity? Evidence from a top touristic country"
**2013/5, Garcia-López, M.A.; Holl, A.; Viladecans-Marsal, E.:** "Suburbanization and highways: when the Romans, the Bourbons and the first cars still shape Spanish cities"
**2013/6, Bosch, N.; Espasa, M.; Montolio, D.:** "Should large Spanish municipalities be financially compensated? Costs and benefits of being a capital/central municipality"
**2013/7, Escardíbul, J.O.; Mora, T.:** "Teacher gender and student performance in mathematics. Evidence from Catalonia"
**2013/8, Arqué-Castells, P.; Viladecans-Marsal, E.:** "Banking towards development: evidence from the Spanish banking expansion plan"
**2013/9, Asensio, J.; Gómez-Lobo, A.; Matas, A.:** "How effective are policies to reduce gasoline consumption? Evaluating a quasi-natural experiment in Spain"
**2013/10, Jofre-Monseny, J.:** "The effects of unemployment benefits on migration in lagging regions"
**2013/11, Segarra, A.; García-Quevedo, J.; Teruel, M.:** "Financial constraints and the failure of innovation projects"
**2013/12, Jerrim, J.; Choi, A.:** "The mathematics skills of school children: How does England compare to the high performing East Asian jurisdictions?"
**2013/13, González-Val, R.; Tirado-Fabregat, D.A.; Viladecans-Marsal, E.:** "Market potential and city growth: Spain 1860-1960"
**2013/14, Lundqvist, H.:** "Is it worth it? On the returns to holding political office"
**2013/15, Ahlfeldt, G.M.; Maennig, W.:** "Homevoters vs. leasevoters: a spatial analysis of airport effects"
**2013/16, Lampón, J.F.; Lago-Peñas, S.:** "Factors behind international relocation and changes in production geography in the European automobile components industry"
**2013/17, Guío, J.M.; Choi, A.:** "Evolution of the school failure risk during the 2000 decade in Spain: analysis of Pisa results with a two-level logistic mode"
**2013/18, Dahlby, B.; Rodden, J.:** "A political economy model of the vertical fiscal gap and vertical fiscal imbalances in a federation"
**2013/19, Acacia, F.; Cubel, M.:** "Strategic voting and happiness"
**2013/20, Hellerstein, J.K.; Kutzbach, M.J.; Neumark, D.:** "Do labor market networks have an important spatial dimension?"
**2013/21, Pellegrino, G.; Savona, M.:** "Is money all? Financing versus knowledge and demand constraints to innovation"
**2013/22, Lin, J.:** "Regional resilience"
**2013/23, Costa-Campi, M.T.; Duch-Brown, N.; García-Quevedo, J.:** "R&D drivers and obstacles to innovation in the energy industry"
**2013/24, Huisman, R.; Stradnic, V.; Westgaard, S.:** "Renewable energy and electricity prices: indirect empirical evidence from hydro power"
**2013/25, Dargaud, E.; Mantovani, A.; Reggiani, C.:** "The fight against cartels: a transatlantic perspective"
**2013/26, Lambertini, L.; Mantovani, A.:** "Feedback equilibria in a dynamic renewable resource oligopoly: pre-emption, voracity and exhaustion"
**2013/27, Feld, L.P.; Kalb, A.; Moessinger, M.D.; Osterloh, S.:** "Sovereign bond market reactions to fiscal rules and no-bailout clauses – the Swiss experience"
**2013/28, Hilber, C.A.L.; Vermeulen, W.:** "The impact of supply constraints on house prices in England"
**2013/29, Revelli, F.:** "Tax limits and local democracy"
**2013/30, Wang, R.; Wang, W.:** "Dress-up contest: a dark side of fiscal decentralization"
**2013/31, Dargaud, E.; Mantovani, A.; Reggiani, C.:** "The fight against cartels: a transatlantic perspective"
**2013/32, Saarimaa, T.; Tukiainen, J.:** "Local representation and strategic voting: evidence from electoral boundary reforms"
**2013/33, Agasisti, T.; Murtinu, S.:** "Are we wasting public money? No! The effects of grants on Italian university students' performances"
**2013/34, Flacher, D.; Harari-Kermadec, H.; Moulin, L.:** "Financing higher education: a contributory scheme"
**2013/35, Carozzi, F.; Repetto, L.:** "Sending the pork home: birth town bias in transfers to Italian municipalities"

**2013/36, Coad, A.; Frankish, J.S.; Roberts, R.G.; Storey, D.J.:** "New venture survival and growth: Does the fog lift?"
**2013/37, Giulietti, M.; Grossi, L.; Waterson, M.:** "Revenues from storage in a competitive electricity market: Empirical evidence from Great Britain"

**2014**

**2014/1, Montolio, D.; Planells-Struse, S.:** "When police patrols matter. The effect of police proximity on citizens' crime risk perception"
**2014/2, Garcia-López, M.A.; Solé-Ollé, A.; Viladecans-Marsal, E.:** "Do land use policies follow road construction?"
**2014/3, Piolatto, A.; Rablen, M.D.:** "Prospect theory and tax evasion: a reconsideration of the Yitzhaki puzzle"
**2014/4, Cuberes, D.; González-Val, R.:** "The effect of the Spanish Reconquest on Iberian Cities"
**2014/5, Durán-Cabré, J.M.; Esteller-Moré, E.:** "Tax professionals' view of the Spanish tax system: efficiency, equity and tax planning"
**2014/6, Cubel, M.; Sanchez-Pages, S.:** "Difference-form group contests"
**2014/7, Del Rey, E.; Racionero, M.:** "Choosing the type of income-contingent loan: risk-sharing versus risk-pooling"
**2014/8, Torregrosa Hetland, S.:** "A fiscal revolution? Progressivity in the Spanish tax system, 1960-1990"
**2014/9, Piolatto, A.:** "Itemised deductions: a device to reduce tax evasion"
**2014/10, Costa, M.T.; García-Quevedo, J.; Segarra, A.:** "Energy efficiency determinants: an empirical analysis of Spanish innovative firms"
**2014/11, García-Quevedo, J.; Pellegrino, G.; Savona, M.:** "Reviving demand-pull perspectives: the effect of demand uncertainty and stagnancy on R&D strategy"
**2014/12, Calero, J.; Escardíbul, J.O.:** "Barriers to non-formal professional training in Spain in periods of economic growth and crisis. An analysis with special attention to the effect of the previous human capital of workers"
**2014/13, Cubel, M.; Sanchez-Pages, S.:** "Gender differences and stereotypes in the beauty"
**2014/14, Piolatto, A.; Schuett, F.:** "Media competition and electoral politics"
**2014/15, Montolio, D.; Trillas, F.; Trujillo-Baute, E.:** "Regulatory environment and firm performance in EU telecommunications services"
**2014/16, Lopez-Rodriguez, J.; Martinez, D.:** "Beyond the R&D effects on innovation: the contribution of non-R&D activities to TFP growth in the EU"
**2014/17, González-Val, R.:** "Cross-sectional growth in US cities from 1990 to 2000"
**2014/18, Vona, F.; Nicolli, F.:** "Energy market liberalization and renewable energy policies in OECD countries"
**2014/19, Curto-Grau, M.:** "Voters' responsiveness to public employment policies"
**2014/20, Duro, J.A.; Teixidó-Figueras, J.; Padilla, E.:** "The causal factors of international inequality in co2 emissions per capita: a regression-based inequality decomposition analysis"
**2014/21, Fleten, S.E.; Huisman, R.; Kilic, M.; Pennings, E.; Westgaard, S.:** "Electricity futures prices: time varying sensitivity to fundamentals"
**2014/22, Afcha, S.; García-Quevedo, J,:** "The impact of R&D subsidies on R&D employment composition"
**2014/23, Mir-Artigues, P.; del Río, P.:** "Combining tariffs, investment subsidies and soft loans in a renewable electricity deployment policy"
**2014/24, Romero-Jordán, D.; del Río, P.; Peñasco, C.:** "Household electricity demand in Spanish regions. Public policy implications"
**2014/25, Salinas, P.:** "The effect of decentralization on educational outcomes: real autonomy matters!"
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**2015**

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## 2016

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