GRAVITATION AND DISPERSION - A DISAGGREGATE VIEW ON URBAN AGGLOMERATION AND SPRAWL IN GERMANY

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1. Introduction

One strand of the regional economics literature, which has expanded during the past decades, studies the extent of spatial agglomeration within countries by examining the size ranking of cities. Many studies have found that an empirical regularity called "Zipf´s law" holds for the city size distribution. It implies that among large cities, their absolute size is inversely proportional to their within-country rank in size. Apparently, since Zipf´s law holds for many countries. Krugman (1996, 40) finds: "We are unused to seeing regularities this exact in economics – it is so exact that I find it spooky". For example, in the U.S., the population in the administrative territory of the largest city, New York, is twice that of the second largest city, Los Angeles, and three times that of Chicago.

Although the regularity described as "Zipf´s law" with respect to the size ranking of settlements had been observed by other researchers, most notably Auerbach (1913), the work of Zipf (1949) was acknowledged by a wider audience. As Gabaix (1999, 739) points out, "Zipf´s law for cities is one of the most conspicuous empirical facts in economics, or in the social sciences generally". If cities in a given country are ranked by population, a graph can be drawn in which the x-axis shows the log of the population and the y-axis the log of the rank. For a wide range of countries, the result will be a straight line with a slope of around -1. This regularity can be specified by a simple linear regression model

$$(1)\ \log(R_i) = \alpha - \beta\ \log(P_i) + \varepsilon_i$$

in which R_i is the rank of city i in the within-country size ranking by population, P_i represents the population of city i, α is a constant, β is the parameter and ε_i is the error term. In a size ranking, in which the size is inversely proportional to the rank, $\beta = 1$, i.e. the slope of the regression line is -1.

Our analysis differs from most previous studies of city size ranking. Assuming a disaggregate view, we focus on the role of the spatial layout of territorial entities. We examine whether the validity of Zipf´s law with respect to Germany is robust to variation in the urban areas taken into consideration. The key research questions are:

1. What is the size distribution among cities in Germany if they are defined by population density across small spatial grids, independently of municipal boundaries?
2. Is the size ranking affected by variation in the size of surrounding zones, which are attributed to urban cores?
3. Are there deviations from Zipf´s law (only) among large cities suggesting scale economies, as expected by the recent literature?

Our analysis adds to the literature by examining to what extent the precise definition of urban agglomerations affects measurement of Zipf´s law, whether increasing market access indicates scale economies among large cities and to what extent there is an intra-urban division in scale economies between central areas and wider urban regions. The next section provides an outline of the literature. Section 3 presents the data and empirical framework. Section 4 discusses the results and the final section provides the main conclusions.

2. Literature review

Since there is no plausible explanation for the necessity of the size ranking of cities to follow Zipf´s law, it is very surprising that it has been observed for many countries (Rosen and Resnick 1980). In Germany, apparently it can be found in the size ranking of cities over many historic periods since 1700 (Just and Stephan 2009). Using current data, Just and Stephan (2009) find that in Germany Zipf´s law holds for administrative cities, agglomerations comprising combinations of administrative cities, administrative regions and for administrative cities within the federal states.

In this context a second empirical regularity (“Gibrat´s law”) is usually referred to in order to underline the plausibility of Zipf´s law. Gibrat (1931) assumes that among a fixed number of cities, their growth follows a similar rate, i.e. it is characterised by a common mean and variance, independently of the initial size. It can be shown that if the rate and variance of city growth proceed independently of city size, a linear size-rank relationship according to Zipf´s law will emerge (Gabaix 1999).

In contrast to these findings Fujita et al. (1999) point out that if a city´s growth rate were independent of size, constant returns to city size would be assumed. However, the new economic geography literature has demonstrated that agglomeration economies do vary by size (Redding 2009).

Duranton (2007) suggests that if the advantages of agglomeration economies dominated the disadvantages of crowding among large cities, innovation (and growth) would increase more than proportionally by size. The regression coefficient in equation (1) may thus be reduced.

Of course, the definition of city size itself is anything but unambiguous. As Alonso (1971, 67-68) points out: "Modern urban centres are surrounded by very large, diffuse zonal boundaries, within which there are marked variations in the proportion of firms and people associated with that centre, and in the intensity of that association. Thus, population does not constitute a conventional countable set, where people are unequivocally members or not. … A number as a measure of population is thus gross oversimplification".

Many researchers argue that agglomerations comprising central cities and their hinterland would provide a more useful spatial concept for the study of urban rank-size distributions than central cities within their municipal territories alone (Gabaix 1999, Rauch 2013, Reggiani and Nijkamp 2012, Rosen and Resnick 1980).

Giese and Südekum (2011) provide further evidence on the validity of Zipf´s and Gibrat´s law for Germany. They focus on administrative cities, but also find a close-to-Zipf size ranking among urban regions (comprising combinations of neighbouring municipalities) in the year 1997. Their analysis also verifies Zipf´s law for "clubs" of cities located within a pre-defined distance from each other (less than 200 km).

3. Data and methods

This analysis draws on data referring to spatial grids, according to the guidelines of the INSPIRE Directive of the European Union (INSPIRE 2010). With grid data, each region is identical in its spatial dimensions (in this case, 1 km^2), the position of each grid is defined unambiguously and its borders remain constant over time. For the purposes of this analysis, data on the residential population was provided by microm Micromarketing-Systeme und

Consult GmbH, a market research firm specialising in territorial analysis. Data on the grid-based population was calculated from a database providing information at the level of individual houses and validated by comparison with district-level administrative data (microm 2011). In the following, cities will be defined as territorial entities with an above-average population density. Allocation of individual grids to urban areas will be implemented by spatial clustering algorithms, which focus on identifying clusters among large numbers of objects characterised by a single indicator. Kaufman and Rousseeuw (1990) suggest the CLARA (Clustering for Large Applications) algorithm for large data sets (in this case comprising around 360,000 observations). In a first step, the highest-density urban cores will be identified. In the second step of the cluster analysis, agglomerations are defined in an iterative process, where new areas will be added to an existing agglomeration if their population density is above a pre-defined value, e.g. 300 inhabitants per grid cell.

4. Analysis

In the first step of the cluster analysis, 772 high-density grids were identified as German agglomeration centres. Agglomerations were then defined according to the iterative process described above, applying step-wise solutions for threshold values ranging from 300 up to 7,000 inhabitants per km² (Table 1). If an average population density of 7,000 inhabitants per km² is defined as enlargement threshold, the resulting definition of agglomerations is much more restrictive and results in a larger number of independent agglomerations (185) than other agglomeration definitions referring to a lower threshold value, according to which more of the initial 772 core grids are combined within larger agglomerations.

The population defined as “urban” in the most restrictive definition comprises only about 14 million inhabitants, whereas according to a solution applying a much lower threshold value for agglomeration enlargement (300), over 39 million, i.e. about half of the German population, are “urban”. In his original concept of urban agglomerations in Germany, Boustedt (1953) defined a population density of 500 inhabitants per km² (at the municipal level) as threshold value for urban core zones. Of course, definition of urban regions by population density alone may only serve as a first step towards a more thorough classification of urban territories. In more recent concepts of urban agglomerations defined for purposes of regional planning, “density” has been measured in terms of the relation between jobs (at the workplace) and the working-age residential population (ARL 1984). This indicator has been accepted as a more accurate measure of urbanisation if it is observed at the level of municipal territories. A pragmatic approach that identifies agglomeration cores by grid-based population data and hinter-lands by a range of indicators compiled at the municipal level has been suggested by the OECD (Brezzi et al. 2012). Our analysis takes a first step towards an exclusively grid-based city definition and explores the applicability of spatial clustering for this purpose by drawing on population density as a basic indicator.

The Zipf parameter β from equation (1) decreases in line with an increase of the average size of agglomerations (Table 1). It has been discussed in the literature that the Zipf parameter may decrease if returns to scale increased with size among larger cities. Our analysis shows that a decrease in slope can also be observed if larger urban zones surrounding a constant range of urban cores (corresponding to a lower threshold value of agglomeration enlargement) are taken into account. The definition of “cities” obviously affects the outcome of an analysis of urban concentration and hierarchy.

Table 1

Zipf parameter β for different definitions of urban agglomeration

2010, OLS estimation of $\log(R_i) = \alpha - \beta \log(P_i) + \varepsilon_i$

Density threshold (population per km²)	Nr. of agglomerations	Average population	β	adj. R^2
7,000	185	75,488	1.263***	0.986
6,000	176	81,358	1.188***	0.988
5,000	164	91,349	1.115***	0.990
4,000	149	108,642	1.016*	0.989
3,000	134	139,900	0.951***	0.968
2,000	114	193,365	0.871***	0.952
1,000	93	291,696	0.822***	0.968
900	91	309,241	0.798***	0.967
700	88	339,310	0.793***	0.968
500	76	448,422	0.746***	0.975
300	70	560,102	0.709***	0.961

Authors´ calculation. *** significantly different from 1 at 1%-level, *significantly different from 1 at 10%-level. R_i = size rank of agglomeration i, P_i = total population of agglomeration i; Data source: microm (2013).

If larger zones surrounding the most densely populated urban cores are considered, the resulting size distribution indicates increasing returns to scale. Such a downward deviation from Zipf´s law can already be observed under a relatively restrictive definition of agglomerations, which takes an average population density of 3,000 inhabitants per km² as a basis and defines 134 cities. A slope of almost exactly -1 is measured among a hierarchy of 149 agglomerations, which emerges under a classification threshold of 4,000 inhabitants per km² If more independent agglomerations are taken into account (and the average size of agglomerations is reduced), the slope increases, i.e. returns to scale diminish.

The dichotomy of scale economies between urban cores and wider urban regions suggests considerable intra-urban differentials. Among the high-density urban cores with over 7,000 inhabitants per km² on average, the size ranking measures scale economies (a Zipf coefficient below 1) in the lower tail, i.e. if the analysis is restricted to the 110 smallest out of 185 agglomerations, with 31,000 inhabitants on average. When urban cores grow beyond this size, diseconomies of congestion may occur, which would disencourage further agglomeration at such a compact level. In fact, for many decades, such intra-urban differentials have resulted in urban sprawl.

In order to assess the relevance of our agglomeration definitions for current territorial planning, we can compare our solutions to agglomeration concepts referred to in regional and urban policy. Under a relatively low density threshold of 300 inhabitants per km², the so defined grid-based Rhine-Ruhr agglomeration is similar in size and density to the conurbation (Europäische Metropolregion Rhein-Ruhr) defined by the Conference of Ministers for Spatial Planning (Ministerkonferenz für Raumordnung, MKRO) in Germany (BMVBS and BBR (eds.) 2007) (Table 2 and Figure 1). Among the 11 conurbations defined by the MKRO, a considerably more densely populated (and comparatively smaller) area has been assigned to the Rhine-Ruhr than to all other regions. Accordingly, the population of the Rhine-Ruhr thus specified is only about twice the size of that of the second largest conurbation, Berlin-Brandenburg. In the low-density grid-based definition (300 threshold) however, the Rhine-Ruhr agglomeration is over three times the size of Berlin.

According to the grid-based analysis, returns to scale among the largest urban agglomerations as measured by the Zipf regression therefore turn out to be much higher than between the conurbations considered as territorial entities in spatial planning (corresponding to a much lower regression coefficient, i.e. 0.709 as compared to 1.560 among the 11 MKRO conurbations).

Table 2
Definitions of German agglomerations compared
Grid-based definition, conurbations (Europäische Metropolregionen) defined for planning purposes and administrative cities (kreisfreie Städte)

Rank	Grid-based definition (density threshold 300 inh./km²)	Population (2010)	Population density (inh./km²)	Conurbations defined by MKRO	Population (2004)	Population density (inh./km²)
1	Rhine-Ruhr	12,445,837	910	Rhine-Ruhr	11,491,200	1064
2	Berlin	3,959,614	2,095	Berlin-Brandenburg	5,938,800	196
3	Rhine-Main	2,305,547	1,103	Rhine-Main	5,306,400	396
4	Hamburg	2,273,030	1,518	Stuttgart	4,643,400	426
5	Stuttgart	2,044,773	1,106	Hamburg	4,237,200	214
6	Munich	1,865,674	1,650	Hanover	3,943,200	212
7	Rhine-Neckar	1,260,322	1,032	Sachsendreieck	3,509,000	290
8	Nuremberg	823,934	1,093	Nuremberg	3,370,965	177
9	Hanover	786,817	1,368	Munich	2,530,000	460
10	Saarbrücken	730,818	604	Bremen-Oldenburg	2,366,400	204
11	Dresden	722,479	1,047	Rhine-Neckar	2,346,400	419

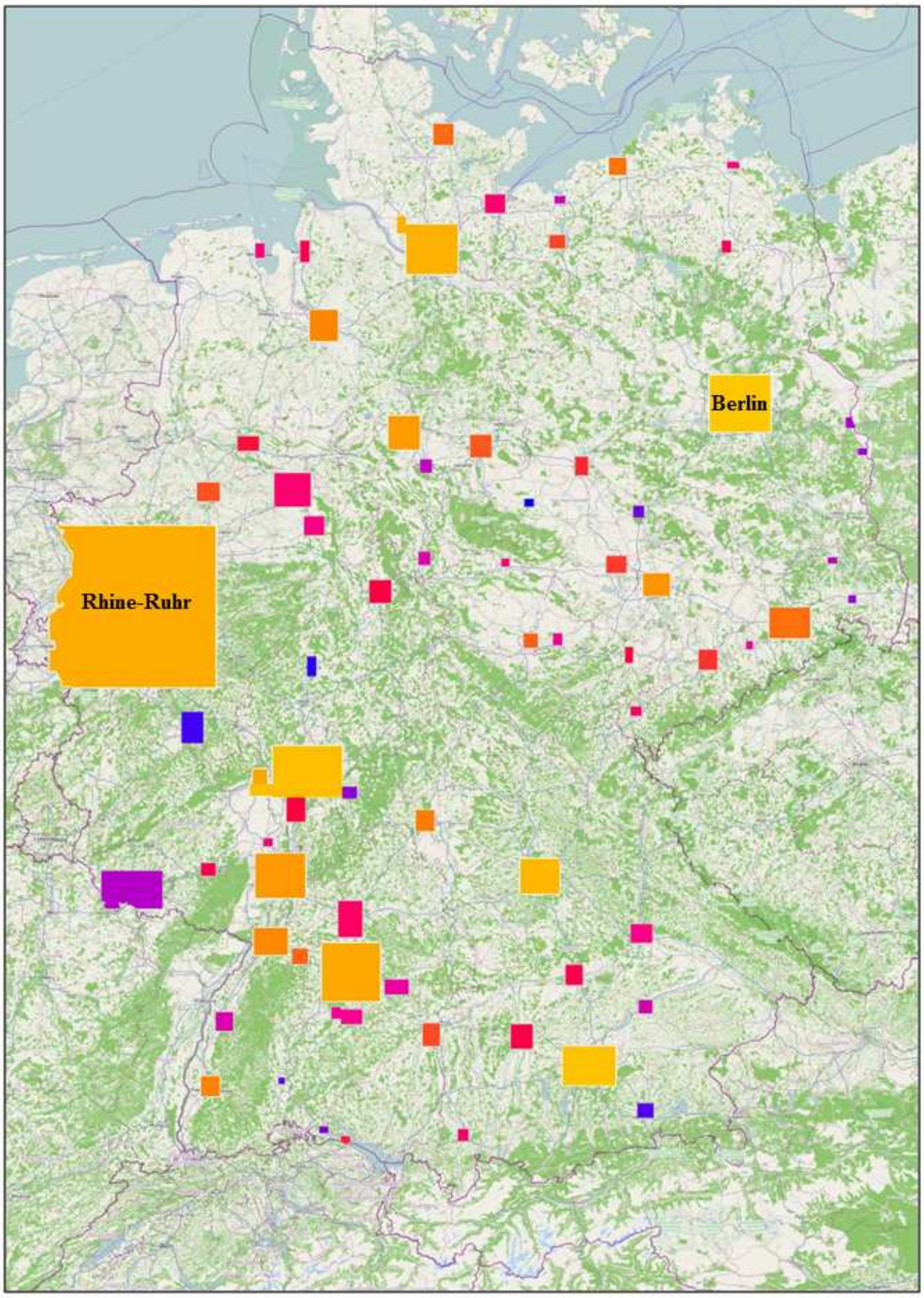
Authors´ calculation. Data source: microm (2013) (Grid-based definition), BMVBS and BBSR (ed.) (2007) (Conurbations defined by MKRO (Conference of Ministers for Spatial Planning)), Federal Statistical Office and the statistical offices of the Länder (administrative cities).

Apparently, if urban agglomerations in Germany are defined by the distribution of the population over space, a much more unbalanced settlement pattern is revealed than the conurbations referred to by the ministerial conference (MKRO) would suggest. While a more balanced distribution of the population across space may be a desirable goal in spatial planning, the forces of gravitation in (economic) space could be even more difficult (and, after all, less desirable) to overcome than decision-makers in some of the smaller agglomerations might expect.

5. Conclusions

With respect to city size ranking in Germany, Zipf´s law appears to be quite robust to variation in the layout of urban regions represented by population figures. It has been discussed in the literature that in a regression of the size rank on the absolute population, the Zipf parameter β may be reduced among large cities due to increasing rather than constant returns to scale. According to our analysis, increasing returns to scale are measured if larger zones surrounding a given set of densely populated city centres are defined as “urban”.

Figure 1
Grid-based definition of urban regions in Germany - density threshold for cluster expansion: 300 inhabitants per km²
2010



Authors´ calculation. Data source: microm (2013).

If the analysis focuses on densely populated areas with at least 4,000 inhabitants per km², the size ranking among the 149 cities thus defined corresponds with Zipf´s law particularly closely. If the density threshold is reduced and larger surrounding areas are included, the resulting size ranking suggests increasing returns to scale. Among the most densely populated cores, returns to scale diminish.

Regarding growth perspectives of cities at different positions in the size distribution, the accuracy of the rank-size rule has often been interpreted as good news for smaller cities, since a ranking according to Zipf´s law may indicate that small cities grow at the same rate as large ones. If the urban hinterland is taken into account, however, scale economies dictate that economic forces tend to favour continuing agglomeration in the very largest cities, even if deviation from Zipf´s law is moderate. Scale economies among urban regions are confirmed by wage regressions, in which a statistically significant coefficient for regional market capacity is found (only) among larger agglomerations defined by a density threshold below 1,000 inhabitants per km^2.

In terms of urban sprawl, the polycentric Rhine-Ruhr conurbation stands out by a particularly high consumption of medium-density urban space. However, concentration of the German population on this largest urban agglomeration is more distinct than the definition of conurbations for purposes of spatial planning (Europäische Metropolregionen) would imply. In the planning-oriented definition, a comparatively smaller and much more densely populated urban area is associated with the Rhine-Ruhr conurbation than with the other large urban agglomerations in Germany. If spatial clustering methods are applied to define all agglomerations in Germany, a greater dominance of the Rhine-Ruhr agglomeration among urban settlements is revealed.

Obviously, it remains an open question what degree of population density may be desirable from the point of view of regional planning. Nevertheless, the analysis based on spatial clustering methods suggests thorough investigation concerning the definition of spatial entities in regional economic analysis.

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