Urban Scaling and Its Relation with Governance Structures and Future Prospects of Cities *draft version 20180312*

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Abstract

We investigated the socioeconomic urban scaling behavior in three European Union countries: Denmark, Germany, and the Netherlands. In the case of Denmark our analysis relates to all 96 municipalities. We investigate the scaling of larger cities, municipalities within the Copenhagen agglomeration, and municipalities in rural areas. We also distinguish between municipalities with high and low centrality. We find superlinear scaling of the gross urban product with population size in all cases, with exponents between 1.14 and 1.23, and for municipalities in rural areas a surprisingly high value of 1.39.

In Germany we distinguish between major cities of which the surrounding urban region belongs to the municipality of the city, the 'Kreisfreie Städte' (in total 106), and 'Kreise', i.e., regions around smaller cities consisting of several municipalities (in total 296). A striking finding is that the scaling exponents differ substantially from one region to another. We find in most cases a significant superlinear scaling with exponents up to 1.31. Our analysis convincingly shows that urban regions with one municipality (Kreisfreie Städte) perform significantly better than urban regions with fragmented governance structures (more than one municipality). Also we find a strong relation between the measured residuals of the scaling equations and the socio-economic position of a cities as perceived by expert reviews.

For the Netherlands we focus on the group of the major cities (in total 21) with their agglomerations and on all 60 municipalities in the Province of Zuid-Holland (PZH). Again in both cases significant superlinear scaling is measured with exponents up to 1.26. Our earlier observation that one-governance urban areas perform better than multi-governance urban areas is confirmed and this is in line with the above mentioned findings for Germany.

Introduction and political context

In recent years there is a rapidly growing interest in the role of cities in our national and global society. Cities are regarded as the main locations of human social, economic, cultural and innovative activity [1]. Recent research on urban metrics shows a more than proportional (superlinear) increase of the socio-economic performance of cities with increasing population [2, 3, 4]. A city that is twice as large (in population) as another city can be expected to have a factor of about 2.15 larger socio-economic performance, for instance in terms of gross urban product. This *urban scaling* behavior is found for human interactions in general and for knowledge production activities [5, 6, 7, 8] in cities. Indicators representing these activities appear to scale nonlinearly with the number of inhabitants of cities and urban agglomerations. Similar scaling is found for other complex systems such as universities [9]. The basis of this scaling behavior is provided by the theory of complex, adaptive systems [10]. Networked structures reinforce nonlinearly as the system grows, particularly more than proportional, i.e. superlinearly, described by a *power law* [11]. A simple way to understand this phenomenon is by realizing that the number of nodes increases *linearly* whereas the number of links between the nodes increases *superlinearly* with the growth of a network. The nodes in the urban complex work are the inhabitants, social and cultural institutions, firms, etcetera. The links between these (clustered) nodes are crucial for new developments, reinforcement of urban facilities, and innovation. Because they increase superlinearly, the socio-economic strength of the city increases more than proportional with increasing size of the city. For an extensive discussion of the theoretical basis of urban scaling we refer to [11]. Evidently, the relation between urban scaling (which is a phenomenon at the meso-level) and dynamic processes in urban systems, for instance the concentration of business companies and professions, mobility, and other forms of traffic relations (which are processes at the micro-level) are important and could provide further understanding of scaling.

The US research on urban scaling is about urban areas (MSA's, metropolitan statistical areas) that have grown autonomously to a specific number of inhabitants, regardless of the formal boundaries of municipalities within an urban area. This is particularly the case for a recent study on urban scaling in Europe [12] where cities are defined as 'functional cities' on the basis of recent OECD-EU definitions of large metropolitan areas [13].

Urban scaling analysis is based on data of cities of different population size within the same time window, and thus urban scaling means a synchronic, 'static' measurement that has a predicting value for what happens with socioeconomic variables if, for instance, a city (i.e., urban area) doubles in population in the course of time. This is, of course, different from a situation in which a city defined as a municipality and being the central city of the urban agglomeration, doubles in population by a formal reorganization of all municipalities within the urban area into one new municipality. Nevertheless it is probable that after some time the newly formed city should meet the scaling values as predicted by its new size of population. But crucial is here the interesting policy question: would these scaling values for the doubled population ('created' by municipal reorganization) not already be attained for the urban agglomeration as a whole, simply because the urban agglomeration regardless of the formal municipal boundaries already has this double population?

Our previous study on the urban scaling of cities in the Netherlands [14] focused precisely on this problem by analyzing the scaling behavior of major cities in three

structural and administrative modalities: the municipality of the central city, their urban agglomerations and their urban areas. In all three modalities superlinearity with power-law exponents of around 1.15 was found. But remarkably, agglomerations and urban areas underperform if we compare for the same size of population an agglomeration or urban area with a city as a municipality. In other words, an urban system as one formal municipality (one-governance) performs better as compared to an urban agglomeration (multi-governance) with the same population size. Moreover, further analysis suggested that cities with a municipal reorganization recently and in the past decades have a higher probability to perform better than cities without municipal restructuring.

A recent OECD study [15] supports our earlier finding. The authors conclude that in line with previous literature, their analysis confirms that city productivity tends to increase with city size. But even more important, on the governance side the authors find that cities (urban regions) with fragmented governance structures tend to have lower levels of productivity. For instance, for a given population size, a metropolitan area with twice the number of municipalities is associated with around six percent lower productivity.

The urban scaling phenomenon is important for new insights into and policy for urban development and, particularly in the Netherlands, for municipal reorganization of urban agglomerations (enlargement of the municipality of the central city by discontinuation of the municipalities of the suburbs). Different from the usual focus on measures for cutting down expenses, the urban scaling phenomenon opens new vistas toward socio-economic progress. Possible effects per medium-sized city could amount to hundreds of millions of euros which means thousands of jobs per year and per urban area. Furthermore, the interpretation of urban scaling laws is important in the discussion on models of urban growth, structure and optimal size of cities and their regions [16, 17].

The main goal of the study presented in this paper is (1) to examine urban scaling in *different national systems* and, with that, to find out to what extent urban scaling depends on characteristics of these national systems; (2) to find further empirical evidence of the above mentioned differences in scaling of *one-governance versus multi-governance urban systems*; and (3) and to relate these differences to *social, economic and cultural patterns* in urban areas.

The structure of this paper is as follows. First we describe our data and method to investigate the urban scaling behavior of in three European Union countries, Denmark, Germany, and the Netherlands. Next we discuss the results and we conclude the paper with a discussion of the policy implications.

Denmark

Data

Denmark with its nearly 6 million inhabitants is administratively divided in five regions and these regions are subdivided into municipalities. In 2007 the number of municipalities was reduced from 270 to 96. This municipal reform, however, mostly involved the smaller, more rural municipalities. Given the population size of Denmark, the number of major cities is restricted: seven municipalities have more than 100,000 inhabitants and only four of these are municipalities of which the central city itself has a

population of more than 100,000 (Copenhagen, Aarhus, Odense Aalborg). These major cities -except for Copenhagen- already had a municipal reform in 1970. Remarkably, there has been no municipality reform whatsoever of the Copenhagen agglomeration (formally called the Capital Region of Denmark). Of the 96 Danish municipalities 26 are in the Copenhagen agglomeration (including Copenhagen). We collected for Denmark the following data: (1) gross urban product, and (2) population (number of inhabitants) of all municipalities in Denmark for the period 1997-2015[1]. In addition we collected for all Danish municipalities their surface areas[2] and the population of the main town or city of the municipality[3]. The surface areas are used to calculate the population density in a municipality, and number of inhabitants of the main town or city is used to calculate the centrality of a municipality.

Scaling Analysis

We first analyzed the scaling of the entire set of 96 municipalities and show the results in the upper part of Fig. 1. We find that the scaling exponent is 1.14. An important issue in the measurement of urban scaling is the effect of outliers. Indeed, as the figure suggests, the measured exponent is sensitive to outliers. A striking example is Billund (indicated with a circle in the upper part of Fig. 1), a small municipality of about 26,000 inhabitants but with a GUP four to five times higher than other municipalities of similar size. The reason for this exceptionally high GUP is obvious: Billund is the home town of Legoland, the largest tourist attraction in Denmark with two million visitors per year. Furthermore, Billund International Airport is the second largest airport in Denmark. Billund has by far the largest relative increase of GUP of all Danish municipalities in the last ten years. If we remove Billund as an exceptional outlier the exponent is 1.16.

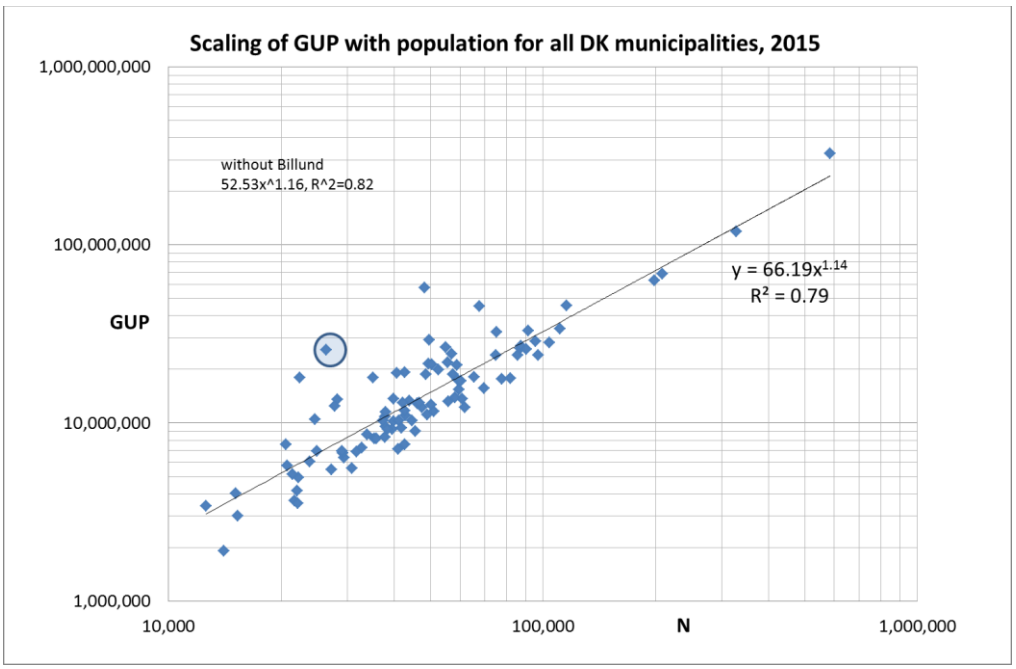


Fig. 1 Scaling of the gross urban product (in 1,000 DDK) for all Danish municipalities.

[1] The data on Gross Domestic Product (in current prices, previous years prices and 2010-prices, chained values) and population at municipality level were provided by Danmarks Statistik (Statistics Denmark) www.dst.dk. Data are compiled and analyzed in file DK-UrbScal.xlsx.

[2] Retrieved from https://en.wikipedia.org/wiki/List_of_municipalities_of_Denmark.

[3] For instance, see https://en.wikipedia.org/wiki/Esbjerg_Municipality.

Other outliers are two municipalities within the Copenhagen agglomeration, Ballerup and Glostrup. For instance Glostrup has twice as many employees as compared with municipalities of similar size because several major international companies are located in Glostrup. Removing all three outliers results in a scaling exponent of 1.18. Nevertheless, in all cases the gross urban product scales superlinearly with population.

It is interesting to investigate the scaling behavior for specific subsets within the total set of all municipalities. One of the distinctions we make is related to centrality: the extent to which residents, or jobs, or BGP, are divided over all cities/towns within a municipality, or all municipalities within a region. If this division is sharply peaked, then one city/town within a municipality, or one municipality within a region, plays the leading role; in such a case we speak about a monocentric municipality or region. With a flatter distribution we have a more polycentric municipality or region. In follow-up research we will apply the Zipf-distribution to calculate mono- or polycentricity. For this moment we use a simple but workable measure of centrality: the ratio of the population of the main town or city in the municipality to the total population of the municipality. In municipalities around larger cities at least half of the total population lives in the central city. Thus, for the typical urban areas the centrality will be above 0.50. Such urban areas are therefore mostly monocentric. In rural areas, however, the main towns of municipalities are often small with less than 10,000 inhabitants and the remaining inhabitants are divided over a larger number of smaller towns within the municipality. As a consequence, the centrality of rural area municipalities is mostly smaller than 0.50 and often smaller than 0.30. In such a situation, the municipalities are more polycentric. This distinction in centrality is important in order to investigate whether scaling also applies in less densely populated, rural areas. Moreover, in our follow-up research we'll also investigate whether or not the scaling exponent depends on the measured centrality, and if so, to what extent.

Let us return to the empirical findings for Denmark. First, we show in Fig. 2 the scaling of all municipalities (n=37) with a population larger than 50,000. We find that the scaling exponent is 1.14 [4]. If we remove the seven municipalities with population above 50,000 within the Copenhagen agglomeration, the scaling exponent is 1.20. This is caused by the fact that the Copenhagen agglomeration municipalities generally have a relatively high GUP (such as mentioned in the Glostrup example) because they are de facto part of the compact capital urban region which is the main Danish economic center. As these agglomeration municipalities are located at the low left side of the regression line they 'lift' as it were the regression line which causes a lower exponent if they are included and a higher exponent if they are excluded.

[4] We refer to [14] for an extensive error discussion. On the basis of these calculations we estimate that the 95% confidence interval is within +/- 0.05 around the measured scaling exponent.

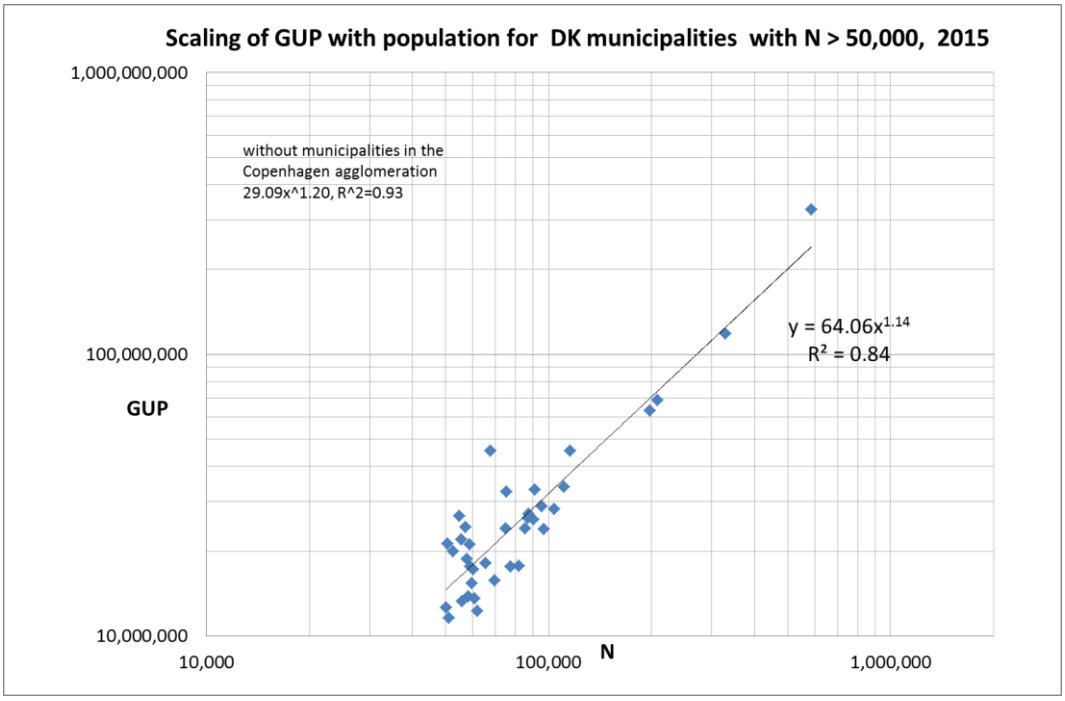


Fig. 2 Scaling of GUP (in 1,000 DDK) for all Danish municipalities above 50,000 inhabitants.

Next, we made a subset of the above discussed 26 municipalities within the Copenhagen agglomeration. As Fig. 3a shows, a scaling exponent 1.22 is found. This is an interesting finding: it means that also within a compact urban area the autonomous municipalities exhibit scaling behavior. In Fig. 3b we show a map of the Copenhagen agglomeration.

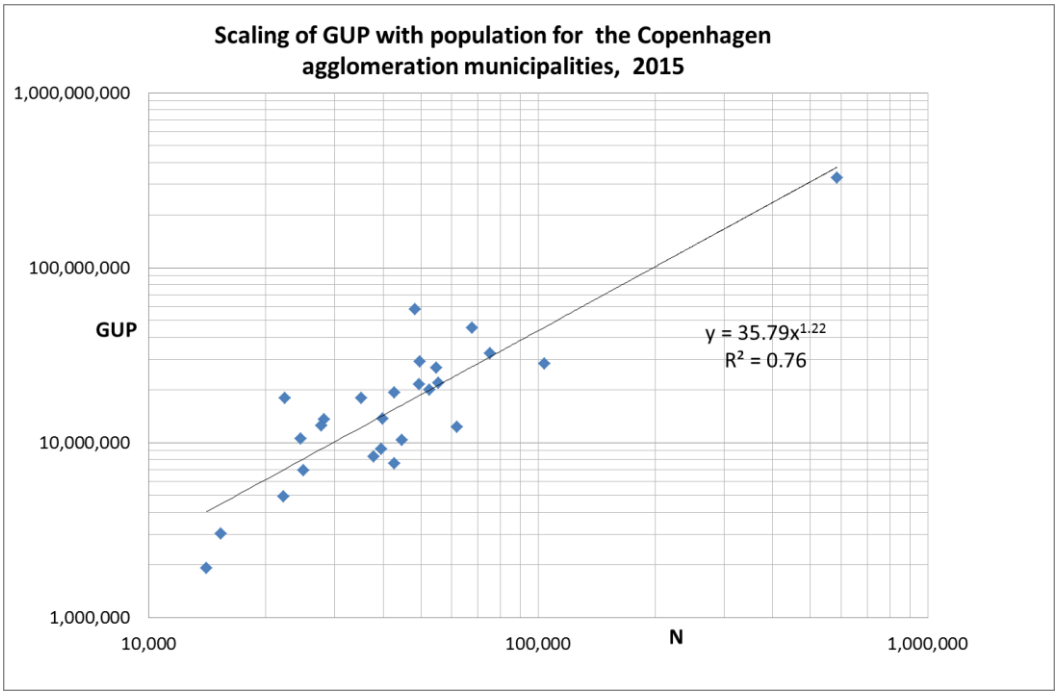
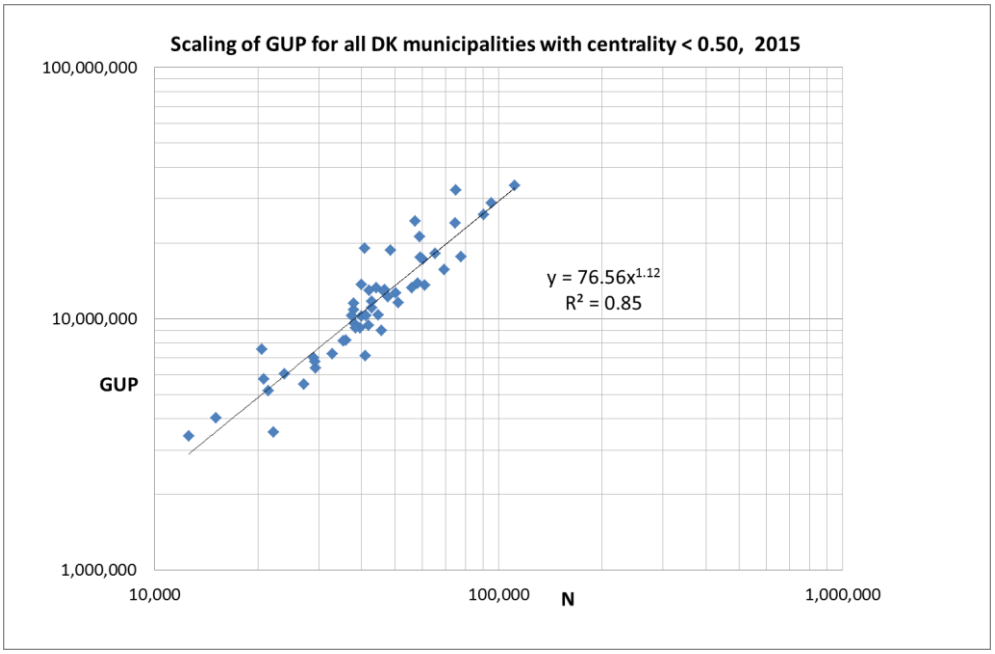


Fig. 3a Scaling of GUP (in 1,000 DDK) for all municipalities within the Copenhagen agglomeration.

Fig. 3b Map of the Copenhagen agglomeration municipalities[5].

As discussed above, rural areas are characterized by municipalities with low centrality. In Fig. 4, upper part, we show the scaling behavior of all Danish municipalities with centrality<0.50 (n=53, more than half of all Danish municipalities, we excluded Billund). The scaling exponent is 1.12, not very different from the scaling exponent of all Danish municipalities (without Billund 1.16). In Fig. 4, lower part, we show the scaling of the municipalities with centrality<0.30 (thus a subset of the municipalities in the upper part of the figure, n=25). No doubt that scaling also applies in these cases. In fact, the scaling exponent for the municipalities with centrality <0.30 is remarkably high, 1.39. Of these 25 municipalities, 24 had a municipal reform in 2007. This is an important result: in the Netherlands heated debates take place on municipal reforms, particular in rural areas. The Danish findings convincingly show that also in the case of rural areas considerable scaling behavior is measured.

[5] *https://en.wikipedia.org/wiki/Capital_Region_of_Denmark#Municipalities_of_Region_Hovedstaden*.



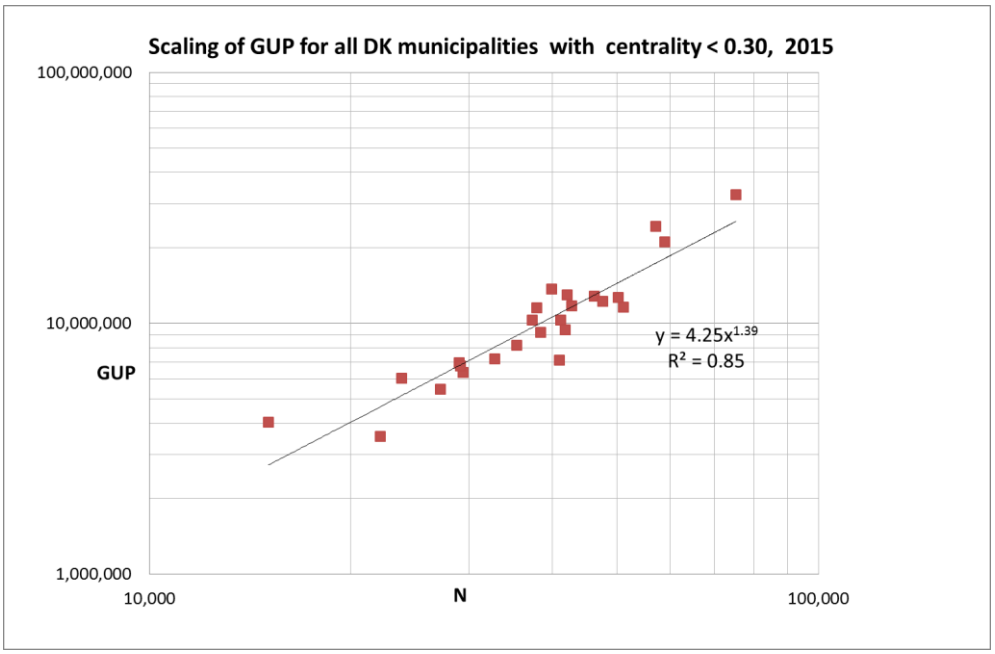


Fig. 4 Scaling GUP (in 1,000 DDK) for all Danish municipalities with centrality <0.50 (upper part) and centrality <0.30 (lower part).

Finally, we measured the scaling behavior of all Danish municipalities with centrality> 0.50 which concerns most of the larger cities. In Fig. 5 we show the results, without the Copenhagen agglomeration. We find a scaling exponent of 1.25 (n=19). If we include the Copenhagen municipalities (almost all of them have centrality>0.50) the scaling exponent is lower, 1.14. We explained the effect of in/excluding the Copenhagen municipalities in our earlier discussion of Fig. 2.

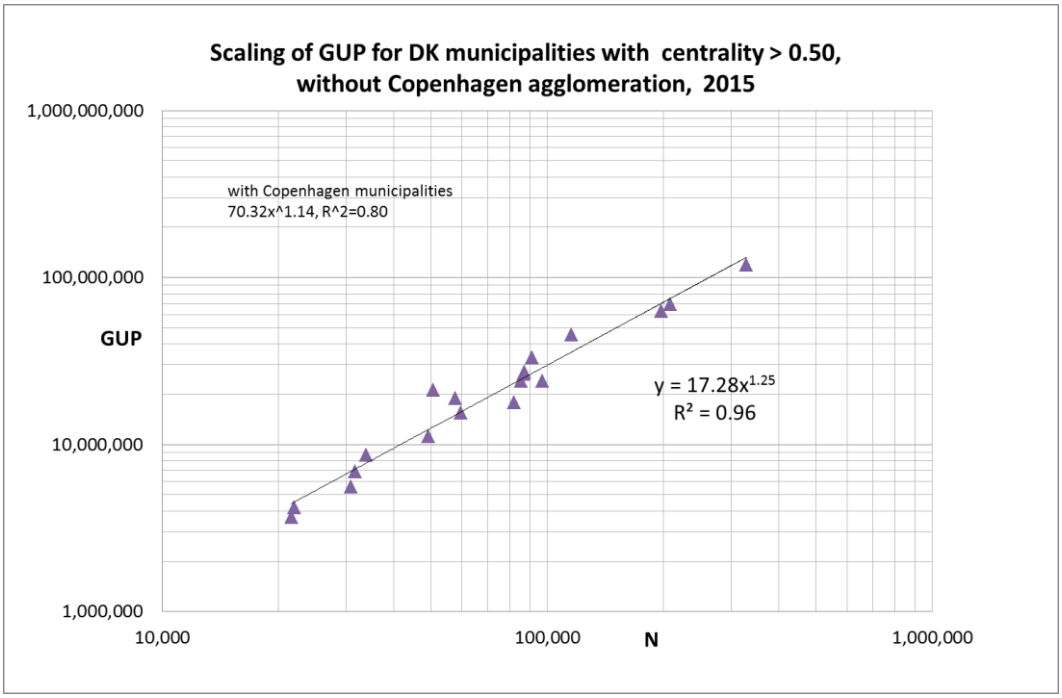


Fig. 5 Scaling of GUP (in 1,000 DDK) for Danish municipalities with centrality >0.50, we exclude the Copenhagen agglomeration.

To conclude, our above discussed results show that scaling behavior at the level of municipalities is present in all investigated contexts: rural areas, major cities, and within the large urban agglomeration of the Danish capital region. An important finding is that the municipalities with centrality smaller than 0.30 are all new and considerably enlarged municipalities due to the Municipal Reform of 2007, and they have by far the highest scaling exponent (1.39) as compared to all other sets.

Germany

Data

Our second case is Germany. We now deal with a country about fifteen times larger in population size as compared to Denmark. Germany with about 82 million inhabitants consists of sixteen federal states, the *Bundesländer*. In total, Germany currently has 106 kreisfreien Städten (together a population of about 27,000,000) and 296 Kreisen (together about 55,000,000 population). We analyzed the scaling of these kreisfreie cities and Kreisen for the different Bundesländer. We clustered the Bundesländer into five regions: Nordrhein-Westfalen (North Rhine-Westphalia) (western part of Germany); Baden-Württemberg and Bayern (Bavaria) (southern part of Germany); Hessen (Hesse), Rheinland-Pfalz (Rhineland-Palatinate), and Saarland (middle part of Germany); Bremen, Hamburg, Niedersachsen (Lower Saxony), and Schleswig-Holstein (northern part of Germany); Berlin, Brandenburg, Mecklenburg-Vorpommern, Sachsen (Saxony), Sachsen-Anhalt (Saxony-Anhalt) and Thüringen (Thuringia) (eastern part of Germany).

We collected the gross urban product, number of jobs in different business sectors and population of all cities of which the surrounding urban region belongs to the municipalities of the city, the *kreisfreie Städte* (kreisfreie cities), and of *Kreise*, i.e.,

regions around smaller cities consisting of several municipalities[6]. We focus in this report on the gross urban project (GUP). As in the Danish case, we collected for all the kreisfreie cities and Kreise the (land) surface areas[7].

Scaling Analysis

Also for Germany we find that the gross urban product scales superlinearly with population for both the kreisfreie cities as well as for the Kreisen. But we see remarkable differences between regions. In Fig. 6 the results are shown for the traditionally industrial western part of Germany, Nordrhein-Westfalen. Largest city is Cologne, with a population of about 1,100,000. The kreisfreie cities scale with 1.33, and the Kreisen with 1.07. Generally, Kreisen underperform as compared to the kreisfreie cities.

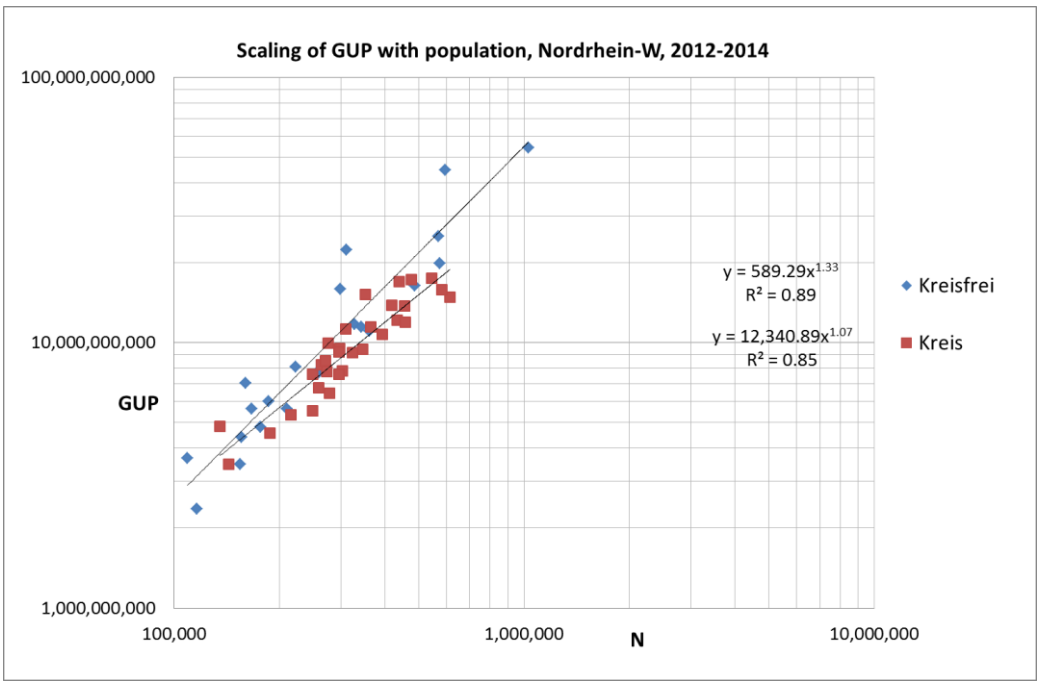


Fig. 6 Scaling of GUP (in €) for kreisfreie cities and Kreisen in Nordrhein-Westfalen.

Fig. 7 shows the results of the economically most booming southern part of Germany, the states Baden-Württemberg and Bayern (Bavaria). Largest city in this region is Munich with a population of about 1,500,000. The kreisfreie cities scale with 1.08, and the Kreisen with 1.17. We notice the difference in the scaling exponents as compared with Nordrhein-Westfalen. Again Kreise underperform as compared to the kreisfreie cities, and we will see this also for all other regions discussed hereafter.

[6] The data on Gross Domestic Product and population at the level of kreisfreien Städten and Kreisen were provided by the Statistisches Bundesamt https://www.destatis.de, data in www.vgrdl.de. Data are compiled and analyzed in file D-UrbScal.xlsx.

[7] For instance, see https://en.wikipedia.org/wiki/Frankfurt.

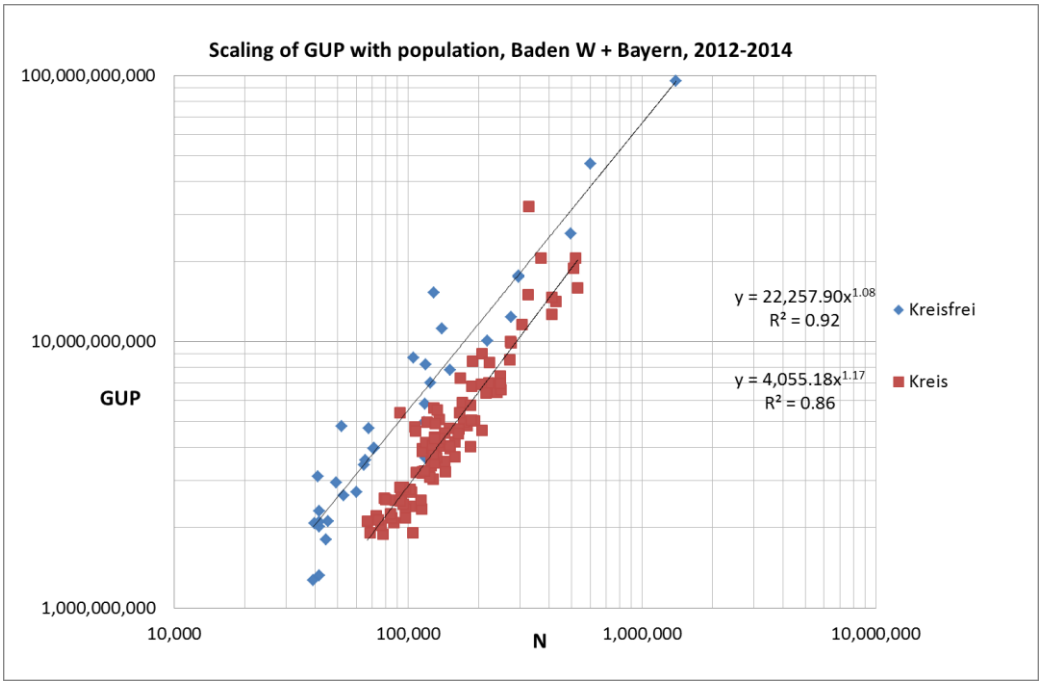


Fig. 7 Scaling of GUP (in €) for kreisfreie cities and Kreisen in Baden-Württemberg and Bayern.

In Fig. 8 the results for the middle part of Germany, the States Hessen (Hesse), Rheinland-Pfalz (Rhineland-Palatinate), and Saarland are presented. Largest city in this region is Frankfurt with about 700,000 inhabitants. The kreisfreie cities scale with 1.31, and the Kreisen with 1.28.

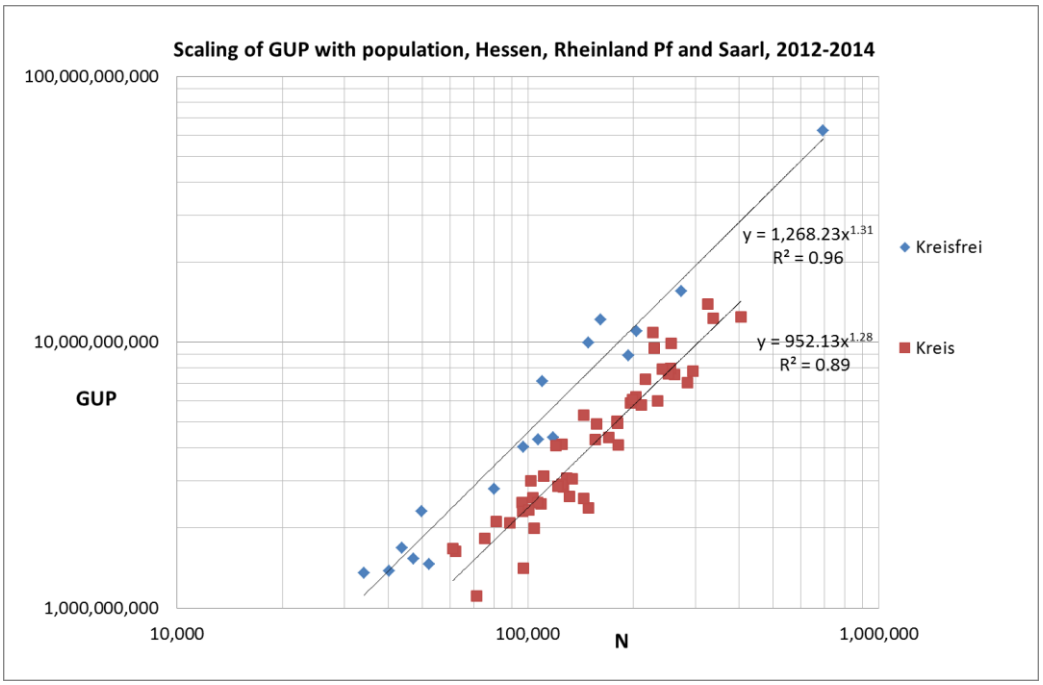


Fig. 8 Scaling of GUP (in €) for kreisfreie cities and Kreisen in Hessen, Rheinland-Pfalz and Saarland.

Fig.9 shows the results for the northern part of Germany, i.e., the states of Bremen, Hamburg, Niedersachsen (Lower Saxony), and Schleswig-Holstein. Largest city in this

region is Hamburg with about 1,800,000 inhabitants. The kreisfreie cities scale with 1.09, and the Kreisen with 1.14.

Fig. 9 Scaling of GUP (in €) for kreisfreie cities and Kreisen in Bremen, Hamburg, Niedersachsen, and Schleswig-Holstein.

In Fig.10 the results are shown for the economically most problematic eastern part of Germany, the states Berlin, Brandenburg, Mecklenburg-Vorpommern, Sachsen (Saxony), Sachsen-Anhalt (Saxony-Anhalt) and Thüringen (Thuringia). Largest city in this region is Berlin with a population of about 3,700,000. We see that in this region urban scaling is hardly significant: the kreisfreie cities scale with 1.03, and the Kreisen with 1.02. In all other regions of Germany the kreisfreie cities show scaling with exponent between 1.08 and 1.33 and for the Kreise between 1.07 and 1.28. Apparently the mechanisms behind scaling, particularly the size-based non-linear reinforcing of the socioeconomic links in networked systems, hardly work in this part of Germany with its difficult economic development. A possible explanation is the decline in population in the eastern part of Germany and particularly the move away of talented people to other regions in Germany.

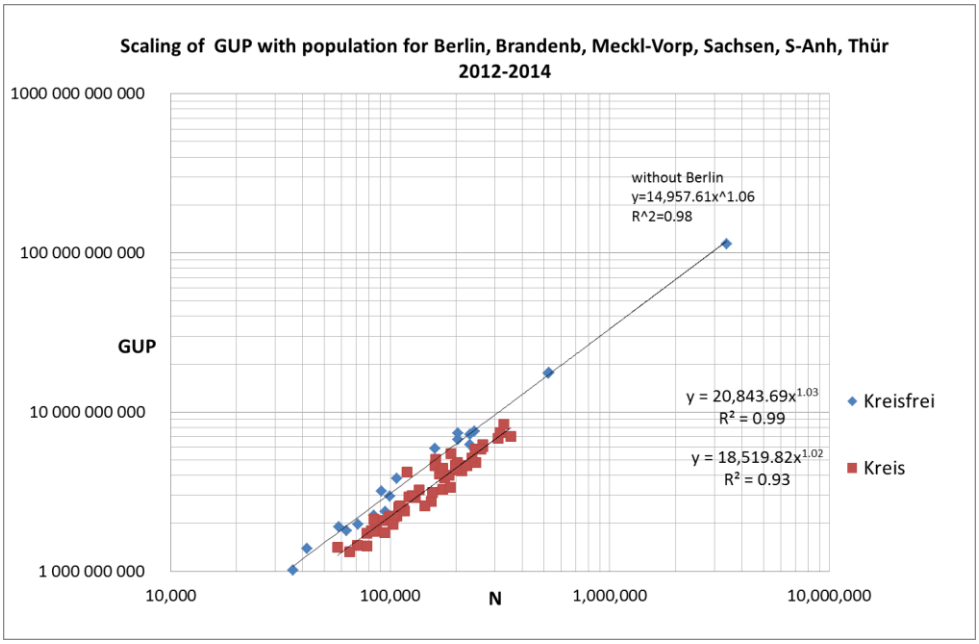


Fig. 10 Scaling of GUP (in €) for kreisfreie cities and Kreisen in Berlin, Brandenburg, Mecklenburg-Vorpommern, Sachsen, Sachsen-Anhalt, and Thüringen.

In Table 1 we present an overview of the scaling exponents for the Kreisfreie cities and Kreise in the five regions.

Region	***Krfr cities***	***Kreise***
Nordrhein-Westfalen	1.33	1.07
Baden-Württemberg	1.08	1.17
Bayern		
Hessen	1.31	1.28
Rheinland-Pfalz		
Saarland		
Bremen	1.09	1.14
Hamburg		
Niedersachsen		
Schleswig-Holstein		
Berlin	1.03	1.02
Brandenburg		
Mecklenburg-Vorpommern		
Sachsen		
Sachsen-Anhalt		
Thüringen		

Table 1 Scaling exponents for the Kreisfreie cities and Kreise in the five German regions.

To illustrate the economic East-West-South division of Germany we show in Table 2 for the five regions the gross domestic product per capita in absolute terms and relative compared to Germany as a whole.

Region	***GDP/capita in €***	***rel. GDP/capita***
Nordrhein-Westfalen	35,947	1.00
Baden-Württemberg	41,334	1.15
Bayern		
Hessen	37,515	1.04
Rheinland-Pfalz		
Saarland		
Bremen	35,768	0.99
Hamburg		
Niedersachsen		
Schleswig-Holstein		
Berlin	27,414	0.76
Brandenburg		
Mecklenburg-Vorpommern		
Sachsen		
Sachsen-Anhalt		
Thüringen		
Germany	**36,003**	**1.00**

Table 2 Gross domestic product per capita of the five regions in absolute terms and relative compared to Germany as a whole.

We clearly see the wealthy position of the southern region in contrast to the substantially less wealthy situation in the eastern region of Germany. The difference in GDP per capita is a factor 1.15/0.76 = 1.64.

In Fig. 11 we combine the results for the kreisfreie cities of all regions. Again clearly visible is the difference in wealth between, for instance, the southern part of Germany (red squares, Baden-Württemberg and Bayern) and the eastern part (blue squares, Berlin, Brandenburg, Mecklenburg-Vorpommern, Sachsen, Sachsen-Anhalt, and Thüringen). By taking the scaling results for only the southern and the eastern part of Germany this difference shows up even more strikingly, see Fig. 12.

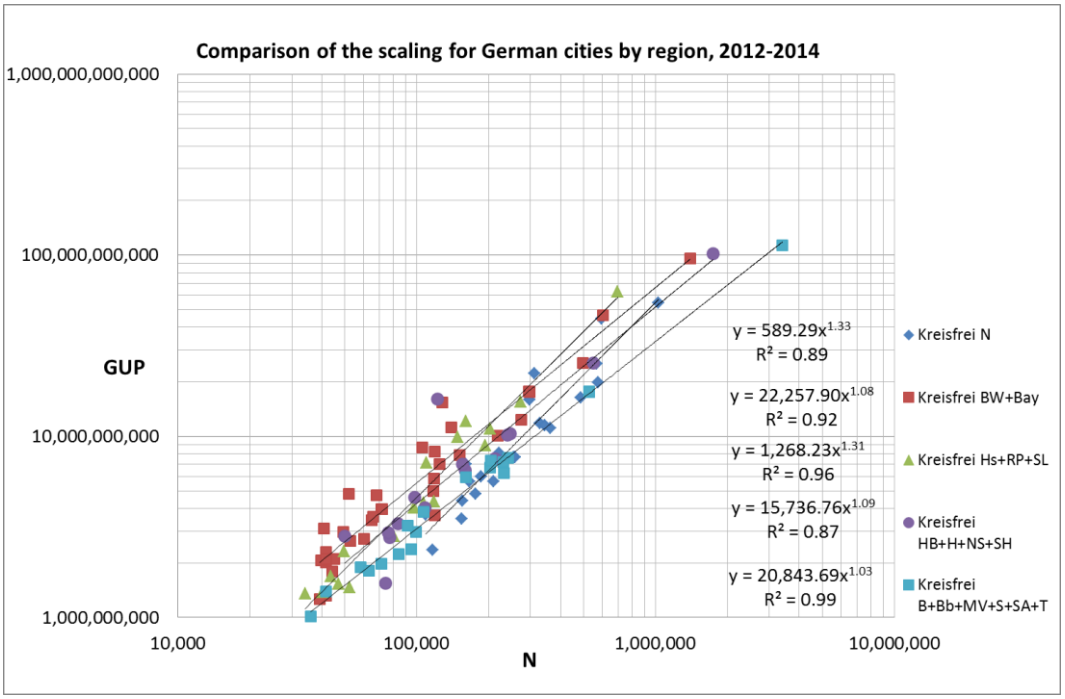


Fig. 11 Comparison of the scaling of GUP (in €) for all kreisfreie cities, grouped by region (compilation of the same data as presented in Figs. 6-10).

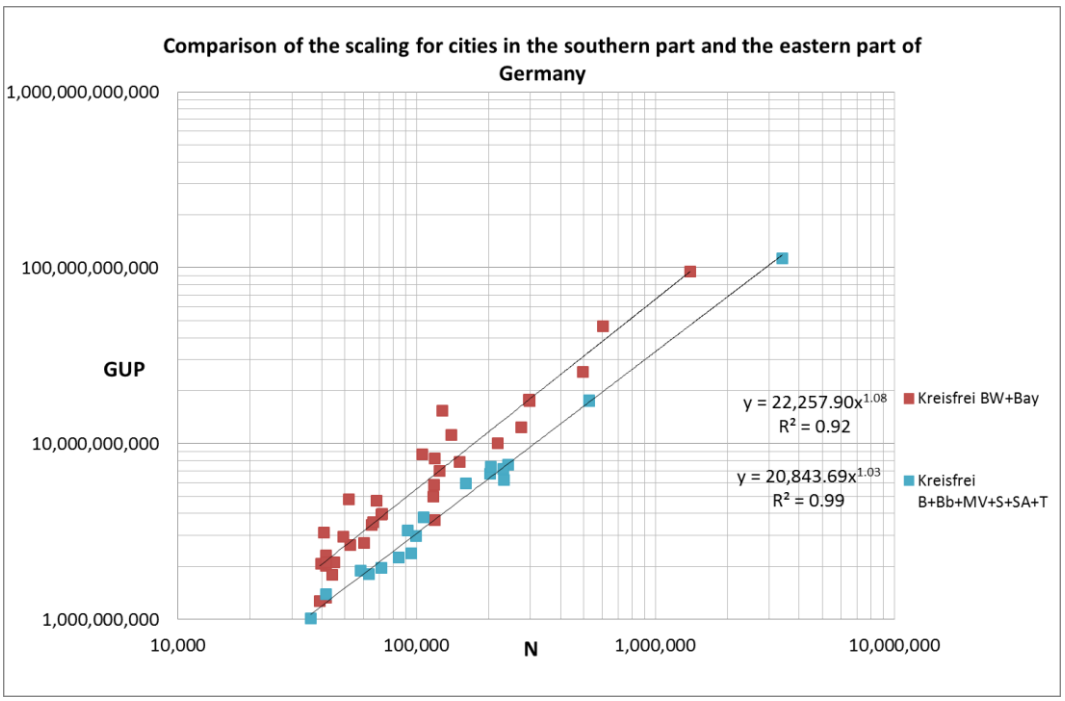


Fig. 12 Same as Fig.11, but now only the southern region in comparison with the eastern region.

Using the parameters of the measured scaling, we find a difference in average GUP of about 1.97, somewhat higher than the difference in the GDP per capita as calculated on the basis of Table 2.

The above findings clearly show a problem in the measurement of scaling in an entire country: the numerous smaller kreisfreie cities in the southern part are at a high level of

GUP, thus they will 'lift' the regression line at the lower population side thereby lowering considerably the exponent of the scaling. Fig. 13 shows this effect: if we calculate the scaling exponent for all German kreisfreie cities together, we find 1.03, this is lower than the scaling exponents of the kreisfreie cities of all German regions, and it is hardly significant.

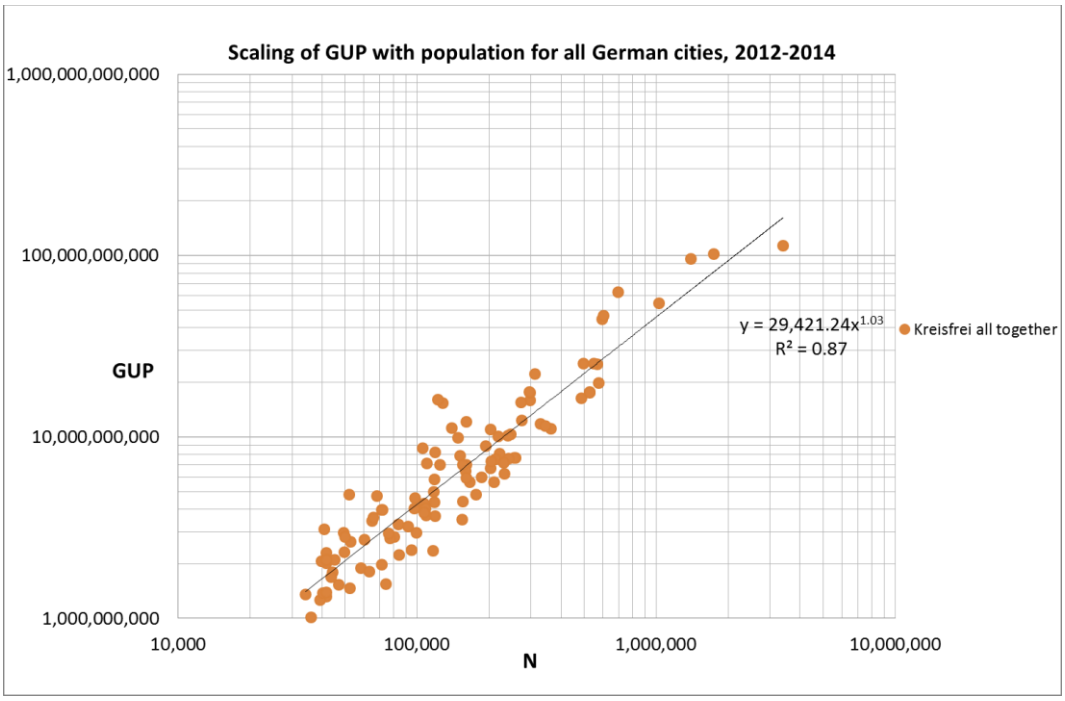
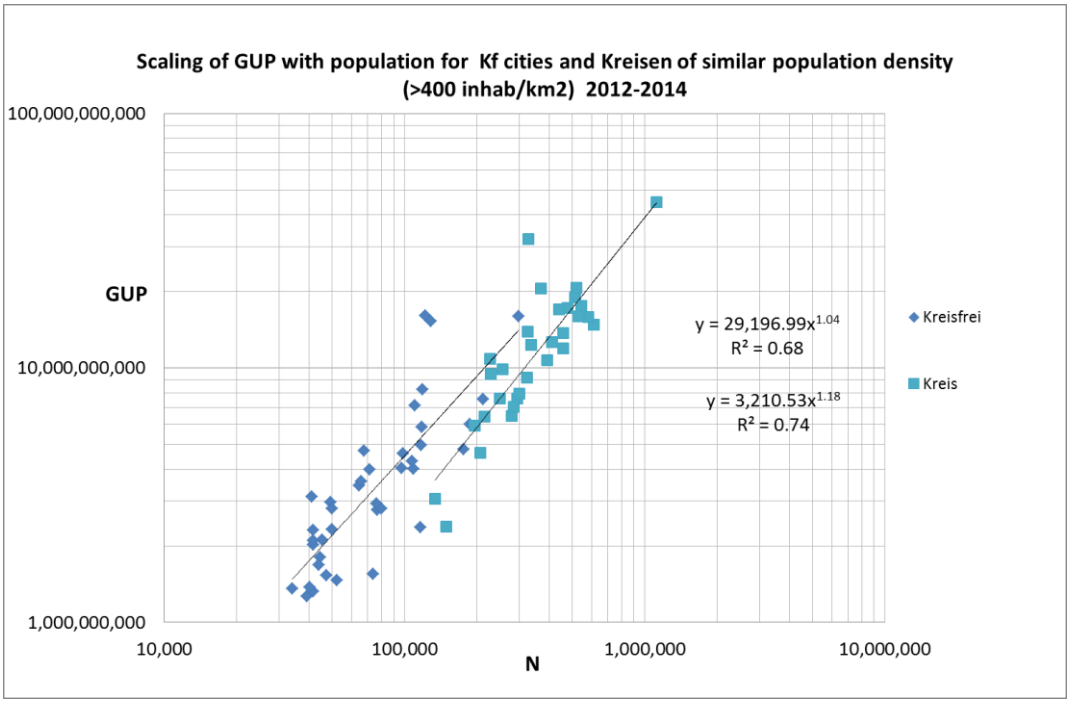


Fig. 13 Scaling of GUP (in €) with population of all kreisfreie cities together.

A crucial element in our study is the question how governance structures influence socioeconomic performance. We made the following analysis to find first indications. In a number of Kreise the administrative centers are cities that are not kreisfreie cities (because they formally belong to a Kreis) but they can be considerably larger than smaller kreisfreie cities[8]. As a consequence, there is an overlap in populations size as well as density between kreisfreie cities and Kreisen. In such cases, Kreisen are densely populated urban regions, just as the kreisfreie cities.

Thus, we created a set of kreisfreie cities and of Kreisen with similar population size and density and calculated the scaling exponents for both groups. The results are shown in Fig. 14. To test the robustness of the results we performed the calculations for density >400 inhabitants/km^2 (upper part of Fig. 14) and for density >500 inhabitants/km^2. Clearly the one-municipality urban regions (the kreisfreie cities) overperform the multi-municipality urban regions. The higher scaling exponent for the Kreise is related to the remarkable situation that the one of Germany's largest cities, Hannover, is not kreisfrei but a Kreis (Landkreis Region Hannover). The same is the case for Aachen (Kreis Städteregion Aachen).

[8] An example is Neuss (Nord Rhine-Westphalia) with about 155,000 inhabitants, but this city is not kreisfrei, it is the administrative center of the Rhein-Kreis Neuss which has a population of about 450,000. The Bavarian city Schwabach on the other hand with about 41,000 inhabitants is a kreisfreie city.



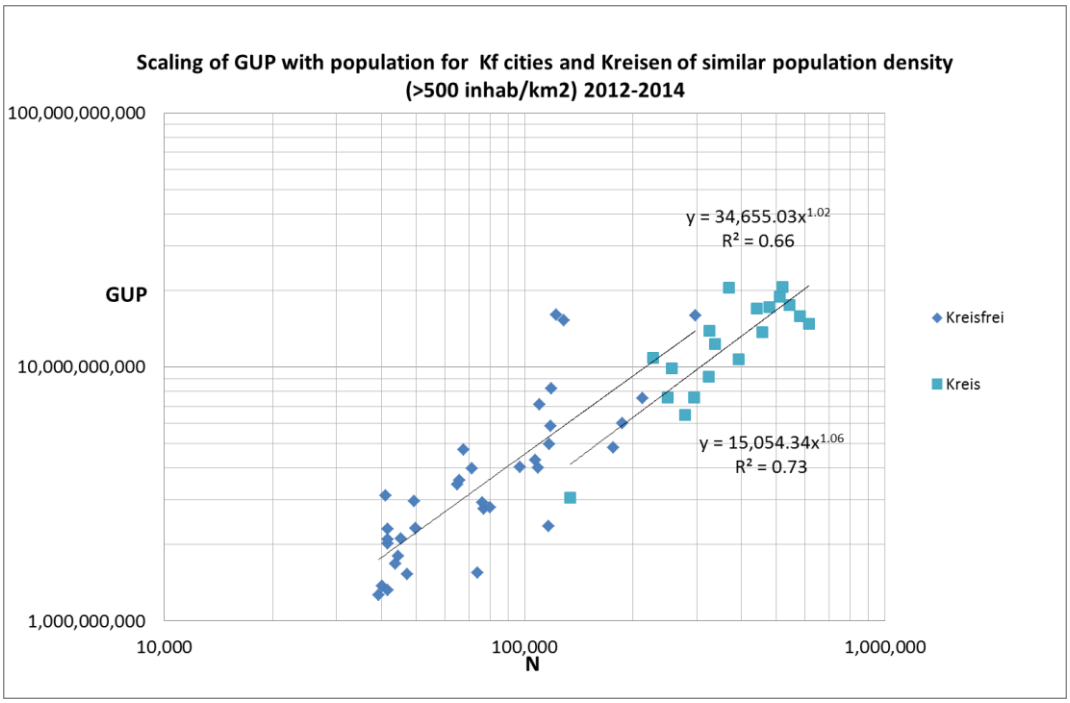


Fig. 14 Comparison of the scaling (GUP, in €) of kreisfreie cities with Kreisen of similar population density (Germany as a whole). Upper part: density >400 inhabitants/km^2; lower part density >500 inhabitants/km^2.

Residual Analysis and Comparison with Other Socio-Economic Data

We calculated for all German kreisfreie cities and Kreisen cities the residuals of the scaling equations. Residuals are a measure of the deviations of the *observed* value from the *expected* value as established by the scaling equation. Qualitatively speaking, residuals are a measure of the deviation of a city, municipality, or Kreis from the

expected value given by the regression line through all measuring points of a specific set. In the Appendix we discuss the mathematical procedure used to calculate the residuals.

Analysis of the residuals may reveal local characteristics of individual cities in terms of success or failure relative to other cities. Positive residuals indicate that a city performs better than expected. We did not find any significant relation between population density of both the kreisfreie cities as well as the Kreise and the value of the residuals.

The intriguing question now is: what about the relation between the *residuals* calculated on the strictly quantitative basis of GUP scaling with population on the one hand, and on the other hand the socio-economic position of a city as perceived by *expert review*? The German socioeconomic research agency Prognos AG[9] performed an investigation of the future perspectives of (kreisfreie) cities and regions (Kreise) in Germany on the basis of a number of indicators and published the results in the report *Zukunftatlas 2016* [18]. In total 29 indicators related to demographics, job market, competition and innovation, welfare and social life quality were used to assess strength and dynamism of cities and regions. On the basis of these assessments, a ranking of all cities and regions was created. For details we refer to the above mentioned report [18].

Fig. 15 illustrates the economic differences between the regions in Germany based on perceived opportunities for the near future, particular the division between the southern and the eastern region.

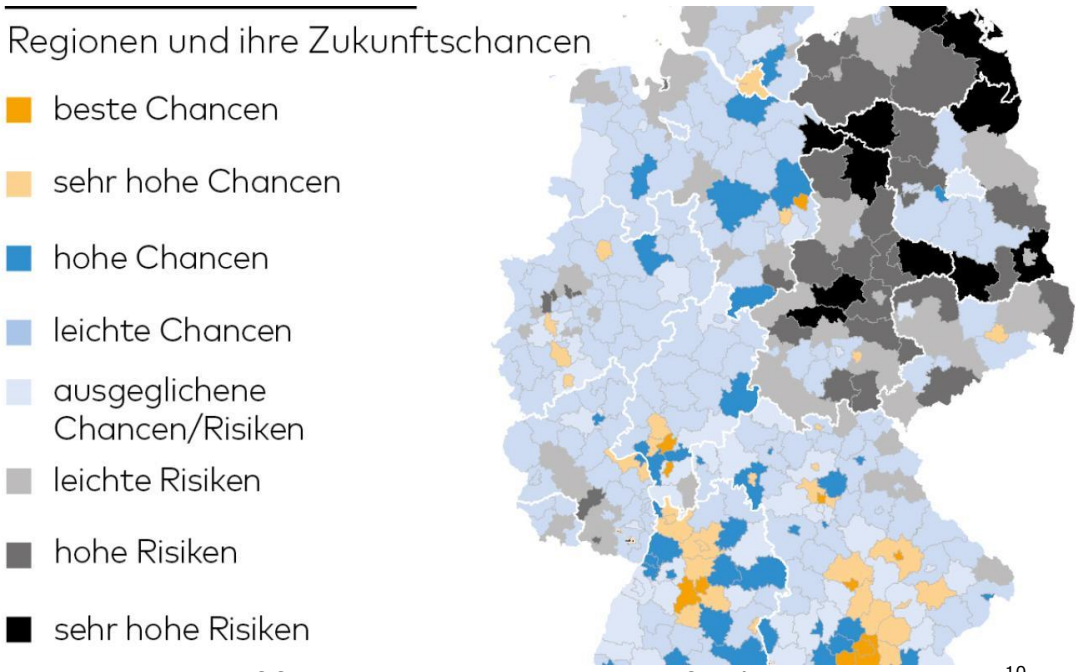


Fig. 15 Assessment of future economic opportunities for the German regions.[10]

[9] See www.prognos.com.

[10] *https://www.welt.de/wirtschaft/article155737236/Diese-zehn-Regionen-haben-die-besten-Zukunftschancen.html* and https://www.prognos.com/zukunftsatlas-map/16/.

By selecting the kreisfreie cities from the Prognos ranking, we find that of the *top-20 cities* 16 have a residual larger than 0.20, see Table 3, upper part. For the *bottom-20 cities* we find that 16 have a residual smaller than -0,20, see Table 3 lower part.

Prognos ranking	**residual**	**kreisfreie city**
1	0.38	München
2	1.01	Ingolstadt
3	1.11	Wolfsburg
4	0.65	Erlangen
5	0.53	Stuttgart
6	0.42	Darmstadt
7	0.68	Frankfurt aM
8	0.61	Regensburg
9	0.17	Heidelberg
10	0.47	Ulm
11	0.22	Hamburg
12	0.50	Düsseldorf
13	0.59	Coburg
14	*-0.31*	*Dresden*
15	0.24	Landshut
16	0.26	Würzburg
17	0.26	Bamberg
18	*-0.20*	*Jena*
19	*-0.05*	*Braunschweig*
20	0.49	Bonn

Prognos ranking	**residual**	**kreisfreie city**
87	-0.25	Remscheid
88	-0.71	Delmenhorst
89	-0.22	Lübeck
90	-0.50	Halle
91	-0.40	Suhl
92	*-0.19*	*Krefeld*
93	-0.55	Gera
94	-0.31	Hagen
95	*-0.10*	*Wilhelmshaven*
96	-0.37	Cottbus
97	-0.21	Schwerin
98	*-0.18*	*Neumünster*
99	-0.30	Duisburg
100	-0.50	Oberhausen
101	-0.21	Pirmasens
102	-0.43	Brandenburg ad H
103	-0.66	Herne

104	-0.48	Dessau-Roßlau
105	*-0.16*	*Bremerhaven*
106	-0.40	Gelsenkirchen

Table 3 Upper part: Top-20 cities; lower part: bottom-20 cities.

We see that there is a strong relation between the measured residuals in this study and the assessment of future perspectives of cities by the Prognos method.

The Netherlands

Data

The Netherlands with around 17,000,000 inhabitants is administratively divided in 12 provinces and 390 municipalities (December 2017). In this study we focus on two cases: (1) 21 major cities in the Netherlands of which the Central Bureau of Statistics (CBS) has defined agglomerations/urban areas that comprise in total 150 municipalities; and (2) the Province of South-Holland (PZH), the most populated province of the Netherlands (density 1,300 inhabitants/km^2) with nearly 3,6 million inhabitants, 60 municipalities; the major urban regions in PZH -Rotterdam, The Hague, Leiden, Dordrecht- are also included in case 1. We collected in both cases for the period 2013-2016 for all municipalities the following variables: (i) number of inhabitants (population); (2) employment (number of jobs); (3) gross urban product; (4) productivity[11]. In addition we collected for all municipalities in case 1 the land surface areas (in km^2, total surface area corrected for water surface area).

Case 1: Major cities in the Netherlands

Scaling Analysis

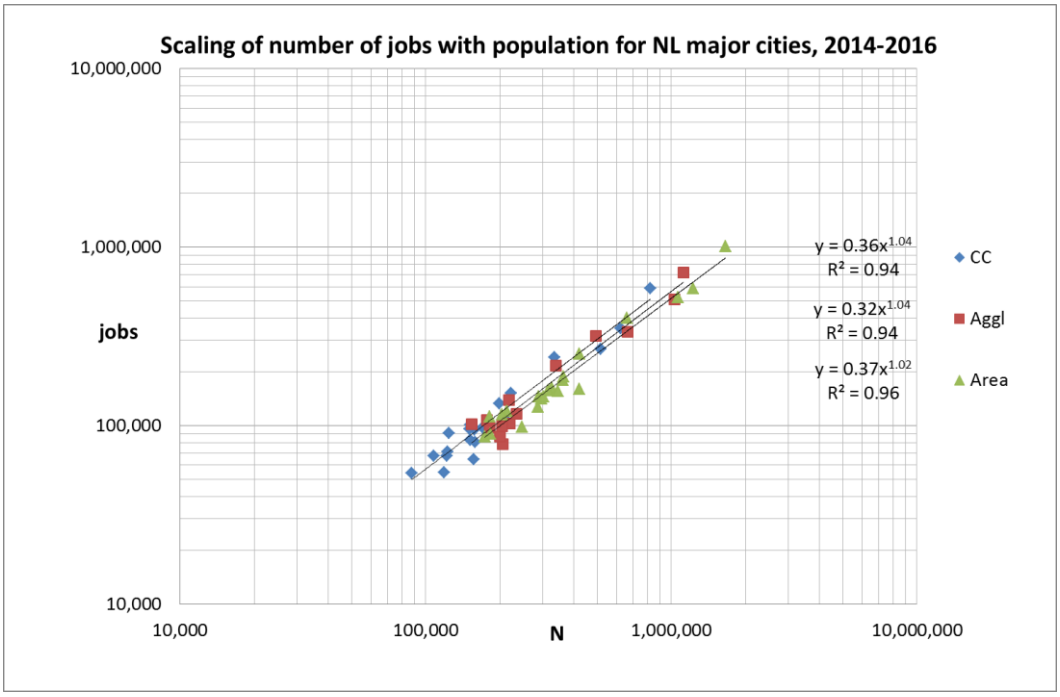
For major cities CBS defines two types of agglomerations. First, the *urban agglomeration* which is the central city and the immediately connected suburban cities that are separate municipalities. Second, the *urban area* in which in addition to the urban agglomeration all other suburban cities (again separate municipalities) that are closely socio-economically connected to the central city are included. The largest urban area, Amsterdam, counts 1.7 million inhabitants.

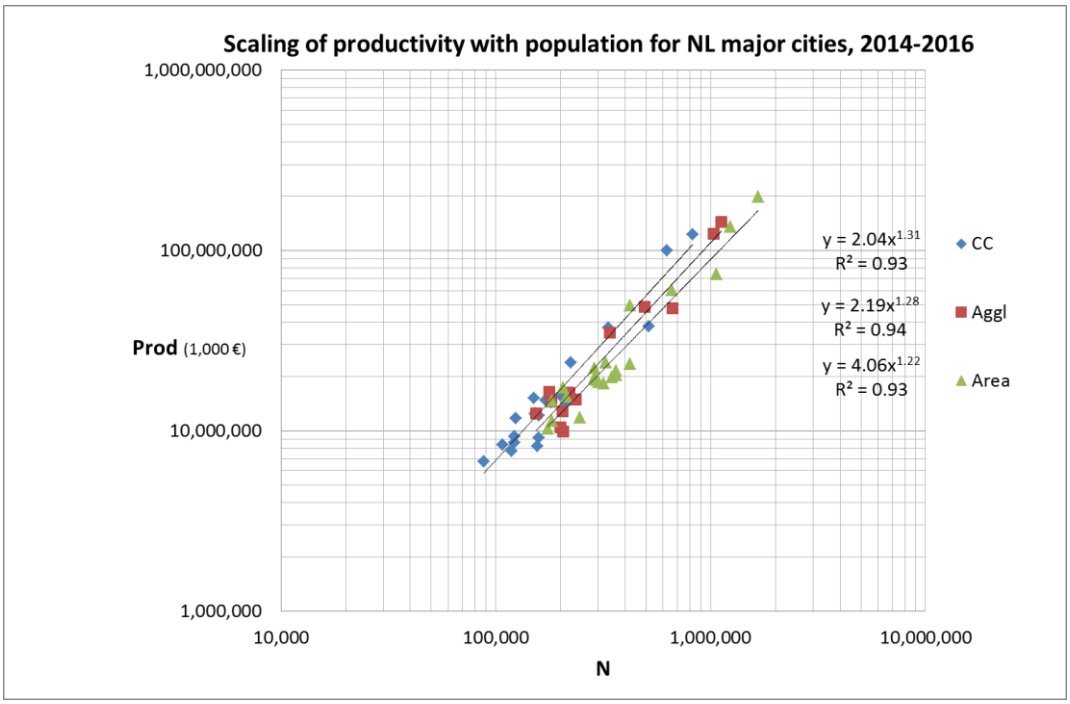
We conducted the scaling analysis for three urban modalities: (1) the major cities as a municipality (in total 21), (2) their urban agglomerations (in total the 21 central cities and 44 suburban cities), and (3) their urban areas (in total the 21 central cities, the 40 suburban cities in the agglomerations, and in addition 89 suburban cities to complete the urban areas). Moreover, for each of the 129 suburban cities the distances (in km) from their city/town center to the center of the central city are collected.

In Fig. 16 (three parts) we present the scaling of the 21 major cities as well as for their agglomerations and urban areas for the number of jobs, productivity, and GUP. Focusing on the GUP scaling we see that the major cities scale with the following exponents: (1)

[11] The GUP data are obtained from the national information system on employment LISA, www.lisa.nl, and the data on the population of municipalities from Statline, the data system of the Netherlands Central Bureau of Statistics (CBS).

1.20 for cities as a municipality; (2) 1.16 for the urban agglomerations of these cities and (3) 1.17 for the urban areas of these cities. We again refer to [14] for an extensive error discussion. On the basis of these calculations we estimate that the 95% confidence interval is within +/- 0.05 around the measured scaling exponents. We observe that all three city modalities scale with a power-law exponent between 1.15 and 1.20 with a slight decrease of the exponent from central cities as municipalities to urban agglomerations and urban areas. This observation is in good agreement with our earlier analysis [14].





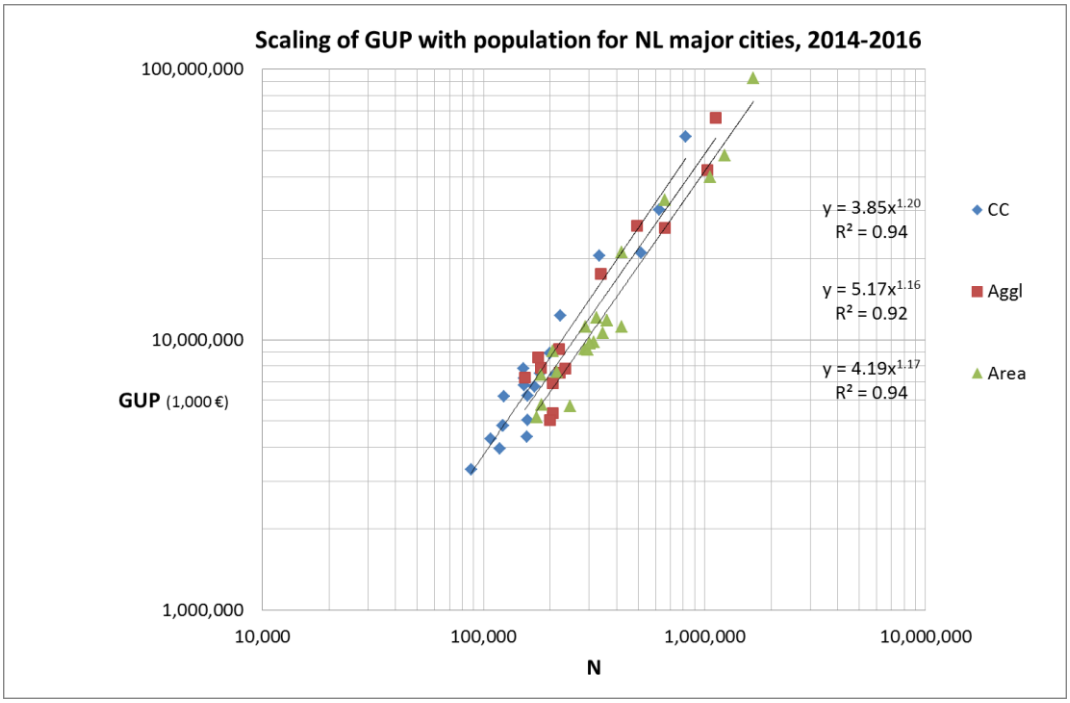


Fig. 16 Scaling of the 21 major cities with number of jobs (first part), productivity (in 1,000 Euro) (second part), and GUP (in 1,000 Euro) (third part). The central cities are indicated with blue diamonds (CC), their agglomeration with red squares (Aggl) and their urban areas with light green triangles (Area).

Also the remarkable phenomenon discussed in [14] is confirmed again: the absolute value of the gross urban product for both the urban agglomerations and the urban areas is lower than for the central cities as municipalities. Thus, although both types agglomerations scale with population, they underperform as compared to cities defined as municipalities. For instance, the expected value for CC (one-governance) is in the case of 200,000 inhabitants around 15% higher than the expected value for Aggl (multi-governance). This gives a first indication of the gains that can be made by the administrative fusion of a central city with its directly connected suburban municipalities. Even if only 10% of these expectations would be realized, we are still talking in terms of 100 million Euros per medium-sized city resulting in thousands of jobs.

In Fig. 17 we show the scaling of GUP for all the municipalities in the urban areas, in total 150, which is nearly half of all municipalities in the Netherlands. We find a remarkably high scaling exponent: 1.27. We see several outliers, i.e., municipalities with an exceptionally high residual. Let us give two examples. The one at the lower end of the population scale is Zoeterwoude, a municipality in the Leiden agglomeration, already discussed in the foregoing section. The outlier at the higher end of the population scale is Haarlemmermeer, a larger municipality in the Amsterdam urban area. Its exceptional position is very well understandable, Amsterdam International Airport Schiphol, the fourth largest airport in Europe, is located in Haarlemmermeer. A simple exercise on the statistical reliability of the scaling exponents is the removal of the outliers. If Zoeterwoude is removed from the analysis, the scaling exponent is 1.28. Removal of Haarlemmermeer gives a scaling exponent of 1.25. Both are well within the calculated 95% confidence interval of +/- 0.05.

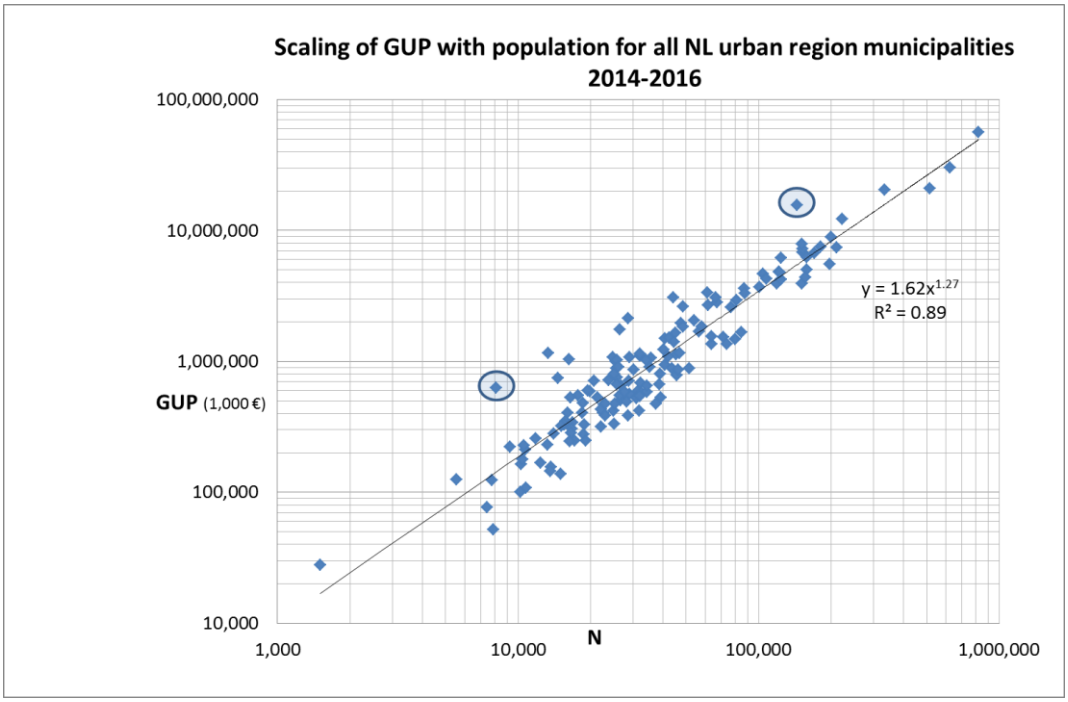


Fig. 17 Scaling of all municipalities in the urban region of the 21 major cities with GUP (in 1,000 Euro). Circles indicate examples of outliers, see discussion in main text.

Analysis and Comparison with Other Socio-Economic Data

We calculated for the major cities and the suburban municipalities their residuals of the scaling equations given in Fig. 16. Analysis of the residuals may reveal local characteristics of individual cities in terms of success or failure relative to other cities [3]. In the foregoing section we discussed examples of large (positive) residuals and explained the reason why these residuals are large. We had a similar example in Denmark, the exceptionally large residual of Billund, the small town with Legoland and a major airport.

In the Netherlands a socio-economic assessment of the 50 largest cities is published annually in the Atlas voor Gemeenten (AvG, Atlas for Municipalities)[19]. These assessments are predominantly based on qualitative indicators. Of these cities, 32 are within the urban agglomerations/areas of the 21 major cities (either as the central city, or as a major suburb). For these 32 cities we compared their residuals with the ranking position (score) in de socio-economic index of the AvG 2017[12]. These residuals (resCC) are related to the scaling of the 21 major cities, i.e., the residuals calculated with the scaling equation of the CC-regression line in Fig. 17. To avoid the influence of the individual residuals as well as individual AvG scores, we calculated average values for blocks of five cities according to the ranking of the residuals, see Table 4. For instance, in the second column 0.38 is the average residual of the top-5 cities, and 18.0 is the average AvG score. We find a correlation of R^2=0.79. This is of course a simple test but it confirms the findings in the case of Germany: a significant correlation of the measured residuals based on the GUP scaling with socio-economic indicators from other sources.

[12] Ranking data on page 232. To make comparison with the positive and negative residuals easier, we take 25-*a* where *a* is the ranking score given in the AvG.

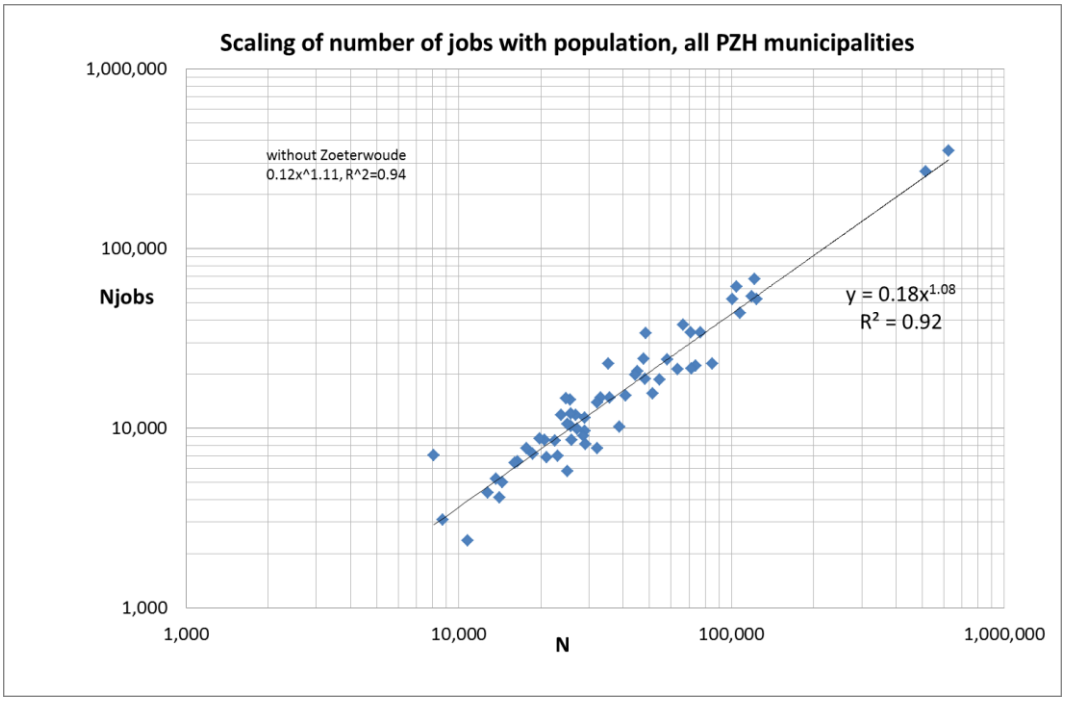
	resCC	av res	score	av score
Haarlemmermeer	0.98		24	
Utrecht	0.25		22	
's-Hertogenbosch	0.24		19	
Zwolle	0.23		17	
Eindhoven	0.22	0.38	8	18.0
Velsen	0.18		12	
Amsterdam	0.18		13	
Arnhem	0.14		-11	
Amstelveen	0.12		23	
Amersfoort	0.08	0.14	21	11.6
Leeuwarden	0.04		-3	
Groningen	0.03		2	
Heerlen	0.02		-21	
Leiden	0.01		15	
Maastricht	0.00	0.02	-9	-3.2
Hengelo	0.00		-6	
Breda	-0.02		20	
Delft	-0.03		0	
Apeldoorn	-0.05		9	
Schiedam	-0.05	-0.03	-15	1.6
Nijmegen	-0.06		-8	
Rotterdam	-0.11		-17	
Zoetermeer	-0.14		3	
Dordrecht	-0.16		-19	
Tilburg	-0.22	-0.14	7	-6.8
Den Haag	-0.25		-16	
Enschede	-0.26		-24	
Haarlem	-0.39		14	
Almere	-0.43		-12	
Vlaardingen	-0.50		-20	
Leidschend-Voorb	-0.65		4	
Purmerend	-0.67	-0.45	-1	-7.9

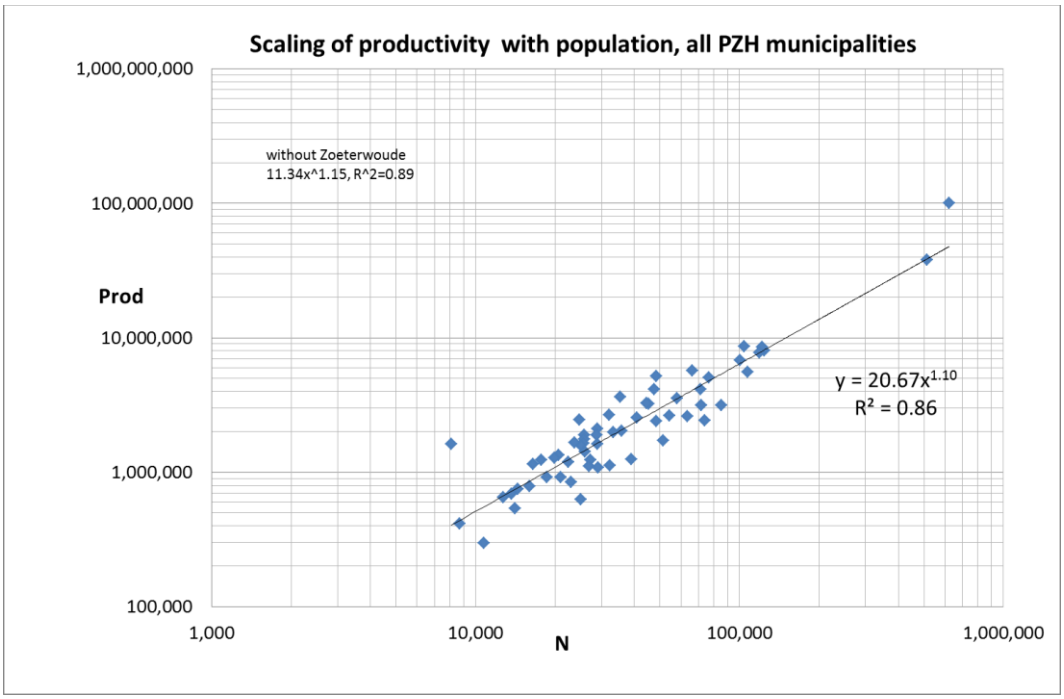
Table 4 Comparison of residuals with scores in the AvG socio-economic review.

Case 2: Province of South-Holland

Scaling Analysis

In Fig. 18 the scaling of the number of jobs (upper part), productivity (middle part) and GUP (lower part) with population for all PZH municipalities is shown. Again we see the municipality of Zoeterwoude (in the Leiden agglomeration) in which the large beer company Heineken is located as an outlier. As discussed earlier, outliers affect the measured scaling exponent, for instance for the scaling of the number of jobs 1.08 with and 1.11 without Zoeterwoude.


Scaling of number of jobs with population, all PZH municipalities
1,000,000
100,000
10,000
1,000
Njobs
without Zoeterwoude
0.12x^1.11, R^2=0.94
y = 0.18x^1.08
R² = 0.92
1,000
10,000
100,000
1,000,000
N


Scaling of productivity with population, all PZH municipalities
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
Prod
without Zoeterwoude
11.34x^1.15, R^2=0.89
y = 20.67x^1.10
R² = 0.86
1,000
10,000
100,000
1,000,000
N

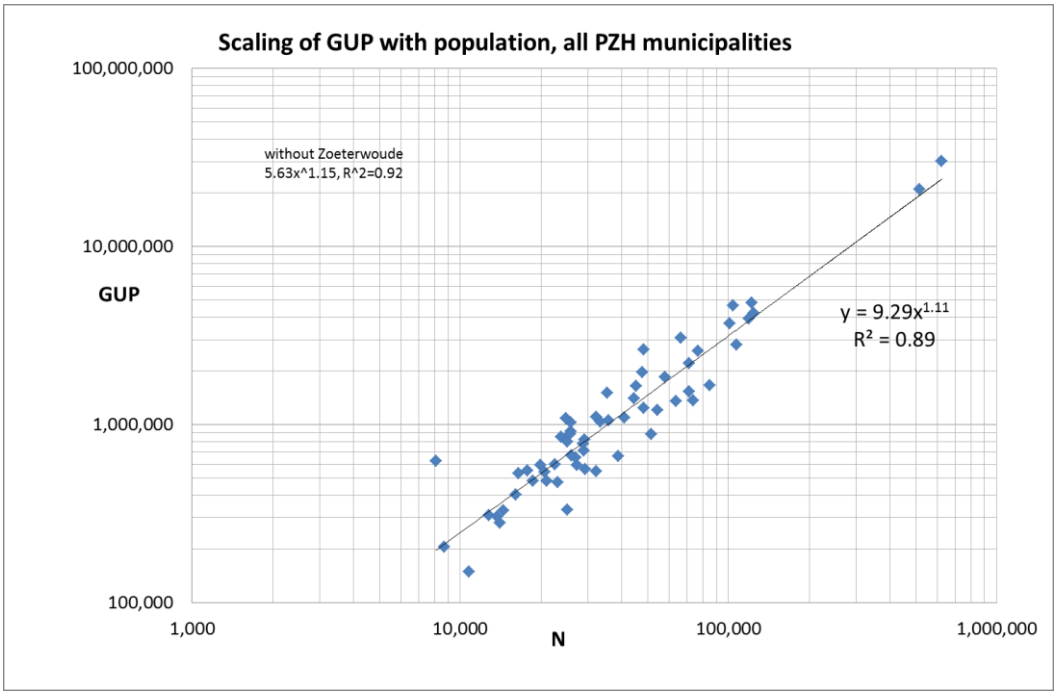


Fig. 18 Scaling of the number of jobs with population (upper part), of productivity (in 1,000 Euro) (middle part) and of GUP (in 1,000 Euro) (lower part) for all municipalities in the Province South-Holland.

Similar to the analysis of the Danish and German data, we focus on GUP. We find that (without outlier) the entire set of PZH municipalities scale with exponent 1.15, a value again within the range of scaling exponents found in this study.

Residual Analysis

On the basis of the scaling equation found for the GUP (Fig. 18, lower part) we calculated the residuals for all PZH municipalities (excluding outlier Zoeterwoude). The results are shown in Fig. 19. We see that of the major cities particularly Leiden and Rotterdam have relatively large positive residuals, whereas the residuals for Dordrecht and The Hague ('s-Gravenhage) are around zero. High positive residuals are found for Rijswijk (The Hague agglomeration) and Sliedrecht (Dordrecht agglomeration). A remarkably low residual is found for Voorschoten (Leiden agglomeration).

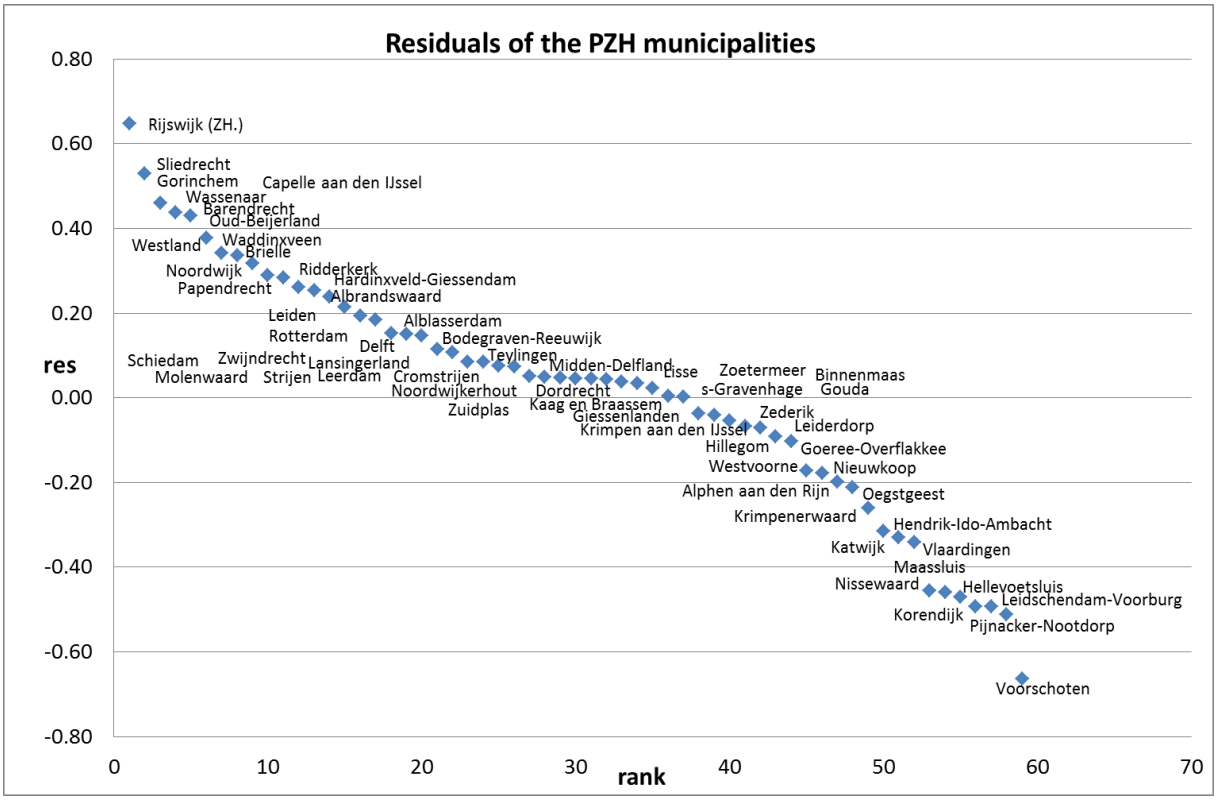


Fig. 19 Residuals of all PZH municipalities[13].

Also here we it would be interesting to compare the residuals of the PZH municipalities with conclusions in socioeconomic reports. Currently we do not have such reports available but it certainly the above mentioned comparison is necessary is follow-up work.

We now focus on the four major urban regions in PZH (Rotterdam, The Hague, Leiden, Dordrecht). An overview of the population size of these urban regions is presented in Table 5.

	CC	***U Aggl***	***U Area***
Rotterdam	623,872	1,032,380	1,230,088
Den Haag	514,596	662,605	1,061,443
Leiden	121,762	204,885	345,973
Dordrecht	118,797	220,233	287,037

Table 5 Population size (average 2014-2016) for the central cities (CC), their agglomerations (U Aggl) and their urban areas (U Areas). See Table 6 for the municipalities involved.

We use the findings of the above discussed analysis of the 21 major cities. This means that the PZH urban areas are assessed in a national context. Table 6 shows the results for the calculation of a set of residuals. The explanation is as follows. In the first column the municipalities of the urban areas are given. Directly below the central city we find the municipalities of the urban agglomeration (for instance in the case of Rotterdam these are the municipalities up to and including Krimpen aan den IJssel. The column resAll shows the residuals of the four cities and their suburban municipalities in relation to the

[13] Excluding Zoeterwoude. Calculated with the same scaling equation as the other PZH municipalities, the residual of Zoeterwoude is 1.27.

scaling of all the municipalities in the urban areas, in total 150. In the next column we find resCC, the residuals in relation to the scaling of the 21 major cities, i.e., the residuals calculated with the scaling equation of the CC-regression line in Fig. 17 (these resCC are also used in Table 4). It is a measure of *over- or underperformance of cities* (as municipalities) *in a national context*. We see that with the exception of Leiden, the other three cities Rotterdam, The Hague and Dordrecht substantially underperform in this national context. In comparison, the resCC residuals for other major cities in the Netherlands are for instance Amsterdam with 0.18, Eindhoven 0.22 and Utrecht 0.25.

Residual resUAg is calculated with the scaling equation of the Aggl-regression line in Fig. 17. It is a measure of over- or underperformance of urban agglomerations (central city and the immediately connected suburban cities that are separate municipalities), again in a national context. The results are quite remarkable. The Rotterdam agglomeration does not improve as compared to the Rotterdam resCC, which means that currently the suburban municipalities are not in a position to reinforce the Rotterdam urban agglomeration. We observe a similar situation for Leiden. The opposite is found for the Hague and Dordrecht.

In our opinion resUAgCC is the most interesting measure. If an agglomeration would be a one-governance city, the *expected position* of the city should be on the CC regression line. Thus resUAgCC indicates the difference in gross urban product between what the agglomeration would 'earn' if it was a one-governance city, and what it actually earns now, as a fragmented, multi-governance urban system. In all four cases it is clear that the multi-governance structure does not succeed in attaining the expected one-governance level of the gross urban product. Urban agglomerations that perform better in this respect are Amersfoort, Amsterdam, Arnhem, Eindhoven, Groningen, 's Hertogenbosch and Utrecht.

The above results are our main observations. Similarly resUAr and resUArCC are calculated in relation to the UAr-regression line. In order not to complicate the discussion we refer to Fig. 20 for a further explanation of the different residuals and leave the conclusions to the reader.

A remark about the population densities. The Rotterdam agglomeration has 8 municipalities, and the overall density is 2680 inhabitants/km^2. Compare this with two German harbor cities, Hamburg and Bremen, both are kreisfrei, i.e., their agglomerations consist of only one municipality. The densities for these one-governance urban regions are for Hamburg 2304 inhabitants/km^2 and for Bremen 1682 inhabitants/km^2, well below the multi-governance Rotterdam agglomeration. The densities of the multi-governance The Hague agglomeration (4 municipalities) and the multi-governance Leiden agglomeration (5 municipalities) are 3656 and 2775 inhabitants/km^2, considerably higher than the kreisfreie cities Hamburg and Bremen and even higher than the kreisfreie one-governance cities Cologne and Düsseldorf with 2542 and 2744 inhabitants/km^2, respectively. Our point is here that population densities are most probably not a main factor in the difference of GUP for the CC versus the Aggl urban modality.

	resAll	*resCC*	resUAg	resUAgCC	resUAr	resUArCC
Rotterdam	-0.17	***-0.11***				
Schiedam	0.06	***-0.05***				
Nissewaard	-0.52	***-0.62***				
Vlaardingen	-0.38	***-0.50***				
Capelle aan den IJssel	0.41	***0.28***				
Barendrecht	0.39	***0.24***				
Maassluis	-0.39	***-0.57***				
Krimpen aan den IJssel	0.01	***-0.18***	***-0.17***	***-0.38***		
Ridderkerk	0.28	***0.13***				
Hellevoetsluis	-0.43	***-0.60***				
Albrandswaard	0.31	***0.11***				
Brielle	0.44	***0.20***				
Westvoorne	0.00	***-0.25***				
Lansingerland	0.07	***-0.06***			-0.11	-0.46
Den Haag	-0.29	***-0.25***				
Leidschendam-Voorburg	-0.54	***-0.65***				
Rijswijk (ZH.)	0.66	***0.51***				
Wassenaar	0.53	***0.32***	***-0.15***	***-0.34***		
Zoetermeer	-0.07	***-0.14***				
Westland	0.25	***0.16***				
Delft	0.06	***-0.03***				
Pijnacker-Nootdorp	-0.51	***-0.65***				
Midden-Delfland	0.19	***-0.04***			-0.12	-0.47
Leiden	0.09	***0.01***				
Leiderdorp	0.02	***-0.18***				
Voorschoten	-0.57	***-0.77***				
Oegstgeest	-0.10	***-0.31***				
Zoeterwoude	1.51	***1.22***	***-0.11***	***-0.25***		
Teylingen	0.14	***-0.04***				
Noordwijk	0.38	***0.18***				
Noordwijkerhout	0.20	***-0.04***				
Katwijk	-0.35	***-0.48***			-0.14	-0.45
Dordrecht	-0.08	***-0.16***				
Zwijndrecht	0.14	***-0.02***				
Papendrecht	0.32	***0.14***				
Sliedrecht	0.63	***0.42***	***-0.10***	***-0.25***		
Hardinxveld-Giessendam	0.38	***0.15***				
Alblasserdam	0.31	***0.09***				
Hendrik-Ido-Ambacht	-0.24	***-0.43***			-0.06	-0.36

Table 6 Set of residuals for the PZH urban agglomerations and urban areas.

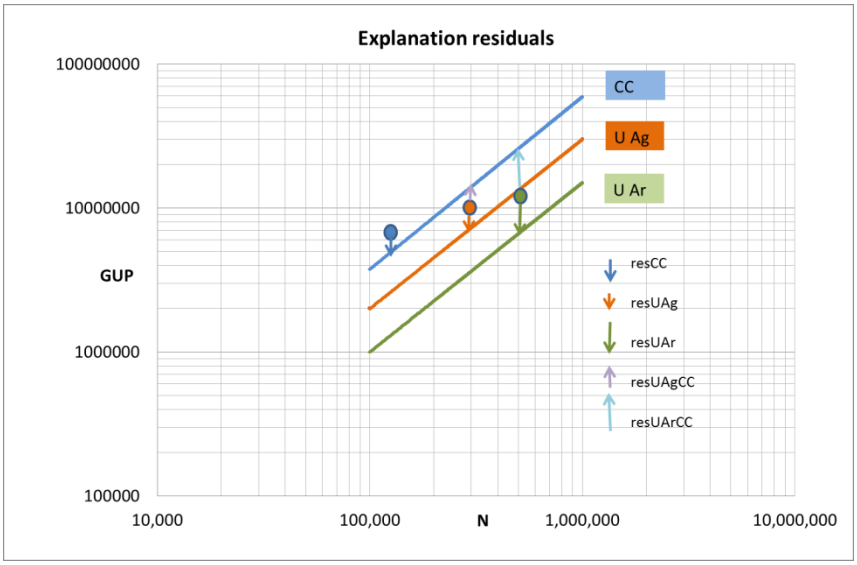


Fig. 20 Explanation of the residuals in relation to the regression lines of the 21 major cities, their agglomerations, and their urban areas.

Finally, we focused our analysis on the 10 PZH municipalities that have been reformed in the period 2000-2009 and for which the municipal reform involved an increase of at least 10% in population as compared to the largest city/town in the new municipality. We calculated the ratio of the GUP for the year 2016 and the GUP for the year 2013. We find for the 10 reformed municipalities 1.14, and for the 50 not-reformed municipalities 1.08, a difference of about 6% to the advantage of the reformed municipalities.

Conclusions and policy implications

In most earlier work on urban scaling the 'cities' are in fact larger agglomerations around central cities. It is emphasized [3] that these agglomerations are socioeconomic units and therefore the defining feature of cities, this in contrast to administrative definitions which are regarded as more arbitrary. We however consider that the governmental definition of cities within the direct urban region around a central city does matter. These definitions often have very longstanding and deep historical, political and social grounds that are frequently the basis of emotional attitudes against the central city. Emotions are related to issues such as identity, supposed threats (lower income housing, higher taxes, green locations and other facilities will disappear, etcetera), and proximity of local authorities.

In this study we have investigated the scaling behavior of all Danish municipalities, all German kreisfreie cities (major cities of which the surrounding urban region belongs to the municipality of the city) and all Kreise (regions around smaller cities consisting of several municipalities). For the Netherlands we analyzed the group of major cities including their urban agglomerations and urban areas; and all municipalities in the Province of South-Holland (PZH).

In the case of Denmark we analyzed the scaling of larger cities, municipalities within the Copenhagen agglomeration, and municipalities in rural areas. We also distinguished between municipalities with high and low centrality. We find in scaling exponents

between 1.14 and 1.23, and in the case of municipalities in rural areas a surprisingly high value of 1.39.

Also in the case of Germany we find significant superlinear scaling of the gross urban product with population size with exponents up to 1.31. Moreover, our analysis shows that urban regions with one municipality (Kreisfreie Städte) perform better than urban regions with fragmented governance structures (more than one municipality). We find a strong relation between the measured residuals of the scaling equations and the socio-economic position of a cities as perceived by expert reviews.

Again in both Dutch cases -the 21 major cities with their agglomerations and all municipalities in the Province of Zuid-Holland (PZH)- significant superlinear scaling is measured with exponents up to 1.26. Our earlier observation that one-governance urban areas perform better than multi-governance urban areas is confirmed and this is in line with the above mentioned findings for Germany.

Undoubtedly the municipalities within urban agglomerations are characterized by socioeconomic connections, and these connections can be measured very well. But this does not mean that the governance structure within these agglomerations has a strong cohesiveness resulting in an optimal social, economic and cultural coherence. Quite the contrary, the urban agglomerations and urban areas consist of independent, autonomous municipalities each having their own political and social agenda. Even a medium-sized compact urban area may consist of ten autonomous municipalities with in total about 350,000 inhabitants. Every four years there are new municipal elections which may involve a complete change of political orientation. This often results in new policy making in which previous collaboration agreements and partnerships within the agglomeration may be revised or even eliminated thereby eroding the culture of mutual confidence. As a consequence, urban agglomerations may suffer considerably for many decades from the lack of vigour and perseverance in the realization of infrastructural, cultural and economic (particularly industrial business areas) facilities.

Our observations in this study lead to challenging conclusions about the importance of a one-municipality instead of a multi-municipality governance in major urban regions. A coherent governance of major cities and their agglomerations may create more effective social interactions which reinforce economic and cultural activities generating a substantial wealth benefit. Even if not all of the differences in performance between central cities and their urban agglomerations and urban areas can be explained by incoherent governance, then still a substantial part of the expected benefits would generate a significant increase of wealth and disposable resources. For instance, if the benefit would be only 10% of the expected value, then still we are talking in terms of 100 million Euros per medium-sized city resulting in thousands of jobs.

Inter-municipal collaboration is meant to improve the relations between central cities and their suburban municipalities, but it is not known how far the improvements would go if the urban area would change to a one-governance structure. This study provides strong indications for the benefits of a one-governance structure, and these indications are in accordance with the findings of the OECD study on the role of urban governance in making cities more productive. And like the recent Dutch study on urban regions as drivers of economic growth [20] our work underlines the importance of governance in urban areas.

Given that major cities are important drivers of a country's socio-economic development, the lack of coherent urban governance may severely hamper developments in national wealth. US researchers concluded in a recent paper: " ……The Netherlands could become even richer simply by growing their cities further" [12, p. 10].

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Appendix

Calculation of the residuals

We calculated the residuals of the power-law scaling of the gross urban product with population for the analysis of the real performance as compared to the expected value. The mathematical procedure is as follows.

A power-law relation between for instance the gross urban product (G) and population (P) can be written as:

$$G(P) = aP^{\beta} \tag{A1}$$

We find empirically (as an example see Fig 1, upper part) the value 66.19 for the coefficient a and 1.14 for the power-law exponent β.

Denoting the observed value of the gross urban product for each specific city with G_i, we calculate the residuals ξ_i of the scaling distribution of each city as follows [3, 14]:

$$\xi_i \;\; = \; ln[G_i \,/G(P)] = ln\left[G_i \,/aP^{\beta}\right] \tag{A2}$$

The residuals are also used to test the heteroscedasticity of the data, we refer to our earlier paper [14].