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Regional hot spots of exceptional longevity in Germany

Sebastian Klüsener and Rembrandt D. Scholz*

Abstract

In investigating processes of demographic change such as the longevity revolution, vanguard populations are of specific interest, as studying them is likely to improve our understanding of the underlying mechanisms driving the change. This paper explores the spatial variation in the occurrence of exceptional longevity in Germany using a large individual-level dataset covering all persons who reached ages of 105 and above in Germany in the period 1991 to 2002 (N: 1,339). The first part of our analysis reveals that many of these individuals died very close to their birth place. This finding of a localised lifetime net migration pattern supports the view that an analysis of regional variation in exceptional longevity can produce meaningful results, as a large share of the individuals were living in the same spatial context, at least early and late in life. In our analysis of regional variation in exceptional longevity, we could detect consistent hot spots in Berlin and north-western Germany. These findings are all the more notable as the areas of highest life expectancy at birth are currently located in the south of Germany.

1 Introduction

In recent decades, the numbers of people reaching ages of 100 and above have increased dramatically. In their contributions to the debate on exceptional longevity, several scholars have noted the existence of ‘hot spots’ or ‘blue zones’ of longevity (Poulain et al. 2004), which are geographical areas with a high concentration of individuals who have survived to very high ages. These hot spots include, for example, Sardinia, especially for men (Pes et al. 2013), Okinawa (Cockerham and Yamori 2001; Willcox et al. 2008) and the Nicoya peninsula in Costa Rica (Rosero-Bixby et al., this volume). The existence of such *longevity hot spots* has been linked to social conditions, such as variation in diets, as well as to genetic differences. However, the evidence cited in these studies is usually based on a small number of cases.

* Sebastian Klüsener (correspondence author), Max Planck Institute for Demographic Research, Germany. Email: kluesener@demogr.mpg.de

Rembrandt D. Scholz, Max Planck Institute for Demographic Research, Germany.

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Moreover, some scholars have pointed out that, for a number of these supposed hot spots, the evidence might indeed be an artefact attributable to issues that arose in the validation of the data (e.g. Poulain 2011 on Okinawa). There are also more fundamental arguments against such research, especially when contextual conditions are seen as important influencing factors, because researchers often do not have information on the migration histories of the observed individuals with exceptional longevity. Thus, they do not know in which varying spatial contexts these individuals lived in different periods of their lives.

Germany is an interesting case for research on hot spots of exceptional longevity, as it has a long history of considerable regional variation in longevity patterns (Scholz and Gehrmann 2010). These differences are attributable in part to the relatively recent unification of the country in the late 19th century, as well as to the division of the country into two states during the second half of the 20th century. Moreover, Germany is positioned in the centre of the European continent, at the crossroads between eastern and western Europe, which was also of relevance for the longevity revolution (Klüsener et al. 2013). For our study we use a large dataset of exceptional longevity created as part of an age validation study, which covers all individuals in Germany who reached ages of 105 and above between 1991 and 2002 (N: 1,339). We will refer to them as 'semi-supercentenarians', even though our sample also includes a small number of 'supercentenarians' of ages 110+ (Cournil et al. 2010). We address two main research questions. The first one looks at what kind of lifetime net migration pattern, measured as the distance between an individual's place of birth and the place of death, can be observed. A very localised pattern would suggest that substantial portions of the population lived—at least in their final years—in the same geographic area they were born in. This would provide support for the application of spatial analysis techniques in investigating regional variation in exceptional longevity. The second research question is related to whether we can detect a consistent spatial variation pattern in the chances of achieving exceptional longevity in Germany.

2 Background and theoretical considerations

2.1 General considerations

Exceptional human longevity has long been of interest to the general public, as well as to scientists. An early study using validated individual-level data on exceptional longevity in Germany was carried out by Geissler (1884). He analysed data from the 1880 census of Saxony, which also included occupational information that allowed him to take into account the socio-economic status of the long-lived people being studied. After validating all of the cases of exceptional longevity recorded in the census, he determined that, at that time, no individual older than 99 years of age was living in Saxony—which was, in the late 19th century, one of the most developed regions in Europe. From today's point of view, Geissler's definition of exceptional longevity set the bar very low, as it included everybody aged 80 and above.

Existing research results on the longevity revolution suggest that contextual conditions are very important for our understanding of the improvements in life expectancy in recent decades and centuries, while genetic change explanations play only a minor role (Burger et al. 2012). These contextual factors include improvements in sanitation and access to health care and nutrition (see e.g. Schofield et al. 1991). Regional hot spots of exceptional longevity are not, however, necessarily attributable to favourable contextual conditions only, as they can also result from specific compositional characteristics of regional populations.

The context-related explanations for longevity hot spots include geographical differences in climate (Robine et al. 2012), diet (Willcox et al. 2006) and occupational activities (Pes et al. 2013). Disparities in access to health and emergency care, which is usually better in (big) cities (see e.g. Watt et al. 1994), might also contribute to the variation in the opportunities to achieve exceptional longevity. In addition, there is evidence that contextual conditions in early life have an impact on the chances of living to a very old age. For Germany, Doblhammer et al. (2005) have shown that children born in the winter are more likely to have very long lives. If temporal variation in early-life conditions has an effect, then spatial variation in such conditions might also have repercussions for spatial survival patterns at later ages. With regard to compositional characteristics, research results have demonstrated that across western Europe, there is a positive association today between socio-economic status/educational attainment and mortality risks (see e.g. Huisman et al. 2013). This may be attributable to a better access to assets. Thus, regions with a high concentration of such individuals (e.g. big metropolitan areas) might be more likely to emerge as longevity hotspots.[1]

Spatial variation in genetic characteristics can also play a role. While genetic shifts probably had little impact on changes in average life expectancy over the past few centuries, it cannot be ruled out that genetic variation is relevant for spatial patterns in exceptional longevity. In this context it is important to note that achieving exceptional longevity is, by definition, a highly selective event.[2] In order to reach such a high age, a person might need to have a specific level of genetic robustness that is not shared by the majority of the population (see e.g. Hjelmborg et al. 2006; Sebastiani et al. 2012). If this genetic robustness is inheritable, it might contribute to the emergence of areas in which many people share certain characteristics, assuming the people in those areas tend to settle and find a partner close to the place where they are born. Research on homogamy suggests that at least in the past, this was the

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[1] However, this might be a more recent phenomenon, as historical research suggests that the positive association throughout western Europe is not necessarily long-standing, as some areas did experience a divergence in mortality levels along a socio-economic status gradient as recently as after World War II (Bengtsson and van Poppel 2011).

[2] Though the definition of what ages represent exceptional longevity can vary over time.

case to a large degree (Ekamper et al. 2011). Thus, it is not surprising that across Europe, genetic similarity decreases with distance (Lao et al. 2008). In Germany, an important genetic border line seems to exist between southern and northern Germany, which approximately follows the Main River (Barbujani and Sokal 1990).

In our study we use information on birth weight and length as proxies for genetic variation because we find considerable overlap between spatial variation in the pattern of exceptional longevity and these characteristics. Birth weight and length are influenced by both socio-economic conditions (Koupilová et al. 1998; Koupilová et al. 2000) and genetic characteristics (Clausson et al. 2000). Based on a twin study, Clausson et al. (2000) determined that between 25% and 50% of birth weight variation can be related to genetics.

Unfortunately, our dataset of semi-supercentenarians does not include genetic information or data on socio-economic characteristics. Therefore, we mostly focus on the spatial variation pattern of exceptional longevity at the aggregate regional level, linking it to historical and contemporary contextual characteristics in the different regions, as well as to compositional characteristics of the regional populations.

With regard to the impact of contextual conditions, it is important to point out that these can vary across time and space (for general considerations, see e.g. Caselli et al. 1987). While, for example, some cohorts might have been born in time periods characterised by considerable spatial variation in infant survival chances, other cohorts might have been born in periods in which these differences had already diminished. Thus, the resulting spatial exceptional-longevity pattern of specific cohorts might reflect to some degree the exposure of these cohorts to spatially varying contextual conditions in different periods of their lives. In addition, the exposure to temporarily elevated mortality risks due to wars, severe economic crises and large epidemics might also differ by cohort. This is very relevant for our study, which is in essence a study of the cohorts born in Germany in the late 1880s and 1890s. In the following section we will provide some background information on the conditions and developments which may have affected spatial variation in the chances to reach ages of exceptional longevity among these cohorts.

2.2 Spatial variation in livelihoods for cohorts born in the 1880s and 1890s in Germany

The cohorts analysed in our study were born in the 1880s and 1890s, with the survivors up to age 105 dying in the 1990s and early 2000s. It this period, Germany underwent a transition from being a western European laggard in the industrialisation process, to being one of the most developed countries in the world. It was also at the centre of two disastrous wars, which led to the division of the country into a capitalist West Germany and a communist East Germany during the period 1945–1990. This division was indeed very relevant for spatial variation in mortality outcomes (Luy 2004; Kibele and Scholz 2009), but it was not the only factor that contributed to the substantial spatial variation in contextual conditions.

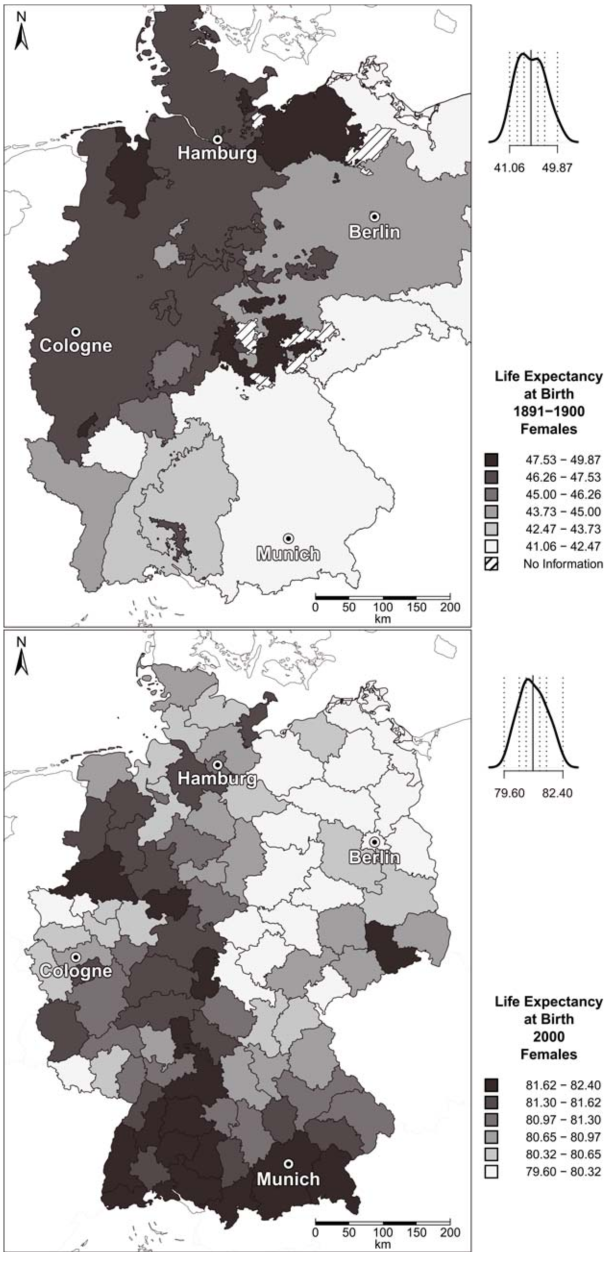
The late 19th century was a period of rapid urbanisation and industrialisation in the German Empire. The country was unified in 1871, but the legacy of having been split up into dozens of independent states for most of its history was still apparent in the spatial variation in economic development levels, agricultural structures and demographic characteristics across the German Empire (see e.g. Weber 1894; Klüsener and Goldstein 2012). In the 19th century, the livelihood opportunities available to the population were particularly limited in southern Germany (Knodel 1967). This was partly the result of the landlocked position of this area of the country, while northern and central Germany had better access to the rapidly developing global markets.

The legacy of long-standing historical political and economic divisions also had effects on spatial variation in early-life conditions. In contrast to most other European countries, the German Empire exhibited a very high degree of regional variation in infant mortality rates. These ranged from around 100 infant deaths per 1,000 live births, or levels typical of Scandinavia, to around 350 infant deaths per 1,000 live births, which was more typical of eastern Europe (Kintner 1988, Klüsener et al. 2013). Areas with high infant mortality rates included southern Germany, particularly Bavaria, and today's eastern Germany; while the lowest rates were registered in north-western Germany. This is also visible in Figure 1, which shows for the period of birth regional variation in life expectancy at age zero. At that time, this indicator was still very much influenced by infant mortality levels. The important determinants of the pattern were regional differences in the prevalence of breastfeeding and nonmarital births, while urban populations still had a survival disadvantage relative to rural populations (Kintner 1988). The regional mortality differences between western, southern and eastern Germany did not start to converge to any significant extent until the two decades that followed World War I (German Imperial Statistical Office).

When looking at the effects of war on these cohorts, it is relevant to note that the cohorts in our study were of prime draft age during World War I (1914–1918). In addition, their age group was also liable to be involved in combat activities in the last few months of World War II as part of the *Volkssturm* (national militia). This makes it likely that the male members of these cohorts would have been killed or disabled in war. Thus, we would expect the gender differences in achieving exceptional longevity to be particularly pronounced in these cohorts. However, these wars should not affect the spatial pattern, as Germany drafted soldiers from all parts of the country. Apart from the Battle of Berlin (1945), no fierce battles were fought on the territory of present-day Germany in these two wars. However, the civilian populations were affected by the war activities in numerous ways. It was in particular the populations of the big metropolitan areas that suffered from food shortages and from bomb raids in World War II. In addition, the Holocaust, in which significant shares of the German elite were killed or forced to leave the country, mostly affected urban populations.

After 1945, Germany was divided in two countries, which initially registered very similar trends in longevity. Substantial disparities did not emerge until the cardiovascular revolution (Meslé and Vallin 2002) started in western Germany in the 1970s (Luy 2004). In addition to this east-west gradient, the differences between

Figure 1:
Female life expectancy at birth 1891–1900 vs. 2000



Source: German Imperial Statistical Office; INKAR Database; authors' own calculations.
Note: Base Map: MPIDR Population History GIS Collection (partly based on BKG 2009)

northern and southern Germany started to shift as well. In the 1950s and 1960s, a number of key industries in northern and western Germany (ship-building, mining and steel industries) went into deep structural crisis, while the southern part of the country, with its focus on machine building and knowledge-intensive industries and services, took the lead economically (see also Sinz 1988). Thus, at the point at which our long-lived individuals died, the most developed part of the country was southern Germany, which had been the least developed region at the time of their birth. These changes also affected mortality levels, as the areas with the highest life expectancy at birth are today located in southern Germany (see Figure 1)

With regard to urban–rural differences, the mortality variation, at least in West Germany, was still not clear-cut in the 1960s, as the highest levels of life expectancy were reported not in the most urbanised areas, but in those rural areas in which a large share of the population were not working in agriculture (Birg 1982). In recent decades, urban populations might have benefited from better access to emergency care. There is also some evidence that access to new health technologies tends to be available first in large towns (Kirchberger 1994: 187), and possibly in university cities. In addition to compositional characteristics, these factors might have contributed to the mortality advantage that urban populations now have over rural populations, which had not existed in the late 19th century, when urban populations were suffering from a number of problems, particularly related to sanitation.

To sum up, Germany experienced substantial changes in the 20th century, in terms of both variation in development by region and urban–rural differences related to mortality conditions. In the following analysis, we will investigate to what degree this spatial and temporal variation is also reflected in regional disparities in achieving exceptional longevity among the cohorts covered in our study.

3 Data and methods

3.1 Sample population of semi-supercentenarians

For our research project, we used a dataset of individuals who reached ages of 105[3] and above in the period 1989–2002 while living in Germany. The dataset was created as part of the International Database on Longevity (IDL). For details on the validation process and general descriptive statistics see Maier and Scholz (2010). After finishing the age validation process, we produced different anonymised datasets for specific

[3] The decision to focus on the population aged 105+ is in part influenced by data constraints, as the available dataset only covers these age groups. With regard to using thresholds above age 105, we were faced with the challenge that even at age 105, we end up with a very small number of observations in some regions. Moving the threshold further up would mean that either the regional pattern is severely distorted by noise, or that we need to decrease the regional detail even further. Therefore, we decided to use the whole age range covered by the dataset.

purposes. One of these datasets is the file used for this study which allows us to investigate the regional variation patterns based on information at municipality level on the place of birth and the place of death (Scholz 2003). For our analysis, we excluded from the dataset all individuals who died before 31 December 1990. This was necessary because until the reunification of Germany, only citizens living in West Germany were included in the dataset, which would have created a bias in the analysis of spatial patterns. This left us with 1,339 persons aged 105 or above who lived during the period of observation in Germany. There are clear differences by sex, as 1,184 of the individuals were female (88.4%). This very large gender gap might to some degree be attributable to the fact that these cohorts were heavily affected by war activities. Of the 1,339 persons, 961 were born within the borders of present-day Germany (71.6%), while another 276 were born in territories that were part of the German Empire at the time of their birth (20.6%). Less than 8% (102) were born outside of the German Empire, most of them in eastern Europe. The latter two groups have to be treated with caution, as their dates of birth have not been validated by an office of vital records at the place of birth. They are excluded from our analyses of exceptional longevity by place of birth, but we do consider them in the analyses by place of death.[4]

Unfortunately, the nature of our dataset implies that we do not have any information on individuals who were born in Germany but reached the age of 105 abroad. However, we benefit from the fact that levels of outmigration from Germany have been relatively low over the last 120 years (Bade 1995). The last major wave of outmigration in the 19th century ended in the early 1890s, around the time when the semi-supercentenarians in our dataset were born (German Imperial Statistical Office). Outmigration would be of concern for our analysis if it were concentrated in certain regions of Germany. One notable exception might be the outmigration of Germans with Jewish denomination in the 1930s, as large parts of this population lived in urban areas.

3.2 Linking individuals to spatial contexts and defining populations at risk

Information on the location of the place of birth and place of death[5] was derived at the municipality level from the VG 250 GIS-file of the Federal Agency of Cartography and Geodesy (BKG 2007). For municipalities of birth that were later dissolved or incorporated into other municipalities, we used the code of the municipality to which the area of the municipality of birth belongs today. From the GIS file, we derived

[4] We included them in the analysis by the place of death because we were not able to separate out war refugees from former German territories and naturalised foreigners from the population at risk.

[5] The place of birth refers to the place of residence of the individual's mother at the time of birth, while the place of death refers to the individual's place of residence at time of death. For those semi-supercentenarians who were still alive in 2002, we used the place of residence at that time.

for each municipality the north and the east value of the areal centroid.[6] In addition, we used shapefiles of the MPIDR Population History GIS Collection.[7] From this collection we made use of district-level maps of 2000 and 2004 and a district-level map of the German Empire for the year 1894 (see Klüsener et al. 2014 for details).

In order to analyse spatial variation in exceptional longevity, we had to define a population at risk. When looking at the place of death, we did not consider it adequate to use the total population in an area as the population at risk, as this would have created biases based on whether a region had experienced substantial immigration or outmigration in recent decades.[8] We therefore decided to use only the elderly age groups to define the population at risk, as they are less affected by selective migration processes. In attempting to do this, we were faced with the limitation that official statistical publications do not provide detailed information on the elderly population by age group. All individuals aged 75 and above are placed in a single category. We therefore decided to generate these data from a German pension insurance system dataset (FDZ RV 2008) which contains information on all living individuals who have ever made contributions to the German pension fund, or who have gained rights to pension payments for other reasons (e.g. widows or mothers for the births of children). This dataset covers more than 95% of the total population aged 65 and above living in Germany. From these data we derived in cross-sectional form for the year 2005[9] regional population data by the following age groups: 75–84, 85–94, and 95+. We compared aggregates of these data at district level with official statistics for the population aged 75+ for the year 2005, with the correlation coefficient being 0.99. This gave us confidence in our decision to use the German pension fund data to derive information on the populations at risk.

For our analyses based on the place of birth, we obtained district-level data on the average number of births in the period 1894–1896 (German Imperial Statistical Office 1901). These three years were chosen for two reasons: one was data availability, and the other was that these birth years were heavily represented in our dataset. Approximately 30% of our individuals were born in these three years, and another 20% were born in the years 1893 and 1897. This suggests that the birth years 1894–1896 are a good representation of the population at risk for the analysis by place of birth.

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6 These are just approximations of the place of birth and the place of residence at age 105+/death, as we lack exact information. This might create small biases in our analysis of distances. These biases might also vary spatially, as the average area of municipalities differs between the federal states of Germany (Laux 2001).

7 These were developed in part based on the VG 2500 (BKG 2009).

8 Bavaria, for example, has registered substantial immigration since the 1960s. But because most of these migrants were of working age, this process affected the elderly population—who could potentially reach the age of 105 in our period of observation—to only a small extent.

9 It would have been even more precise if we had generated the information on the population at risk retrospectively for the time when the individuals with exceptional longevity were in these age groups. However, data availability constraints did not allow us to do so.

3.3 Methods

Our analysis is divided into two parts: the first part is an investigation of the lifetime net migration pattern, while the second one is an examination of the spatial variation in exceptional longevity by both place of birth and place of death. For the first part of the analysis, the distance calculation between a person's place of birth and the place of death is based on great circle distances.[10] From these data we derived density curves and descriptive statistics.

For the analysis of spatial variation in exceptional longevity in the second part, we aggregated the individual data at the regional level. This was also done in order to comply with German data protection regulations.[11] We used different definitions of the event of interest, as well as of the population at risk, in order to test to what degree the emerging spatial patterns of exceptional longevity were consistent. This included looking at exceptional longevity by sex (total, male, female) or using different age categories as population at risk (75+, 85+, 95+). We also replicated our analyses at different geographic scales, as the choice of the geographic scale can have substantial implications for outcomes and interpretations. This issue is commonly referred to as the *modifiable areal unit problem* (Openshaw 1984). We based our analysis on the following administrative divisions: German federal states (N = 16), *Regierungsbezirke* (N = 40) and regional planning regions (N = 97).[12] However, at all three levels we encountered the problem that some metropolitan areas constitute their own regions (Berlin, Hamburg), while others are incorporated into bigger regions. We therefore decided for all three divisions to also carve out the other two big cities in Germany with more than one million inhabitants, which are Munich and Cologne.

In comparing the events of exceptional longevity by place of birth with the number of births that occurred at the time the semi-supercentenarians were born, we had to deal with the challenge that Germany has undergone substantial reforms of administrative boundaries at all of the levels considered. To obtain an estimate of the number of births that occurred within the regions that currently exist, we used an *areal interpolation* procedure based on area weighting[13] (Goodchild and Lam 1980).

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[10] Great circle distance is the shortest distance between two points on the surface of a sphere (in our case, the earth). For additional details, see Banerjee (2005).

[11] German data protection regulations require that in order to calculate regional rates based on individual-level information, each region must contain at least three individuals.

[12] We use the administrative boundaries as of 31 December 2002.

[13] The areal interpolation method is based on the assumption that births by mother's place of residence are distributed homogenously across space within the *source regions*, for which we have data. This is a strong assumption, as the population is unlikely to be homogenously distributed across space, and we cannot expect the occurrence of birth events to be constant across each source region. However, the potential error emerging from the estimation is largely dependent both on the geographic detail of the source regions and the geographic detail of the *target regions*, for which the estimations are produced: the higher the geographic detail of the source regions in comparison to the target regions, the

In mapping the spatial pattern of exceptional longevity, we were faced with the problem that we dealt with a rare event, which implies that our analysis might be distorted by random noise. We therefore used the Local Empirical Bayes Smoother (Marshall 1991; Bailey and Gatrell 1995: 307 ff.), which allowed us to derive a more stable pattern by adjusting the raw rates in each region based on Bayesian principles using information from neighbouring regions. The Local Empirical Bayes Smoother is related to the Global Empirical Bayes Smoother. In the latter, prior mean and variance are assumed to be constant across a sample. In the Local Empirical Bayes Smoother, the prior is derived for each region *i* from a subsample, which only includes regions *j* in the neighbourhood of each region *i* (for neighbourhood definitions, see below). The procedure is based on the assumption that nearby regions *j* are, in terms of structures and processes, more similar to a region *i* than more distant regions.[14] This is also referred to as the First Law of Geography (Tobler 1970).

The prior mean for the raw rate at region *i* is derived by:

$$\hat{\mu}_i = \frac{\sum_{i \in J_i} O_i}{\sum_{i \in J_i} P'_i} \tag{1}$$

where J_i represents a set of neighbours *j* to a region *i*, including *i* itself, based on a chosen neighbourhood definition[15] (Anselin et al. 2006). O denotes the observed events and *P* the population at risk. The local estimator for the prior of the variance

smaller the potential error emerging from the estimation procedure. As we had very detailed source data at the level of 947 districts for the births that occurred 1894–1896, while the number of our target regions varied between 18 (16 federal states and two cities) and 99 (97 regional planning regions and two cities), we decided not to use more complex estimation methods, such as, for example, the EM algorithm (see Gregory 2002). In order to derive the estimates, we applied a spatial intersection in which we intersected a GIS polygon file with border and area information on the source regions with the file of the target regions. In this way we obtained a GIS dataset with the smallest common polygons (also called zones of intersection), which enabled us to derive the estimates for the target regions.

[14] We illustrate our Bayesian smoothing technique with a simple example. Imagine a country with 10 regions and a total population at risk of 10,000 individuals. In our example, one sub-region *i* has a population at risk of just 100 persons and recorded two persons achieving exceptional longevity. As the population at risk and the number of events are very small, it is likely that this outcome is highly influenced by randomness. Now imagine that this region *i* has just one neighbouring region *j*, which has a population at risk of 1,000 individuals, and which recorded 40 events of exceptional longevity. Based on Bayesian principles, this information is more reliable as it is based on a larger population at risk. This information from neighbouring region *j* is taken into account in the smoothing of the rate of region *i*, based on the assumption that nearby regions are more similar in terms of the processes influencing exceptional longevity compared to more distant regions. In our example, the algorithm would determine the number of events recorded in region *i*, which was two out of 100, to be rather small in comparison to the number in region *j*, which was 40 out of 1,000. It would therefore adjust the rate of region *i* in the direction of the rate of region *j*, taking the population at risk in the two regions into account as a measure for the reliability of the information.

[15] We use a first-order queen definition of neighbourhood, which treats all regions *j* as neighbours that border *i* along at least one common border point.

is derived as follows:

$$\hat{\sigma}^2_i = \frac{\left[\sum_{i \in J_i} P_i (\hat{\pi}_i - \hat{\mu}_i)^2\right]}{\sum_{i \in J_i} P_i} - \frac{\hat{\mu}_i}{\overline{P}'_i} \tag{2}$$

where $\hat{\pi}_i$ denotes the estimated rate for region i and $\overline{P}'_i$ is the local average population at risk, which is obtained with the following equation:

$$\overline{P}'_i = \frac{\sum_{i \in J_i} P_i}{N} \tag{3}$$

4 Results and discussion

Our empirical analysis consists of two parts, with the first part providing information on the reliability of the results obtained in the second. Thus, we decided to present and discuss the analysis of the lifetime net migration pattern before we present and discuss the results of regional variation in exceptional longevity.

4.1 Lifetime net migration pattern of the population aged 105+

In presenting our analysis of the lifetime net migration pattern, we will first look at the broad regional pattern. For this analysis, we divided the 16 German states into four regions (see Table 1 for details). The regions North, West and South are

Table 1:
Migration matrix (place of birth/place of death)

Place of death	Place of birth*				Former territories of the German Empire	Foreign countries (at time of birth)
	North	West	South	East		
North	**158**	11	¡3	40	63	12
West	25	**300**	15	31	89	37
South	6	19	**142**	33	50	40
East	5	8	¡3	**164**	74	13

Note: *Includes only people who died within the borders of present-day Germany.
North: Bremen, Hamburg, Lower Saxony, Schleswig-Holstein.
West: Hessen, North Rhine-Westphalia, Rhineland-Palatinate, Saarland.
South: Baden-Württemberg, Bavaria.
East: Berlin, Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, Thuringia.
Source: Age validation study 105+ Germany; authors' own calculations.

made up of states in the former West Germany, while region East is formed by the territories that belonged to the German Democratic Republic as well as West Berlin. The category 'former territories of the German Empire' refers to areas that belonged to Germany at the time of birth of the cohorts studied. In addition to the territories east of the Oder–Neisse line, these also include areas which today are part of Denmark, Belgium and France. The migration matrix shows that in each of the four regions a substantial share of the semi-supercentenarians were born in the former territories of the German Empire. In addition, we see that a significant share of those born in the East region died in one of the western German regions (almost 40%). To a large degree this is likely to be the result of the establishment of the GDR, which caused large numbers of people to migrate from East to West Germany in the period 1945–1961. However, if we look at the migration matrix within western Germany (highlighted in the upper left corner), we see very little migration between the three regions that we distinguished. Thus, the emergence of the south as the most developed region of Germany starting in the late 1950s is not reflected to any significant extent in this migration matrix. Perhaps these cohorts, who were born in the 1880s and 1890s, were already too old to have been greatly affected in their migration patterns by this process.

Just how localised the lifetime net migration pattern was for most individuals becomes even more clear if we look at the distances between the place of birth and the place of death. Of the 961 persons who were born within the present-day borders of Germany and who had reached the age of 105 while living in Germany, 301 were, at the age of 105+, still or again living in their place of birth (approximately 31%). The median distance between their place of birth and the place of death was 25 km (see the upper graph in Figure 2). The pattern for individuals born in western Germany, where the median distance was around 15 km, was even more localised. For those born in eastern Germany, on the other hand, the median distance was, at 104.6 km, much higher, which again reflects at least in part the impact of the division of Germany on the east-west migration pattern (see the middle graph in Figure 2).

However, as big cities in particular are likely to attract people from more distant locations, there might be a substantial degree of variation within Germany. We therefore did an additional analysis in which we identified all of the individuals who were residing in one of the four biggest cities of Germany (Berlin, Hamburg, Cologne, Munich) at the end of their lives (see the lowest graph in Figure 2). The pattern was indeed less localised for those individuals than for their counterparts living elsewhere in Germany. However, this was only true for distances of between zero and 50 km, as many of the semi-supercentenarians residing in the four biggest cities were not born in the city itself, but in an area near the city. If we look at the median distance between the place of birth and the place of death, we can see that it was, at around 31 km, quite low for this group as well.[16] Overall, our results suggest

[16] We also looked at differences by sex, but as we did not find substantial differences, we do not present the results here.

Figure 2:
Distance between place of birth and place of death

Source: Age validation study 105+ Germany; BKG (2007); authors' own calculations.

that, despite the turmoil of the 20th century, the distance between the place of birth and the place of death was very small for most of the individuals observed in the dataset. This was the case even if the individuals lived in big metropolitan areas which had experienced substantial in-migration over the past 100 years.

Our finding that the lifetime migration pattern was highly localised for a large number of semi-supercentenarians lends support to the argument that an analysis of spatial patterns of exceptional longevity would produce meaningful outcomes. But it also raises the question of whether this result could have been expected, or whether it is an unexpected finding which might stem from differential mortality between *stayers* and *movers* at high ages. Theoretically, it is possible to argue that individuals of high ages who still reside in their birth region might have had competitive advantages relative to people of the same ages who lived outside of their birth region. These advantages might stem from selection effects as a result of life course decisions taken earlier in life. The tendency to stay in the home region might, for example, be particularly high for those who married early, and whose marriage partner was from the local area. Thus, the stayers who reach high ages might be a select group who profited from the protective effect of marriage very early in life, and who were deeply embedded in local community and kin structures throughout their adulthood. These structures might have benefited them at higher ages as well, as they might have had better access to social capital in the form of a higher number of family members living nearby who could assist them in their daily activities, or in the form of a greater number of long-standing friendships with people living in the area or better contacts in the neighbourhood.

An alternative explanation is that the observed pattern of small distances between the place of birth and the place of death simply represents the lifetime net migration pattern typical for these cohorts of Germans. It is not easy to determine whether this was the case as there seems to be little research on lifetime net migration distances by age and cohorts in general. Conceptually, it is also a problem that, with increasing age, people are likely to become frailer. This elevates the risk that they will leave their former place of residence to live near their children or in a retirement home situated in another locality.[17] Unfortunately, our dataset is not organised in a longitudinal form. Thus, we can only differentiate lifetime net migration distances by age of death, which we did in Table 2 in order to see whether the share of stayers increases at higher ages of death. This—admittedly crude—analysis does not provide any indications of such a tendency, however.

[17] However, research by Kibele and Janssen (2013) for the 80+ age group in the Netherlands shows that most moves in the last three years of the life cover only small distances, which suggests that regional mortality patterns of the kind studied in our analysis are hardly affected by such moves.

Table 2:
Lifetime net migration distance by age at death (N = 817*)

	105	106	107	108+
0–10 km	38.7%	40.6%	34.4%	36.8%
10–100 km	33.0%	30.6%	33.3%	36.8%
>100 km	28.3%	28.8%	32.3%	26.5%
N	424	229	96	68

Note: *Includes only people who were born and died within the borders of present-day Germany. Persons still alive in 2002 are excluded.
Source: Age validation study 105+ Germany; authors' own calculations.

4.2 Regional variation in exceptional longevity

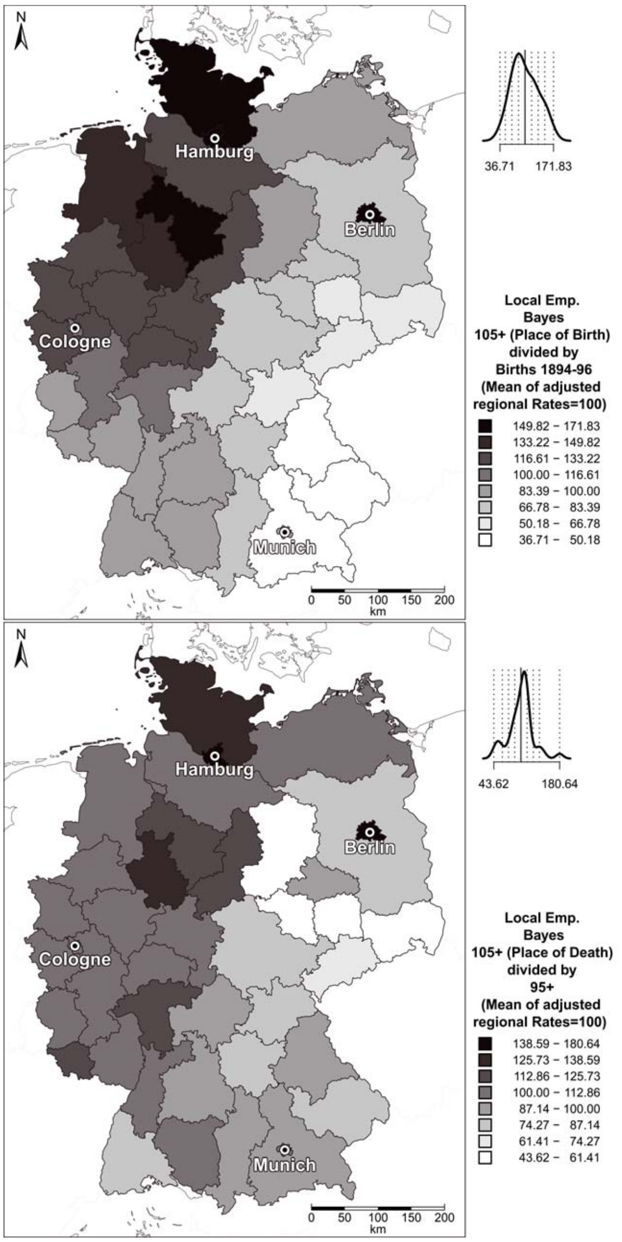
In presenting our analysis of spatial variation in exceptional longevity across Germany, we will only show the results at *Regierungsbezirk* level, while omitting the outcomes from the other two geographic scales at which we replicated the analysis (German states, regional planning regions). This is because the resulting spatial pattern turned out to be quite similar for all three geographical scales. Therefore, we decided to focus on the *Regierungsbezirk* level, as doing so provides a good balance between the number of events of exceptional longevity within a region and the need for a certain level of regional detail.

In Figure 3 we present the spatial pattern of exceptional longevity at the *Regierungsbezirk* level, with the upper map showing the spatial pattern by place of birth, and the lower map displaying the pattern by place of death. For the latter, we used the population aged 95+ as a base population. It is important to note that the rates we obtained from our calculations cannot be interpreted as survival rates, as, for example, the number of years in which the semi-supercentenarians were born is larger than the number of birth years from which we derived the number of births. As a result, the emphasis is on relative regional differences, while the absolute rates do not have a specific meaning. Therefore, in order to make it easier for the reader to compare the spatial variation in the two maps, we decided to standardise both maps in Figure 3 by the mean value of the adjusted regional rates.[18]

Overall, the patterns of the two maps do not differ substantially. This was to be expected, given the results of the first part of the analysis, which showed that most of the individuals with exceptional longevity died in the region in which they were born. The outcomes do not vary much if we repeat the analysis for different populations at risk (e.g. people aged 85+ or women only). In both maps, Berlin stands out as the eastern German region with the highest rates of exceptional longevity. The northern

[18] Both maps use a standard deviation categorisation centred on the mean, with each category covering an interval of 0.5 standard deviations.

Figure 3:
***Hot spots* of exceptional longevity in Germany by place of birth and place of death**



Source: Age validation study 105+ Germany; German Imperial Statistical Office (1901); FDZ RV (2008); authors' own calculations.
Note: Base Map: MPIDR Population History GIS Collection (partly based on BKG 2009).

German city of Hamburg also displays high rates of exceptional longevity, although it forms part of a larger cluster in north-western Germany that also covers Schleswig-Holstein, Bremen and parts of Lower Saxony and Westphalia (Figure 3). The cities of Cologne and Munich, on the other hand, cannot be characterised as hot spots of exceptional longevity in a Germany-wide comparison, although Munich seems to be a local hot spot relative to its surrounding areas. Eastern Bavaria in southern Germany and the whole of eastern Germany apart from Berlin have low rates of exceptional longevity.

In discussing these results, we will focus first on the regional pattern and the hot spot in north-western Germany. We will then turn to the differences between the four biggest cities and the surrounding areas. When we compare the spatial pattern of exceptional longevity with the life expectancy maps in Figure 1, we can see that the maps in Figure 3 resemble the pattern that existed at the time the semi-supercentenarians were born more than that which existed at their time of death.

If we assume that this outcome is related to varying spatial contextual conditions throughout the life course, two possible explanations for this finding seem most plausible to us. First, the spatial variation in exceptional longevity with the hot spot in north-western Germany could be influenced to a large degree by the spatial variation in early-life conditions that existed in Germany in the late 19th century. This would be in line with research findings on seasonal variation in early-life conditions (month of birth), which suggest that the chances of individuals reaching ages of 105 and above might have been affected by their early-life conditions (Doblhammer et al. 2005). A second possible explanation is that the livelihoods of the cohorts covered in our study, who reached retirement age in the 1960s and early 1970s, were only marginally affected by the fact that southern Germany became the most developed region with the highest life expectancy levels in Germany during the second half of the 20th century. Perhaps the impact of these shifts would be visible in younger cohorts, who were also affected to a much greater extent by selective migration to the south. In order to look into this issue, we studied regional life expectancy data by age in recent decades (Birg 1982, SB 2012 and our own calculations[19]). These data show that in 1970 above-average life expectancies at birth were recorded in West Germany both in the northern states of Schleswig-Holstein, Hamburg and Bremen and in the southern German states of Bavaria and Baden-Württemberg. In line with our expectations, we can see that the advantages of the northern states at that time were even more pronounced at ages 60+ (Birg 1982: 25). These findings also confirm our assumption that over the last 40 years, these above-average life expectancies of the northern states have diminished. Since the early 2000s, the values in all of the northern states, apart from the city-state of Hamburg, have dropped below the German average. If this trend continues—assuming it is relevant for the chances of achieving exceptional longevity—it is not unlikely that the cluster of high prevalence of exceptional longevity in northern Germany will disappear in the near future.

[19] Based on data provided by the statistical offices of the German states.

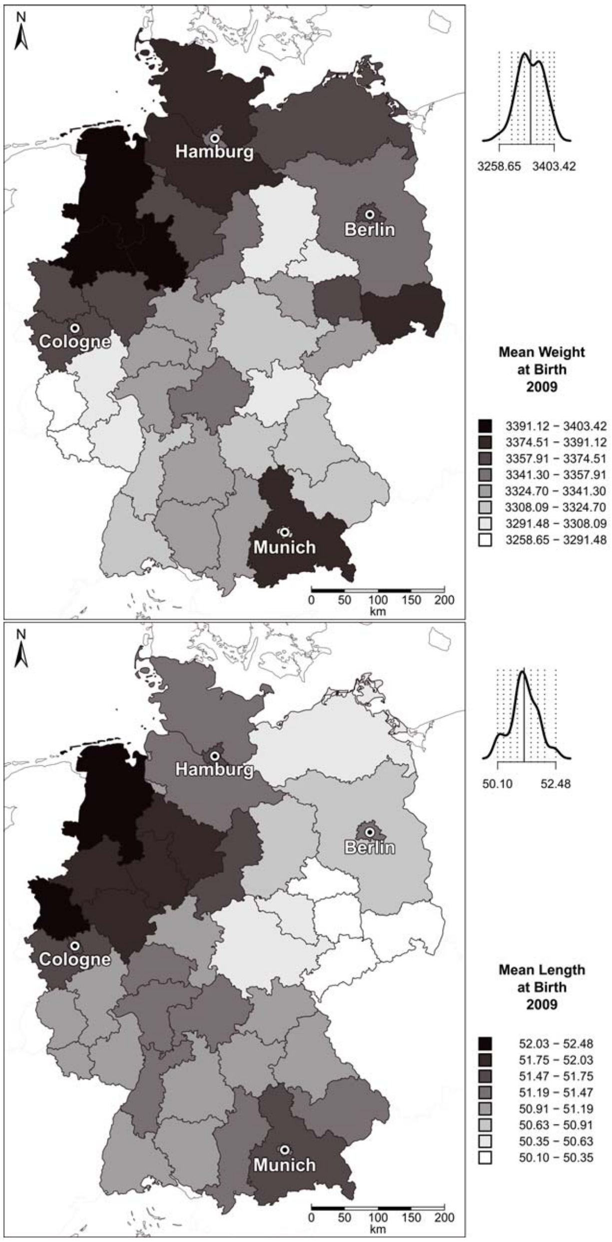
There are, however, alternative explanations for the emergence of the hot spot of exceptional longevity in north-western Germany. Another way in which this area of Germany stands out from the rest of the country is in terms of the variation in the mean weight and length at birth. Unfortunately, we have regional information on these indicators for the last 20 years only (FDZ 2012). But over this time period, the spatial variation in these measures remained rather stable. Therefore, given the evidence that this type of variation is largely influenced by genetics (Clausson et al. 2000), it is not unrealistic to assume that these differences might have already existed in the 19th century. Figure 4 shows the spatial variation in average birth weight and length in Germany in 2009. The pattern suggests that the highest birth weights and birth lengths can be observed in north-western Germany. If this spatial variation had already existed in the late 19th century, children born in north-western Germany might have been more robust than children born in other parts of the country. This may also be one explanation for why life expectancy was higher in north-western Germany at that time (see Figure 3). However, further research on this alternative explanation is needed.

Turning to the big cities, we can see that Berlin and Hamburg are important hot spots, while Munich is a hot spot relative to southern Germany. This is remarkable considering that the populations of these cities were severely affected by the two wars. In countries less affected by war, the advantages of the big cities might be even more pronounced. For the hot spot in Berlin, it would have been helpful if we had been able to distinguish between West and East Berlin. Unfortunately, however, this was not possible. We would expect to find a particular concentration of semi-supercentenarians in the western part of the city, which was part of West Germany during 1945–1990. As a result, the population of West Berlin benefited from innovations such as the cardiovascular revolution decades earlier than the population in East Berlin. However, as the former capital of the German Democratic Republic, East Berlin was also privileged in terms of better access to medical services compared to other parts of East Germany. Therefore, it might still be a hot spot relative to the other eastern German regions.

Another factor contributing to the high concentration of semi-supercentenarians in Berlin is related to the unique history of the city in the 20th century. Most big cities in Germany experienced substantial suburbanisation processes in the 1950s and 1960s, in which significant shares of the socio-economically advantaged population moved to areas outside of the city. In West Berlin these suburbanisation processes did not start until after 1990, which might have contributed to the high concentration of semi-supercentenarians in the city.

Another possible reason why bigger cities emerge as hot spots is that they offer favourable conditions for very old people. As we mentioned in our background section, there is evidence that big cities have access to new medical technologies earlier than smaller towns or rural areas. In addition, large cities usually have more efficient emergency care systems, as well as a wide variety of hospitals that specialise in specific treatments. Regional life expectancy data provide evidence that conditions for the oldest old are quite favourable in big cities. For example, over the last 40 years

Figure 4:
Spatial variation in birth weight and birth length



Source: FDZ (2012); authors' own calculations.
Note: Base Map: MPIDR Population History GIS Collection (partly based on BKG 2009).

Berlin has never had above-average life expectancy levels at birth or at ages up to 65. But the picture looks different at very old ages, as Berlin consistently reported life expectancy levels above the German average among people aged 80+ during the period for which we have data for all of the German states (2002–2010). In 2002/2004, only three of the 16 German states had higher values than Berlin: the other two German city-states of Hamburg and Bremen, and Baden-Württemberg in the south-west.

5 Conclusion and outlook

Overall, our findings show that in Germany, despite its troubled 20th-century history, the distance between the place of birth and the place of death is very small for most of the semi-supercentenarians observed in the dataset. This lends support to the argument that an analysis of the spatial patterns of exceptional longevity can provide meaningful results, even if we only know the place of birth and the place of death of a person. Our analysis of the geographic variation in exceptional longevity resulted in a clear spatial pattern. Consistency checks in which we varied the definitions of the event of exceptional longevity and the population at risk did not substantially alter our outcomes. Hot spots of exceptional longevity could be identified in Berlin and in north-western Germany. This pattern very closely resembles the spatial variation in life expectancy during the period when the semi-supercentenarians were born. To some extent it also reflects the current spatial variation in life expectancy at age 80. These findings might be interpreted as providing support for the argument that the contextual conditions both early and late in life are relevant for understanding the spatial variation of exceptional longevity in Germany. However, our findings on spatial variation in contextual conditions are less conclusive than the findings on the influence of temporal variation in early-life contextual conditions (Doblhammer et al. 2005). Moreover, alternative explanations such as the influence of genetic variation cannot be ruled out at this stage.

One of the limitations of our study is that we only have information on the place of birth and the place of death of individuals, and not on their complete migration histories. Another restriction is that our dataset of semi-supercentenarians does not include socio-economic or genetic information, which means that we cannot directly control to what extent the regional variation in exceptional longevity stems from spatial variation in these characteristics.

Developments over the coming decades might provide us with additional insights into the question of to what extent contextual or genetic differences are relevant. If contextual effects of early-life conditions are very important for achieving exceptional longevity, we would expect the spatial hot spot in north-western Germany to disappear over time, as spatial variation in infant mortality has decreased substantially in Germany for the cohorts born after 1925. In this case, we would expect to see the hot spots of exceptional longevity move to southern Germany, where the highest life expectancy levels are currently recorded. If, however, spatial variation in genetic factors has an impact on the probability of surviving to high ages, we might expect the hot spot in north-western Germany to persist over time.

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