

Non-survival to pension age in Denmark and Sweden: a sub-national investigation

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Mortality keeps improving even in the most developed countries. Deaths before senior age become more and more occasional and thus are increasingly considered unnecessary and perhaps even avoidable. Denmark belongs to the most developed countries of the world in terms of progress in lowering human mortality levels. Yet there is still much room for large improvements – compared to Sweden, Danish population has almost the same survival profile up to age 50 but then there are striking differences in later ages. Between ages 50 and 65 about 10% of Danish males die while in Sweden this proportion is only about 7%. This paper explores the regularities of non-survival to pension age across Danish municipalities and compares them to ones in Sweden. The main focus of this exploration is identification of the spatial patterns based on the mortality characteristics of the population that are studied using the advanced spatial clustering algorithm that utilizes tree edge removal technique. The methodological challenge resolved along the way is the construction of reliable life table estimates for the small municipal populations. The results suggest that the main reason for the observed gap between Danish and Swedish municipalities, especially for males, is the lagging behind development of the most deprived areas, which corresponds with the results on widening gaps along socioeconomic dimensions.

Keywords: Small-area estimation, life tables, adult mortality, municipalities

The puzzle of relatively high Danish adult mortality

Radical and non-stop reduction of mortality has been documented across human populations becoming a central topic in the field of public health and demography (Oeppen & Vaupel, 2002), with a particular emphasis on the better studied developed countries where most significant advancements have been made in lowering death rates (Vaupel et al., 2021). Despite these stark improvements, however, there remains much room for further progress particularly in terms of avoiding premature deaths (Beltrán-Sánchez et al., 2015; Fernandez & Beltrán-Sánchez, 2015). Even the best performing populations are unequal and heterogeneous. For example, both Denmark and Sweden evidently belong to the most advanced countries in terms of progress along the route of demographic transition, yet there are still marked differences in the age profiles of survival in these two populations. Danish population has almost the same survival profile up to age 50 but then there are striking differences in later ages: between ages 50 and 65 about 10% of Danish males die while in Sweden this proportion is only about 7% (Figure 1).

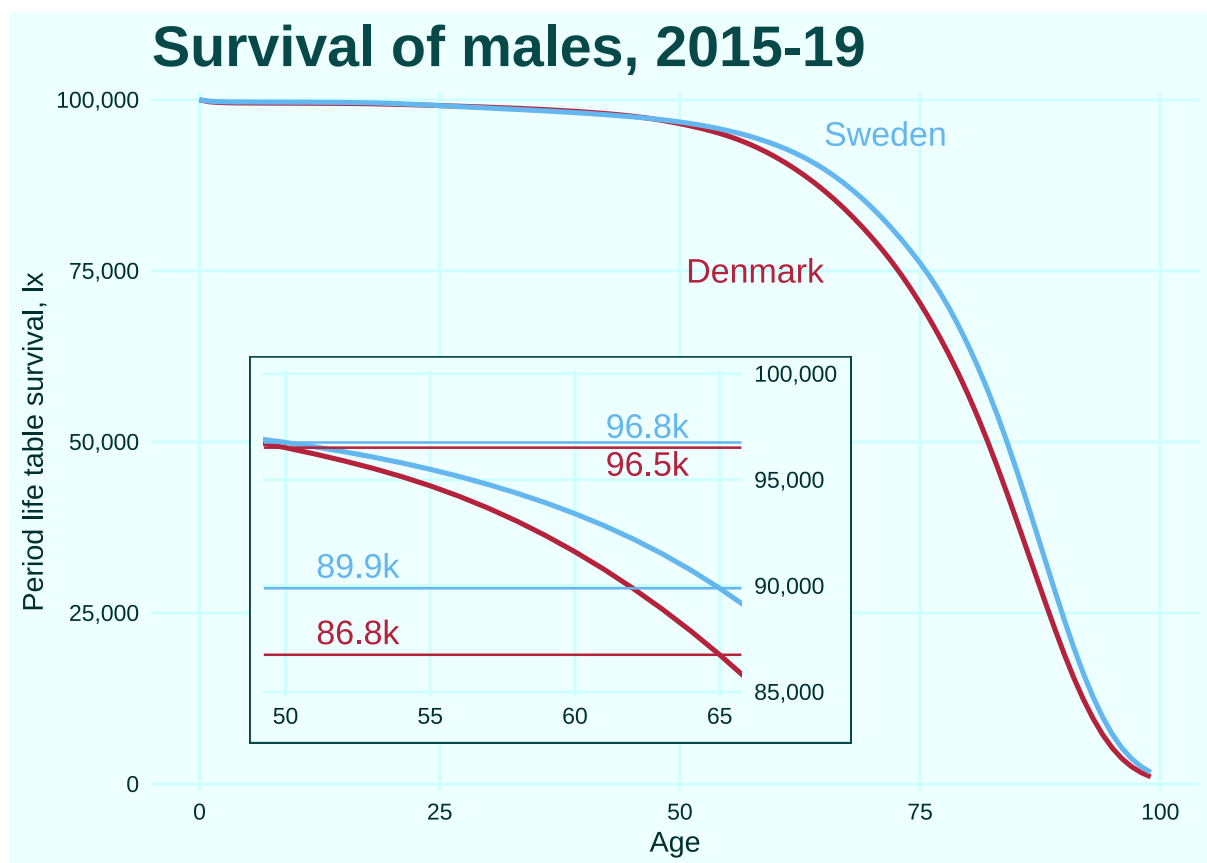


Figure 1. Life table survival profiles of males in Denmark and Sweden, 2015–2019. Source: National Statistical Offices.

This huge gap in non-survival to pension age between the similar neighbouring developed populations warrants a closer investigation. Excessive preliminary deaths just before retirement are a huge source of inequality both in terms of survival itself,

the ultimate treasure of life (Vaupel, 2010), and other flavours of societal inequalities. It is quite striking how large are persisting inequalities in survival even in the advanced welfare states such as Denmark and Sweden. Non-survival to state pension age is particularly disbalancing for the pension systems and the unfairness of not surviving to the age of benefiting from the system to which one contributed for decades (Brønnum-Hansen et al., 2017). There's also a strong evidence that this preliminary adult mortality is extremely unequal along the socio-economic gradients disproportionately affecting the most deprived strata of the population (Brønnum-Hansen et al., 2021). Our recent analysis of these socio-economic disparities reveal that the difference in chances not to survive to pension age from age 50 between better-off and most deprived quartiles of the population is four-fold (Strozza et al., 2022).

This paper addresses inequality in pre-pension survival by taking a closer look at the spatial differences in non-survival to pension age across Danish municipalities and comparing them to the Swedish ones. I employ spatial clustering algorithm that utilizes tree edge removal technique, SKATER (Assunção et al., 2006), to identify the spatial clusters of municipalities based on their mortality characteristics. To proceed to spatial clustering I first have to address the challenge of dealing with small populations of the municipalities to obtain the reliable non-survival estimates. For this task I use the state-of-the-art demographic technique TOPALS (De Beer, 2011, 2012), which is a flexible relational model that is known to perform great with small population estimates (Denecke et al., 2023; Gonzaga & Schmertmann, 2016; Rau & Schmertmann, 2020).

The methodological development in small area demographic estimation saw relatively recent major improvements (Denecke et al., 2023; T. Wilson et al., 2021). Moreover, data availability and quality is a big challenge in most contexts (Schmertmann & Gonzaga, 2018) which specifically hinders comparability across countries (Kashnitsky et al., 2021). The existing studies that document differences and spatial regularities of mortality at subnational level of granularity are rather scarce, and yet subnational investigations consistently reveal the huge disparities within countries, and marked differences exist between populations (Smits & Permanyer, 2019).

Spatial modelling in mortality analysis was addressed in a few existing studies. For example, Carracedo et al. (2018) explore the persisting East/West divide among European Union countries at the national level using explicit spatial modelling techniques (Anselin, 1995), the finding that was earlier documented in multiple descriptive demographic studies (Vallin & Meslé, 2004, 2005). Subnational explorations of mortality are even less common. Analysing European Union at NUTS-2 level of granularity, Richardson et al. (2014) observe a widening sex gap which means that the regions with more lagging behind male mortality become with time even more deprived.

Few studies focused closely on spatial differences of mortality within specific countries. Rau and Schmertmann (2020) looked at the numerous districts of

Germany, they conclude that socioeconomic inequality is the main driver of district-level disparities in mortality. Recently in another close-up look at German districts Hrzic et al. (2023) unfolds a complicated story of post-unification convergence in subnational mortality. Despite the overall convergence in mortality achieved mostly through the catch-up development of the Eastern German districts, they also document the increasing district-level inequalities in mortality within federal lands.

In a rare subnational mortality analysis that goes beyond discussing one specific county, B. Wilson et al. (2020) compare mortality in the counties of Sweden and Finland, which correspond to the NUTS-3 geographical level. Unlike most previous studies they focus on both life expectancy and lifespan inequality measured with a modification of Gini coefficient. They unravel persistent spatial and temporal differences and specifically discuss the double-disadvantaged male populations in the lagging behind regions of Finland.

In this paper I focus in Danish municipalities and compare them to the neighbouring Swedish ones. I explore the spatial dimension applying spatial clustering. The focus on spatial disparities in survival to pension age is of clear relevance to local and national governments. The spatial differences at subnational level are stubbornly persistent (Keenan et al., 2022) and they represent a large part of the variance in survival and are generally a decent first level approximation to the socioeconomic gradients.

Methods and Data

Data

There are 98 municipalities in less than six million populated Denmark. This results in municipal populations being very small, with the median size less than 50 thousand inhabitants. The distributions of the units by population size is highly unequal with smaller municipalities being more numerous. On the other hand, the largest municipalities represent a large proportion of population, with the capital municipality of Copenhagen containing more than 10% of country's population; and half of the total country's population lives in 22 largest municipalities out of 98 (Appendix 1).

Swedish municipalities are roughly comparable with the Danish ones, although they are smaller and more numerous, 290 municipalities in a country of slightly less than 11 million people. The largest municipalities in both countries are directly comparable, while there are many more smaller units in Sweden compared with Denmark. In Sweden, half of the population lives in 32 largest municipalities out of 290 – there are many more smaller units in Sweden to consider.

Statistics Denmark provide estimates of life expectancy for the municipalities. However, to overcome to some extent the problem of small populations death counts are combined over a five-year period and only provide estimates for the total population, not differentiating by sex. And of course full life tables are not available. I use full life tables to calculate non-survival in the age interval 50 to 65 years. To compare my life expectancy estimates to the ones provided by Statistics Denmark I also pooled together counts in five-year periods (Appendix 2).

TOPALS

The small population size of the units in our study poses a methodological challenge when it comes to estimating life tables. In small populations, often times no deaths are recorded at certain ages which results resulting in a lack of data to inform the calculation of age-specific death rates. To address this issue, we employ the relational model TOPALS (tool for projecting age patterns using linear splines), developed by de Beer (2011, 2012). The basic principle of a relational model is that the information is derived from a standard whenever there are no directly observed events to calculate death rates (Figure 2).

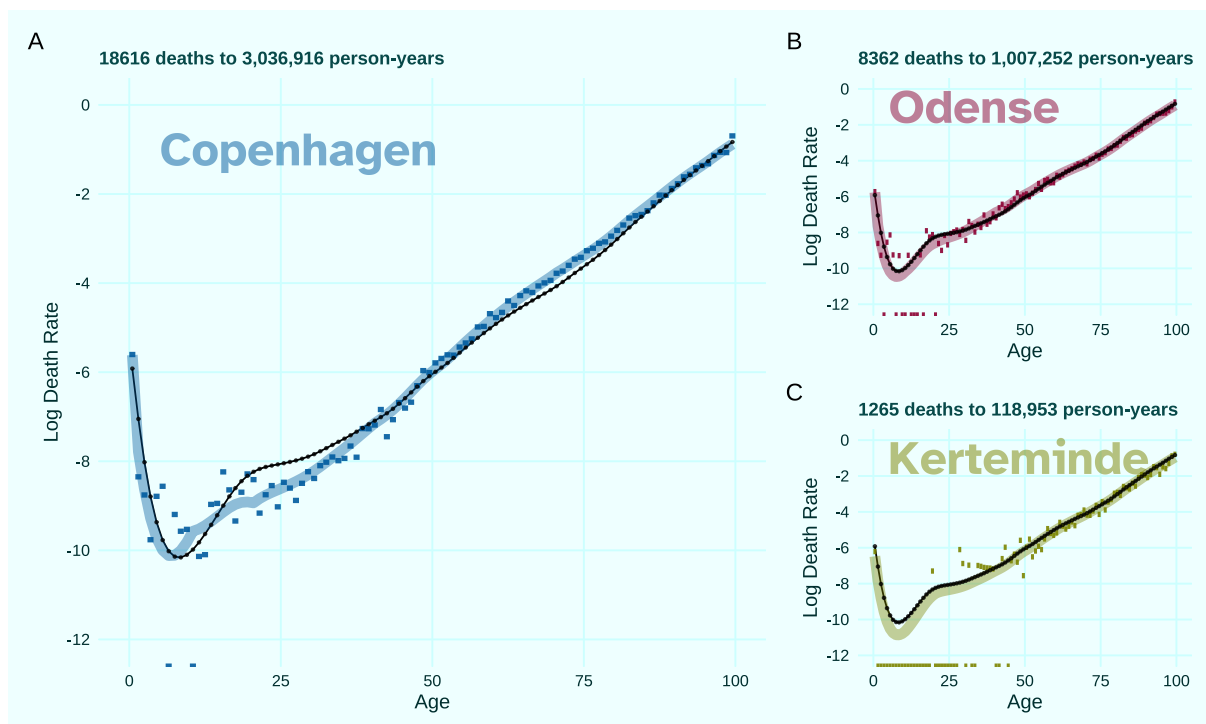


Figure 2. TOPALS fit to mortality schedules for three Danish municipalities of varying population size: A – Copenhagen 600k; B – Odense 200k; C – Kerteminde 24k.

In this case, TOPALS uses splines to estimate the intensity of mortality at selected key ages and adjust the standard to be closer to the observed data. I follow the implementation of the model described by Gonzaga and Schmertmann (2016). By using this relational model, I aim to overcome the challenge of small population size

and produce reliable estimates of life tables for our study. This will allow us to better understand the mortality patterns in the population and inform future public health policies and practices.

Figure 2 illustrates TOPALS model fit of the observed death rates to obtain smooth mortality schedules. Solid line represents the national standard – mortality age profile of the total Danish population. The observed death rates “pull” the standard producing a smooth municipality specific mortality schedule estimate. Even the largest Danish municipality Copenhagen recorded no deaths at ages 6 and 10 within the five years 2015–19 used for analysis here (Figure 2A). In a three times smaller population of Odense (Figure 2B) those ages without observed events in these five years become a handful with the highest age happening to be 20. In a yet much smaller population of Kerteminde (Figure 2C) it is exceptionally rare to observe any deaths below age 30, and the highest age without any deaths recorded within the five year period is 44. As the population gets smaller, there are more specific one-year age groups for which we observe no events to estimate death rates, and thus rely on the model to derive the best estimate from the relevant population of the standard.

The relational model also does a great job smoothing the mortality schedules. In small populations and especially at younger ages when deaths are rare, death rates can be very erratic due to stochasticity, the random chance of observing or not a rare event. TOPALS smooths out the jerkiness of age-specific death rates enforcing the smooth shape derived from the standard mortality schedule. The recent exhaustive comparison of several state-of-the-art techniques for small area demographic estimation (Denecke et al., 2023) suggests that especially in the context of very small populations TOPALS performance is more robust and predictable.

SKATER

Once the challenge of life table construction for the small populations is resolved, I use spatial clustering approach to explore the spatial regularities of non-survival to pension age. For this task, I use the most robust algorithm known as SKATER, Spatial (K)lustering Analysis by Tree Edge Removal (Assunção et al., 2006), to identify the spatial clusters of municipalities based on their mortality characteristics. SKATER is a powerful and flexible clustering algorithm that is well-suited for analysing and understanding spatial data. This particular clustering algorithm is superior over the other clustering techniques since it can produce spatially informed contingent clusters. Similar to the widely adopted k-means method, it groups data points into clusters based on their similarity, but is also incorporates the neighbourhood structure of the data through construction and utilization the Minimum Spanning Tree. The algorithm takes into account the spatial relationships between the data points and considers both the distance between the points and the density of points in the area.

As with any application of unsupervised machine learning techniques, the process includes an influential and potentially error-prone element of the choice of number of

clusters. In our case of spatial clustering, this selection process is two-step since the algorithm first requires to select the number of k-nearest neighbours to be used for the construction of the neighbourhood matrix, and then the number of clusters needs to be chosen taking into account the pre-calculated neighbourhood matrix. This is a curious trade-off process where both choices influence each other.

The standard way to select the appropriate number of k-nearest neighbours and clusters is through the maximization of variance ratio criterion ensuring that the resulting clusters are most distinct from each other and at the same time most homogeneous within them (Caliński & Harabasz, 1974). This two-step selection process is represented in Appendix 3: first, based on the variance ratio maximization I choose to use the neighbourhood matrix calculated using 5 nearest neighbours; then, setting the number of cluster to the optimal value of 5 I check the appropriateness of the initial choice of the number of neighbours. Several iterations of this process allows to conclude the robustness of this choice via iterative optimization of both parameters.

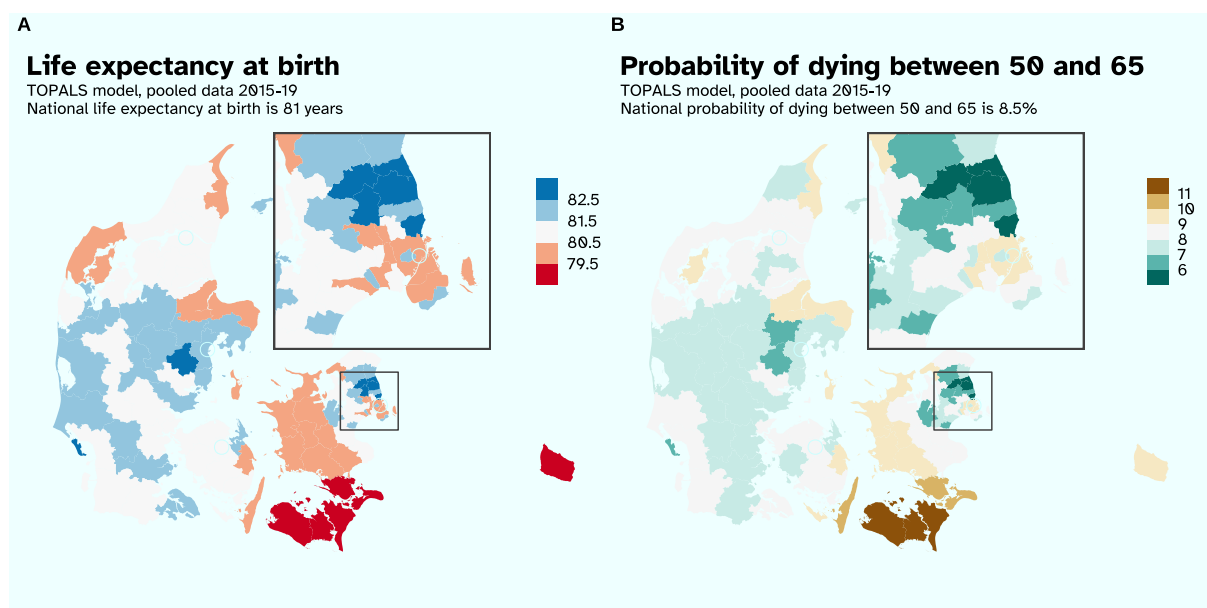


Figure 3. Maps of Danish municipalities: A – life expectancy at birth; B – probability of dying between ages 50 and 65.

Results

Exploring the fitted life tables

Having constructed full life tables for all municipalities of Denmark, we can appreciate the vast spatial variability of mortality across the country. Figure 3A

presents the estimated life expectancies. The clear advantage of having full life tables is that we can easily calculate any more specific quantity based of the detailed age profiles of mortality. Figure 3B presents the probabilities of non-survival between ages 50 and 65. Both panels show very similar spatial patterns with a clear hotspot of higher mortality in the municipalities located at the southern islands and the area of lower mortality around the capital region and in the mainland Jutland. In fact, the similarity of both maps is quite interesting – mortality in the age period of our specific interest, 15 years before the pension age, is largely proportional to the summary measure of the whole age profile of mortality – life expectancy at birth. This suggest a more systematic nature of higher mortality deprivation of some areas. A scatterplot that directly compares the two quantities presented in Figure 3 is available in Appendix 4.

Life expectancy is the best available summary measure of current mortality. Yet, it's quite non-intuitive, or rather the intuitive interpretations of it in terms of individual expected longevity are easily misleading (Aburto et al., 2021; Heuveline, 2023; Luy et al., 2020). Here it's curious how the change of perspective from life expectancy to the probability of dying in the age interval while preserving the spatial pattern almost unchanged sharpens the perception of inequality between the areas – the lagging behind municipalities experience twice higher probabilities of dying compared with the most prosperous municipalities.

Figure 4 depicts the distributions of life expectancy of males and females in both countries in the two five-year periods 2010-14 and 2015-19. To represent better the whole-country picture, along the vertical axis the municipalities occupy space proportional to their total population. Several clear results emerge from the comparison of the municipal life expectancy distributions. First, both males and females of Denmark are lagging behind Swedish counterparts. Even the five years of constant mortality improvements between the two period were not nearly enough for Danes to catch up with the Swedes. Yet, the pace of mortality improvement is clearly higher in present-day Denmark. The variability of life expectancy values is higher for Swedish municipalities, which is not very surprising given the number of very small populations among them (see Appendix 1). Finally, unlike the largely equal reduction of mortality in Danish municipalities, the change of the female life expectancy distribution for Swedish municipalities suggest an increase in inequalities mostly through the faster developments in the upper part of the distribution.

Another interesting regularity is the double disadvantage of areas with lowest male life expectancy. Figure 5 explores this regularity through plotting the sex gap in life expectancy against the level of female life expectancy. The pronounced positive association between these variables means that the municipalities with lower female life expectancy also experience largest sex gaps in life expectancy. This is a clear sign of double male disadvantage in the most deprived areas – even in the worse performing areas males are performing relatively worse than females. This suggest that males are the most problematic subpopulations even in the municipalities with the elevated levels of overall mortality.

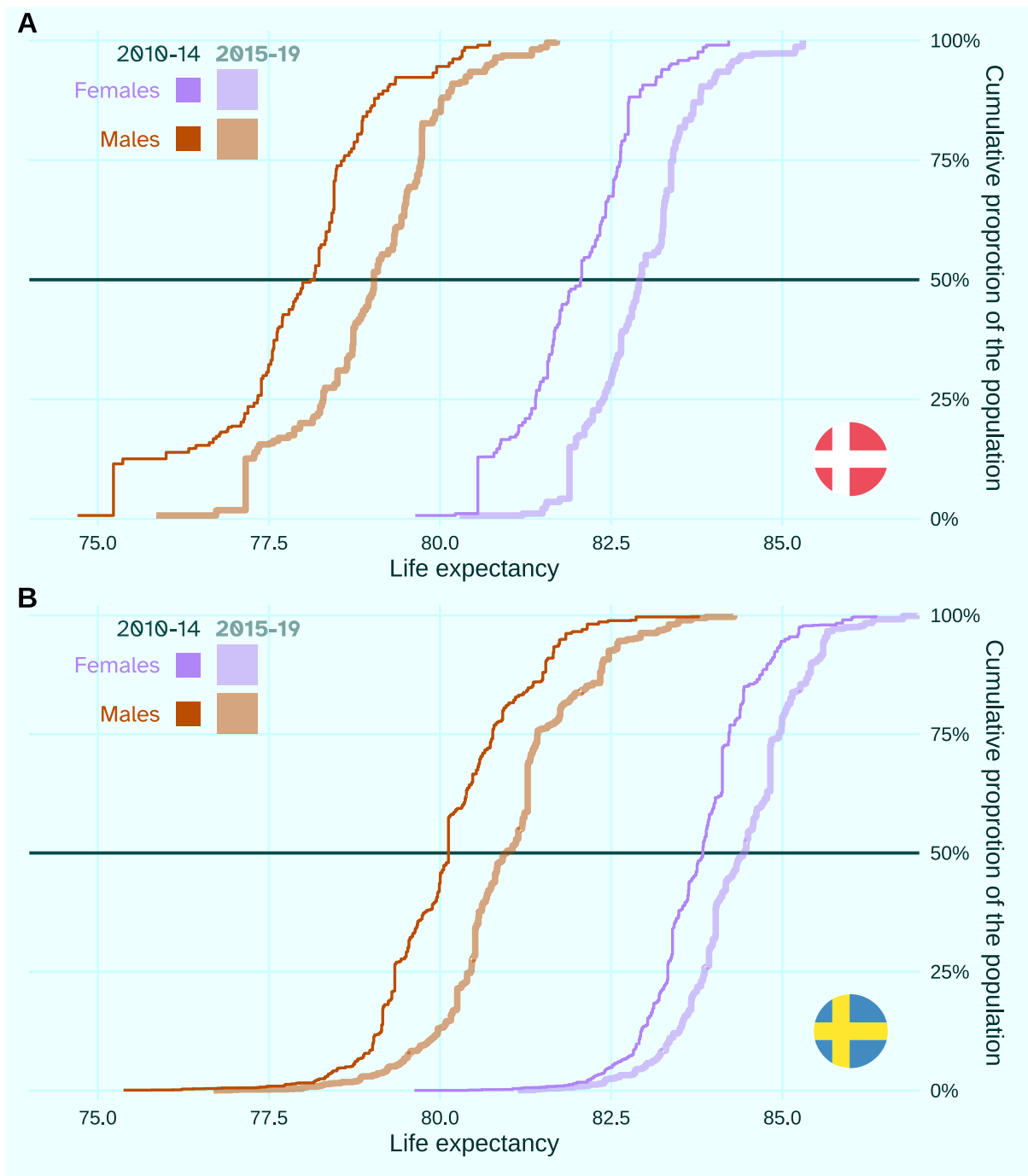


Figure 4. Life expectancy in municipalities of Denmark (panel A) and Sweden (panel B); sex is represented by colour; for each country and sex there are estimates for two five-year periods, 2010-14 and 2015-19; along the vertical axis municipalities are represented by their proportion in the total population.

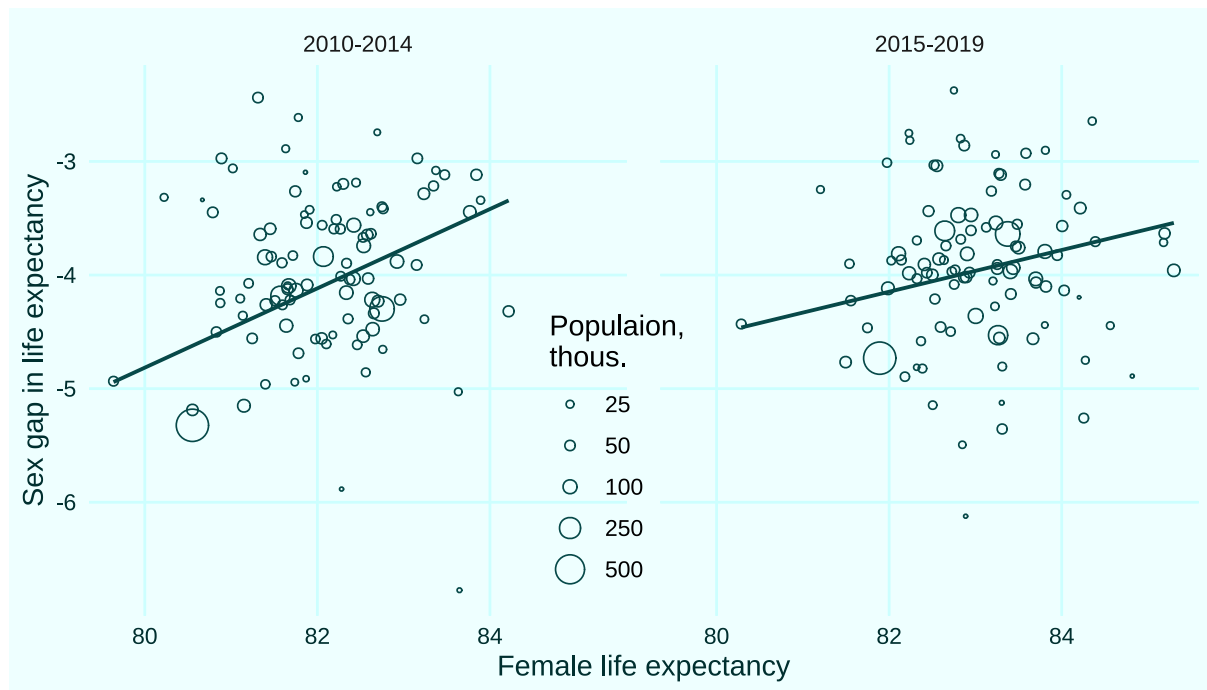


Figure 5. Association of the sex gap in life expectancy across Danish municipalities with the level of female life expectancy.

Although, this positive association became less pronounced with time, which suggest that male mortality in the most deprived areas sees a catching-up improvement and the sex gap is gradually closing up. We can also guess the same dynamics from the distributions in Figure 4A – the lower part of the Danish male distribution sees a larger increase in life expectancy values over the 5 years of analysis.

Spatial clustering

Figure 6 presents the outcome of spatial clustering based on the non-survival of males in the age interval 50 to 65 years. I chose to focus on male non-survival as it presents a more interesting case of higher spatial variation and because the earlier results suggest that the most problematic subpopulations are males in the most deprived areas.

The five spatial clusters immediately communicate the widely acknowledged link between mortality levels and the levels of general development (Ghislandi et al., 2019). The picture drawn by pre-pension non-survival largely resembles countless other maps that depict various socioeconomic characteristics of Danish population; see for example the resemblance to the labour market commuting patterns (Graversen et al., 2013). This simple observation provides additional validity to the results of spatial clustering.

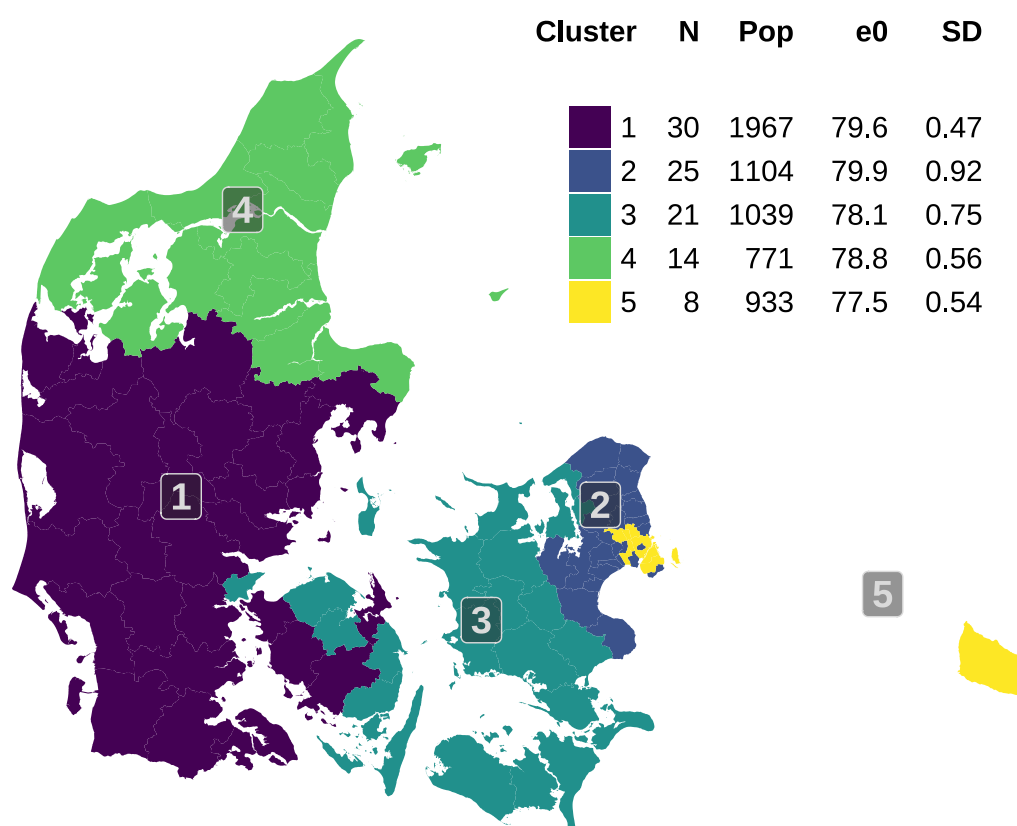


Figure 6. Spatial clustering of Danish municipalities based on the male probability of death between 50 and 65. Clusters are constrained to represent at least 10% of the country's population. The neighbourhood matrix used is k-nearest neighbours with k=5. The number of clusters selected is 5 based on Calinski-Harabasz (1974) pseudo F-statistic, see Appendix 3.

The distinctive feature of spatial clustering is contingency of the resulting clusters. Of course, space agnostic methods, like simple k-means clustering, can maximize variance ratio much further than the spatially constrained methods, but the resulting clusters would be hardly interpretable since they would be scattered all across the country. Spatial clusters, in the contrast, are perfectly interpretable and make immediate sense at the face-value.

The inset table provides summary statistics across the five clusters. The clusters are designed in a way that none of them is allowed to contain less than 10% of the total country's population. We can see that the largest clusters 1 and 2 unite municipalities around the capital region and in the mainland Jutland with the lowest levels of male mortality at ages 50 to 65, a bit more than half of the Danish population live in these two clusters. These are easily the same areas that stand out in Figure 5. Next, the municipalities of cluster 4 in the Northern part of Jutland experience slightly higher male mortality. With another gap goes cluster 3 which encompasses the municipalities of the Western part of Zealand and Eastern part of Fyn. Finally, the

highest mortality is clustered in capital region in cluster 5, and this is a curious peculiarity of Denmark.

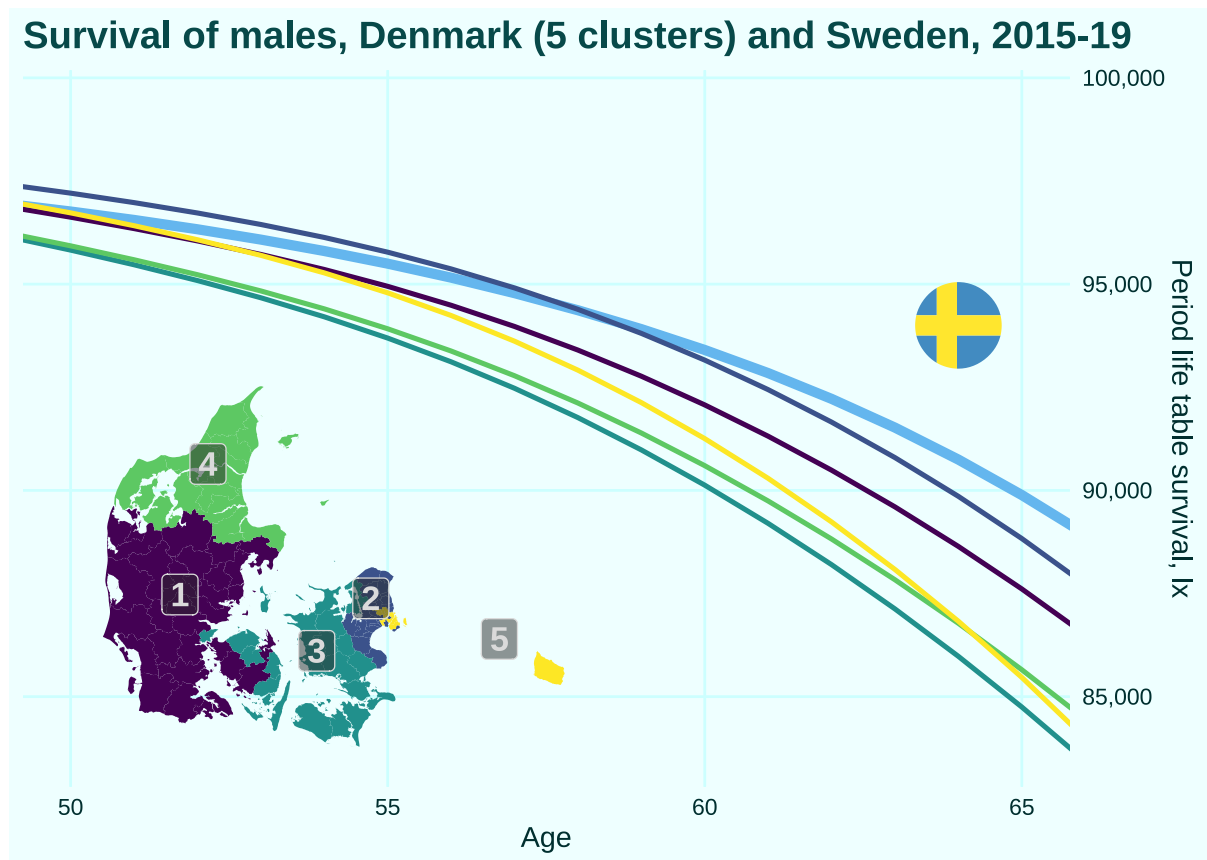


Figure 7. Survival of males between ages 50 and 65 in the 5 Danish clusters in comparison with Sweden.

Finally, I constructed the life tables for the pooled populations of the five clusters and compared the survival curves from the corresponding life tables in the age interval 50 to 65 years with the one for the pooled population of Swedish males (Figure 7). The most affluent Danish clusters start off at approximately the same level of survival by age 50 as the population of Swedish males, Danish cluster 2 starts even at a visibly higher level. Yet over the course of the next 15 years Danish males from the more affluent municipalities of the clusters 1 and 2 experience much higher death probabilities and arrive to age 65 with much lower number of survivors than Swedes. The less affluent municipalities of clusters 3 and 4 follow the same trajectory only at consistently lower levels of survival. The most curious case is the survival trajectory of the cluster 5. Males in the capital region of Denmark start the age interval at exactly the same level of survival as the Swedish males. Yet, over the 15 years of this age interval they experience the highest mortality among all the studied here populations. In the end, by age 65 they arrive with similar level of survival as the least affluent male populations of the clusters 3 and 4.

Discussion

This paper explores the spatial regularities of non-survival to pension age across Danish municipalities and puts it in the context of similar development in Sweden. I construct full life tables for the small municipal populations and then perform spatial clustering based on their mortality characteristics. The construction of reliable life tables for the small municipal populations is methodologically challenging, but is necessary for understanding subnational mortality. Even the most developed countries like Denmark and Sweden exhibit high levels of spatial inequality in mortality and spatial analysis highlights the areas where further developments in mortality reduction deserve more attention.

I find evidence that much of the lagging behind mortality is driven by relatively higher mortality of males in the specific subpopulations of more deprived areas. This observation is consistent with the findings of differential mortality in Denmark across socioeconomic gradients – the risks of early deaths are disproportionality higher among socioeconomically disadvantaged male subpopulations (Strozza et al., 2022). The double disadvantage of the most deprived subpopulations is a well-documented phenomena (Rau & Schmertmann, 2020); studies show that these vulnerable subpopulations also suffer from higher lifespan variability (Seaman et al., 2019; B. Wilson et al., 2020).

The curious national level observation of the decoupling survival curves after age 50 of Danish and Swedish populations (Figure 1) found full support in the closer analysis of developments in the subpopulations of the five clusters (Figure 7). Except for the cluster 5 that represents the capital region, all clusters demonstrate proportional development along similarly curved trajectories. There is a stark difference in the trajectory of survival in the age interval 50 to 65 of Swedish males – they experience much lower chance to die in these ages.

The capital region of Denmark represents the most curious case with high level of survival by age 50 at the beginning of the age interval and an distinctive fall out development over the 15 years of focus in this study. This peculiarity of Copenhagen deserves further investigation. One bold speculation that I may form about it is that the capital region experience such high levels of out-migration at later adult ages that the remaining population of stayers may be negatively selected on health; this would be sort of the opposite, usually unexplored, side of the same selection phenomenon that largely causes the healthy migrant paradox (Andersson & Drefahl, 2017; Wallace & Darlington-Pollock, 2020; Wallace & Kulu, 2014). The age pyramids observed in large metropolitan areas are surprisingly similar to the age profile of the intensity of internal migration (Kashnitsky et al., 2017). This finding of lowest mortality in outer-urban territories and higher mortality in the city centres is also documented in literature and is known as urban agglomeration belt area effect (Lerch, 2023; Lerch et al., 2017).

This paper provides insights into the large disparities in survival rates that exist even in developed countries such as Denmark. The results of this analysis may come valuable for public health practitioners and policymakers, shedding light on the areas where further progress in mortality reduction may be most urgently needed. Highlighting these disparities and offering insights into their causes is crucial for the development of more effective and targeted public health interventions, aimed at improving health outcomes and reducing mortality in the most vulnerable subpopulations.

Replication materials

The replication materials for this study are openly available at <https://github.com/ikashnitsky/mun-non-surv>. The results of this study demonstrate the robustness of the recent state-of-the-art methods that empower small area demographic investigations and provides a valuable framework for future studies in this area.

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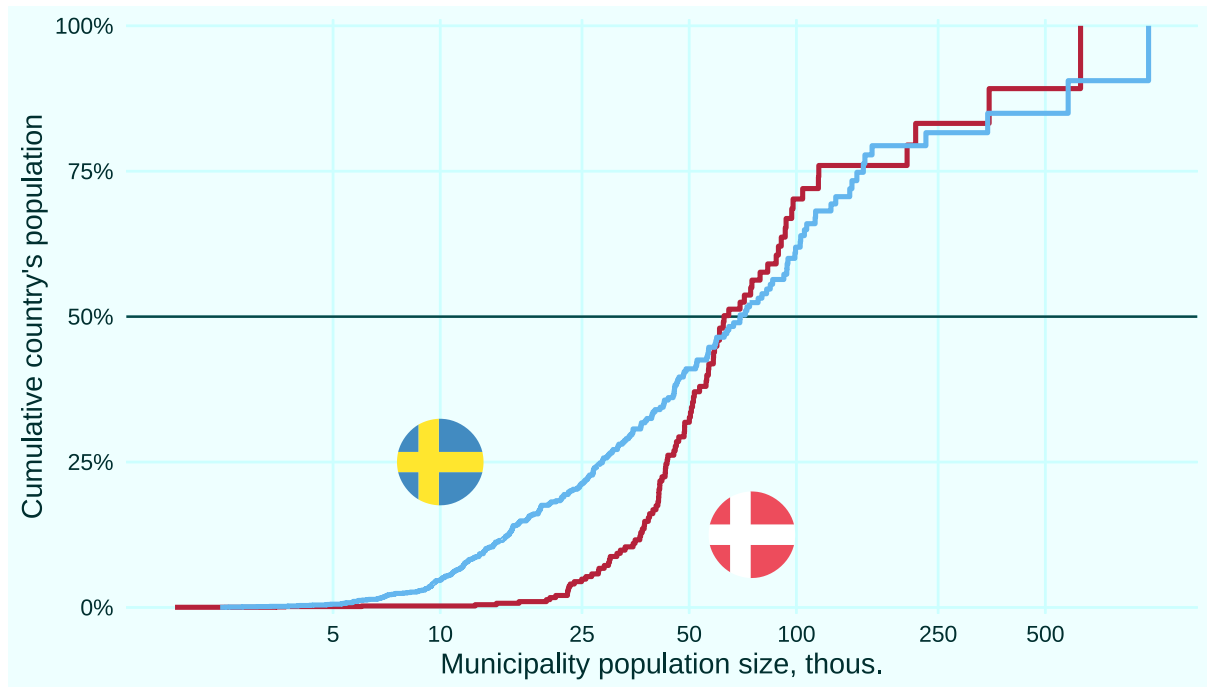
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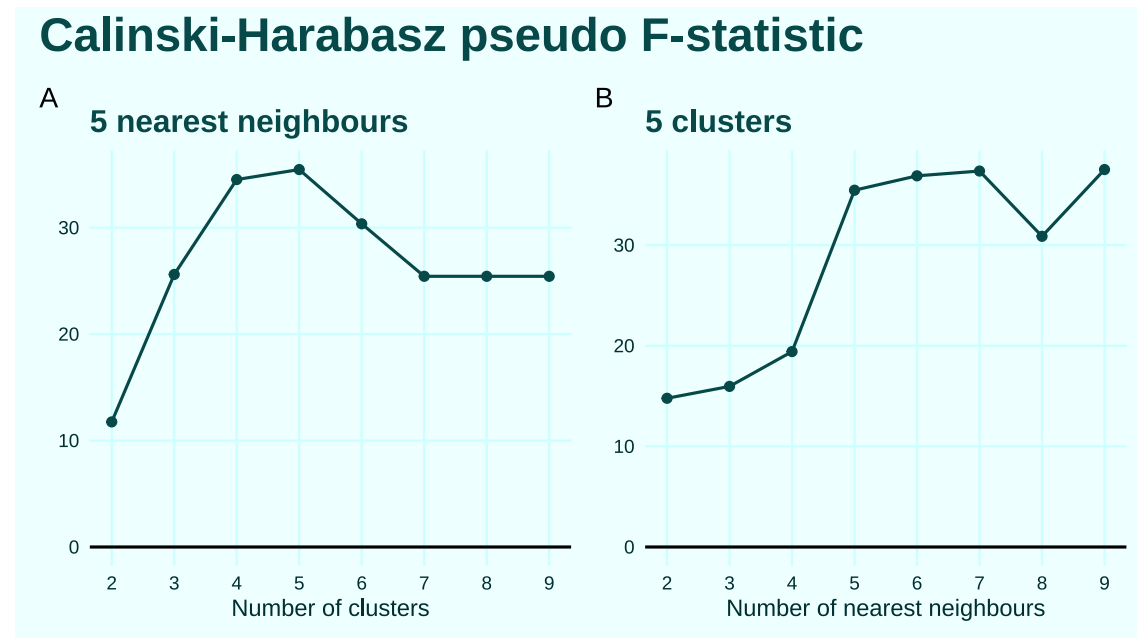
Appendix 1. Empirical cumulative densities of population sizes of municipalities in Denmark and Sweden. Source: National Statistical Offices.



Appendix 2. Comparison of TOPALS fitted life expectancies with the ones published by Denmark Statistics



Appendix 3. Calinski-Harabasz pseudo F-statistic calculated for: A – varying number of clusters between 2 and 9 and the neighbourhood matrix calculated with 5 nearest neighbours; B – varying number of nearest neighbours between 2 and 9 used for the calculation of neighbourhood matrix and the number of cluster chosen to be 6 based on the results of the previous step.



Appendix 4. Scatterplot of TOPALS fitted life expectancies against the probability of dying in the age interval 50 to 65 years.

