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The case of Norway, 1900-2060

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Abstract:
Historically, official Norwegian mortality projections computed by Statistics Norway have consistently under-predicted life expectancy. The projected age distribution of deaths may be used to check if the official mortality projections are plausible. The aim of the paper is to verify whether the projections predict a continuation of the ongoing compression in mortality and of the steady upward shift in the ages at which people die. We use official period data on observed (1900-2015) and projected (2016-2060) sex- and age-specific mortality to estimate the age distribution of life table deaths. We analyse trends in life expectancy at birth, modal and median ages at death, and standard deviation of the age distribution at ages > 30.

The historical shifts towards longer longevity are projected to continue into the future. The projections suggest a steady increase in the modal and the median age at death for men and women towards values between 90 and 94 years in 2060. At present these ages are in the range 83-90 years. Simultaneously, deaths become more concentrated around the mean, as the standard deviation of the age distribution is projected to fall continuously.

Statistics Norway's projection methodology is capable of tracking ongoing processes of mortality shifts towards higher ages and a compression of mortality around the modal and mean ages. Mortality projections could potentially benefit from including assessments of the age distribution of deaths.

Keywords: age distribution; life expectancy; median age; modal age; mortality compression; mortality delay; Norway; population projection

JEL classification: C53, I10

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Sammendrag

Siden begynnelsen av 1900-tallet har det vært en markant økning i forventet levealder i Norge, som i de fleste andre utviklede land. At dødeligheten skifter til høyere alder har implikasjoner for offentlige finanser og tjenester, særlig når det gjelder pensjonsopptak og helsekostnader. Når folk lever lenger etter at de har gått av med pensjon, forlenges gjennomsnittlig pensjonsopptak. Selv om mange land har implementert reformer for å minimere effekten av aldring ved å regne med lengre levetid i pensjonssystemet, forventes pensjonskostnadene å fortsette å øke. Videre er helsekostnader sterkt knyttet til alderen. Eldre mennesker har oftere flere helseproblemer. Som sådan bruker eldre mennesker flere helsetjenester. Samtidig tyder noen undersøkelser på at behandlingene eldre personer får, er billigere enn yngre personers. Imidlertid er eldre i gjennomsnitt dyrere enn yngre mennesker, da de krever lengre sykehusopphold og behandlinger for flere sykdommer samtidig. Gode befolkningsframskrivinger av modal alder ved død (det vil si den alderen hvor de fleste dør) og sannsynligheten for å dø i den alderen, er derfor viktig for å sikre tilstrekkelig helse- og omsorgsstyring for aldrende befolkninger.

Historisk har de offisielle norske dødelighetsframskrivingene beregnet av SSB konsekvent underestimert den reelle økningen i forventet levealder. Den forventede aldersfordelingen av dødsfall kan brukes til å kontrollere hvorvidt de offisielle dødelighetsframskrivningene er troverdige. Formålet med denne artikkelen er å verifisere om projeksjonene forutser en fortsettelse av den pågående komprimeringen i dødelighet, samt et stadig oppadgående skift i aldrene hvor mennesker typisk dør.

Vi benytter offisielle periodedata om observert (1900-2015) og framskrevet (2016-2060) kjønns- og aldersspesifikk dødelighet for å estimere aldersfordelingen av dødsfall i en dødelighetstabell. Vi analyserer trender i forventet levetid ved fødsel, modal og median alder ved død, og standardavviket av aldersfordelingen for de som er eldre enn 30 år.

Framskrivningene fra 2016 tyder på en jevn økning i modal- og medianalder ved dødsfall for menn og kvinner til mellom 90 og 94 år i 2060. I dag ligger disse i området 83 til 90 år. Samtidig blir dødsfall mer konsentrert rundt gjennomsnittet, da standardavviket i aldersfordelingen forventes å falle kontinuerlig. De historiske skiftene mot lengre levetid forventes dermed å fortsette i framtiden, og SSBs framskrivingsmetode synes å være i stand til å spore løpende prosesser med dødelighetsskift i høyere aldre og en dødelighetskomprimering rundt den modale alderen for død. Framtidige dødelighetsframskrivninger kan potensielt dra nytte av å inkludere vurderinger av aldersfordeling av dødsfall.

1. Introduction

Since the beginning of the 20th century, there has been a tremendous increase in the length of lives of humans, in Norway as in most other developed countries. Currently, these countries have relatively low levels of mortality. In Norway, life expectancy at birth for men and women has risen from 52 and 55 years in 1900, to 80 and 84 years in 2015. Improvement in longevity has been observed also in other countries (Meslé and Vallin, 2011), and has resulted in a pronounced growth of the elderly population worldwide (United Nations, 2013). In addition, the older population itself is ageing. Globally, the share of older persons aged 80 years or over (the 'oldest old') was 14 per cent in 2013 and is projected to reach 19 per cent in 2050 (United Nations, 2013). If this projection is realized, there will be 392 million persons aged 80 years or over by 2050, corresponding to a threefold increase in the number of oldest old individuals.

Historically, official Norwegian mortality projections have consistently underestimated life expectancy. During the past decade, Statistics Norway has computed these projections by means of a modified Lee-Carter model. The resulting age distribution of life table deaths may be used to check if the official mortality projections are plausible. The aim of this paper is thus to assess whether the current method predicts a continuation of the ongoing compression in mortality and shifts to higher ages. This is important and relevant because mortality shifts to higher ages has profound implications for public finances and services, especially in terms of pension uptake and health care costs (Bloom et al., 2015). In case people live longer after retirement, the average period of pension uptake is prolonged. Although many countries have implemented reforms to help minimize the impact of ageing by accounting for longer life expectancies in the pension system, pension costs are expected to continue to rise (Bloom et al., 2015). Furthermore, health care costs are strongly associated with age. Older people have more health problems and suffer more frequently from multi-morbidity (Verbrugge et al., 2017). As such, older people use more health services (Bloom et al., 2015). At the same time, some research suggests that the treatments older persons receive are cheaper than those of younger persons. This has been shown, for instance, for mortality related health services costs (Gregersen, 2014). However, in total, older people are on average more expensive than younger people, as they require longer hospital stays and treatments for multiple illnesses simultaneously (Bähler et al., 2015). How increasing life expectancy affects the relationship between health and illness in older age continues to be debated (Chatterji et al., 2015; Jagger et al., 2016; Zeng et al., 2017). A summary from 2015 concludes that there is some evidence of a compression of morbidity in high income countries, if one considers trends in functioning and disability status. However, uncertainty remains about the health of future older generations given different risk factor exposures in different cohorts and increases in the prevalence of chronic diseases (Chatterji et al., 2015). A recent study reports less cognitive impairment, more healthy life years and a decline in mild disability, but no decline in severe disability (Jagger et al., 2016). The latter finding concurs with conclusions in yet another study stating that lifespan extensions might expand disability of physical and cognitive functioning as an increasing number of frail, elderly individuals survive with health problems (Zeng et al., 2017). Longer surviving groups have nevertheless less average disability, and slower disability increases, than shorter surviving groups (Verbrugge et al., 2017). Near death, however, disability rises sharply for all. Adequate projections of the modal age at death (the age at which most people die) and the probability of dying at that age thus appear essential to ensure adequate health and care management for ageing populations.

The arguments given above show that a reliable population projection of the elderly is of paramount importance for the planning of welfare, in Norway inasmuch as in other developed countries. Therefore, it is useful to check whether future mortality trends according to the official Norwegian mortality projections, computed by Statistics Norway, are plausible. When preparing these projections in 2016, Statistics Norway focused on historical and future trends in the life expectancy; see below for illustrations. The life expectancy reflects the mean age at which people die. Other indicators, such as the modal age at death or the statistical variation around the mean age, provide important additional information – yet they were not part of the assumptions Statistics Norway formulated with respect to future mortality. After the projections were published, we felt the need to assess the plausibility of trends in future mortality by inspecting a broader range of indicators than just life expectancy.

The aim of the paper is to verify whether the 2016 population projections published by Statistics Norway project a continuation of the ongoing trends. More specifically, we analyse whether mortality becomes more concentrated around the mean age at which people die, and whether the steady upward shift in the ages at death ("delay of mortality") is expected to continue. We examine changes over time in the distribution of the age at which people died from 1900 to 2015. Next, we use the projection results from 2016 to 2060 to examine how this distribution is expected to change in the future. We analyse the mean of the age distribution of life table deaths, i.e. the life expectancy at birth, as well as the median and modal ages as measures of location of the distribution. We also examine historical and projected values of the standard deviation of the distribution of deaths as a measure of spread, to assess if a further compression of mortality is likely.

2. The age distribution of deaths

In earlier periods, the age distribution of life table deaths for humans was bimodal, with the first local mode at the left end (age 0) and the second local mode at an old age (Horiuchi et al., 2013). In recent years in low-mortality countries such as Norway, the peak at age 0 has become less pronounced. We focus on the peak that is evident in old age and denote the corresponding age the modal age at death. In the remainder of this paper, it is understood that the age distribution of deaths is one that follows from a life table calculation based on age-specific death rates, not the distribution of empirically observed or projected numbers of deaths. The reason is that historical variations in cohort size, caused, for instance, by the baby boom after World War II or by business cycles, will affect numbers of deaths many decades later, even if mortality rates are constant. Life table deaths only depend on death rates, not cohort sizes.

Whereas both the life expectancy at birth (the mean of the age distribution) and the median age at death are affected by mortality among infants, children and young and middle-age adults, the modal age is solely determined by old-age mortality (Horiuchi et al., 2013). This feature gives a special significance to the modal age because the lifespan extension during the recent few decades is mainly due to the reduction in old-age mortality (Wilmoth et al., 2000). As such, the modal age at death may be considered an equally adequate or more suitable longevity measure for assessing historical changes in old-age survival, compared with the life expectancy or the median age. Whether this also is the case for projected old-age survival in the future is less clear, and will be examined here.

The median, mean, and mode of the distribution of deaths are measures of location. A measure of spread is given by the variance or the standard deviation of the distribution, reflecting the compression of mortality around the mean or the modal age at death. A critical issue for the projection of mortality is thus to investigate how future patterns in the variance of the age at death will unfold (Tuljapurkar and Edwards, 2011), as well as related measures for mortality compression (Kannisto, 2000).

Indeed, when we observe that the variance does not change over time, while the mode increases, this may be the consequence of a shift of the distribution to higher ages (ignoring possible changes in higher order moments). In that case, we speak of a delay in the time of death, or shifting mortality. On the other hand, a constant mode combined with decreasing variances reflects a compression of mortality. In practice, a mixture of these two features is observed (Bergeron-Boucher et al., 2015).

3. Material and methods

We utilize data on the number of deaths and population size by age, sex, and year, obtained from Statistics Norway for the period 1900-2015. We computed mortality rates, assuming piecewise constant forces of mortality within one-year age intervals. We employed the rates in period life tables to compute the number of deaths per age (0-108 years) in the life table population for each year for which we have data. This variable is conventionally known as the dx-column of the life table. In case one selects a life table radix equal to one, one can interpret the dx-column as the probability distribution for the age at which the life table population dies. The purpose of the current analysis is to check whether the historical trends in the year-on-year distributions of deaths diverges markedly compared with the projected distributions. A comparison of distributions for a long series of years is difficult. Therefore, we summarized these distributions by using three measures of location, and one measure of spread, and inspected time series of those measures. We computed the life expectancy at birth (e_0) from the life tables. To find the modal and the median age, we used methods presented in Canudas-Romo (2008), also used in Horiuchi et al. (2013) and Missov et al. (2015). We interpolated between integer ages by assuming, for each year, a Gompertz model for the age pattern of the force of mortality. Estimation was done by weighted regression with mortality rates as dependent variables, and the inverse variances of those rate estimates as weights. Although not perfect, the Gompertz curve describes mortality quite well between ages 30 and 90 (Wetterstrand, 1981), and hence we restricted the fit to that age interval. The Gompertz model was used to extrapolate the distribution below age 30 and beyond age 90. Finally, we computed the standard deviation of the distribution, restricted to ages 30 and over as a measure of compression. Infant and child mortality contribute strongly to the variation of total life length, but, as Tuljapurkar and Edwards (2011) argue, by including them, one may mask important trends in old-age mortality - the focus of our analysis. We selected 30 as a cut-off age, thus avoiding a possible effect of changes in the accident hump (elevated mortality in ages between 15 and 30). As an alternative to the standard deviation, which measures variation around the mean of the distribution, we could have used the standard deviation around the modal age. In the section on results, we refer to a study by Canudas-Romo (2008) that uses the standard deviation around the mode. It finds a more or less continuous compression of mortality in six developed countries during the 20th century – qualitatively similar to our findings for Norway using the traditional standard deviation.

For the years 2016-2060, we relied on the mortality rates used in the medium variant of Statistics Norway’s 2016 official population projection. The methodology used to obtain the projected mortality rates in those population projections is described in detail elsewhere (Aase et al., 2014). In short, Statistics Norway projects future mortality rates by first using the 'product-ratio method' version of Hyndman et al. (2013) of the Lee-Carter model (Lee and Carter, 1992). The method estimates parameters for changes in the mortality level over time for the product and the ratio of men's and women's mortality rates by age, based on data for the years 1990-2015. This relatively brief period was selected because life expectancy increased rapidly during those years (in particular for men). At the same time, old projections published by Statistics Norway until 1996 had systematically underestimated life expectancy increases. Those old projections extrapolated mortality observed during periods that started in the year 1968. In case Statistics Norway had based its 2016 mortality projections on data for the years 1968-2015, it had run the risk of underestimating longevity improvements. The product-ratio version of the Lee-Carter model maintains the coherence between male and female mortality. A two components product-ratio version of the Lee-Carter model fits well to the Norwegian data for ages 0-100. The first component describes the main trends in age specific mortality in the period, while the second component covers systematic patterns that remained in the residuals after the inclusion of the first component.

When extrapolating the trend over time in the observed development in mortality, Statistics Norway assumed that each of the four-time indices of the model follows a 'random walk with drift' (RWD) process. Thus, the year-on-year step for each index consists of a certain fixed term (the drift) plus a normally distributed error term which has zero expectation. The result is an index with increasing variance around a linear trend. We only show results for the main (medium) variant, represented by an average across 2000 simulated trajectories by means of bootstrapping.

The life expectancy of men has increased more rapidly than that of women in Norway (and many other countries) during the latest decades. A mechanical extrapolation of the Lee-Carter model would have led to a cross-over of male and female rates for important ages. This is considered an implausible development, and thus the drift estimates were changed such that the sex difference in life expectancies is reduced from 3.7 years in 2015 to two years in 2060. Appropriate values of the drift parameters were found after trial and error. A sex gap equal to two years in 2060 is clearly an arbitrary choice, but it is in line with current opinions among demographers about a likely reduction in the mortality sex gap in developed countries in the future; see, for instance, the paper by Raftery et al. (2014) for references.

The relatively short base period in the official projections attempts to account for recent changes in life style factors, morbidity, medical care and prognoses with implications for future mortality at various ages. According to the official projections, many of the changes since 1990 are likely irreversible and thus likely to continue also in the future. Examples include profound changes in for instance smoking and health care advances for cardiovascular diseases and cancer, which have lowered mortality. On the other hand, obesity is on the rise and likely to result in an increase in illnesses and deaths associated with overweight (NCD-RisC, 2016). Furthermore, resistance to antibiotics has been hypothesized to possibly increase in the future, which may result in an increase in infectious deaths. Lastly, dementia is prevalent among the oldest old and thus likely to increase in the future. Deaths from dementia have increased markedly over the last two decades, and currently account for around 8% of all deaths in Norway (Norwegian Institute of Public Health, 2017).

Although the official projections extend to the year 2100, we have limited our analyses of projection results to the shorter period 2016-2060. In the very long run, projections become extremely uncertain, in particular for high ages. For instance, the 80 per cent prediction interval around the death rate of men aged 90 in 2100 (an age close to the projected life expectancy that year) stretches from 60 per cent to 160 per cent of the predicted rate value. The prediction interval widens rapidly, to between 38 and 254 per cent of the prediction at age 97. For women, the prediction intervals around age-specific death rates at high ages are similarly uncertain in the very long run. We do not have much confidence in the projection results at such a distant future.

As with the registered rates, we employ these extrapolated rates in a life table to estimate the number of deaths per age (0-108 years), sex and projected year, and use the methods described above to calculate the life expectancy, the modal and median ages at death, and the standard deviation of the distributions of ages at death for men and women.

4. Results

Table 1a, and Figures 1 and 2 show a strong postponement of death during the previous century and the past decade, as all three measures of location of the age distribution have increased markedly.

Table 1a. Modal age at death, median age at death, life expectancy, and standard deviation of the age distribution of life table deaths ages 30 and beyond (in years)

Year	Life expectancy	Modal age at death	Median age at death	Standard deviation
	Men			
1900	51.8	77.8	74.1	12.1
1940	63.2	78.9	75.1	12.3
1980	72.3	79.2	75.1	13.1
2015	80.2	86.5	83.4	10.7
2020	81.0	87.1	84.4	10.4
2060	87.2	92.7	90.2	8.6
	Women			
1900	55.1	78.6	74.7	12.5
1940	68.6	80.2	76.6	12.1
1980	79.1	85.4	82.2	11.0
2015	83.9	89.7	86.9	9.6
2020	84.6	90.3	87.6	9.6
2060	89.2	93.9	91.5	8.2

Since the beginning of the 1900s, the life expectancy at birth of men and women rose by almost 30 years. This makes an average increase of 0.26 years of age per calendar year, or slightly more than three months per year. For future years, however, annual increases are smaller: for men and women the projected averages are, respectively, 0.15 and 0.12 years per year in the period 2020-2060 – roughly one day per week (Table 1b). In other words, the improvement in life expectancy at birth is expected to slow down. Technically speaking, this is caused by the straight line (RWD) extrapolation of the time indices of mortality in the logarithmic scale in the Lee-Carter model. When the log of the rates falls linearly over time, the increase in life expectancy is less than linear. It turns out that this is also the case for the mode and the median of the distribution of deaths; see Figure 1 and Table 1b.

Table 1b. Average annual increases in life expectancy, modal age, and median age for men and women (expressed in years of age per calendar year)

	Life expectancy		Modal age at death		Median age at death	
Period	Men	Women	Men	Women	Men	Women
1900-1940	0.286	0.336	0.028	0.040	0.027	0.046
1940-1980	0.228	0.264	0.007	0.130	-0.001	0.141
1980-2020	0.218	0.136	0.204	0.123	0.231	0.135
2020-2060	0.154	0.117	0.132	0.088	0.147	0.099

Bergeron-Boucher et al. (2015) find a slight decline in the modal age for women in Sweden during the years 1900-1940. They also notice that the average pattern of 15 low mortality countries with pre-1940 data in the Human Mortality Database is one of a minor increase in the modal age for women between 1900 and 1940 (with a slope equal to 0.04 years of age per calendar year) and a much stronger increase in the period 1940-2010 (a slope of 0.138; the latter period includes 10 additional countries). Norwegian mortality closely mirrors the international pattern, with slopes in the modal age for women equal to 0.04 (1900-1940) and 0.13 (1940-2010).

Stagnating longevity for men during the 1950s and 1960s has been observed in a number of Western countries (Meslé and Vallin, 2011). Life expectancies stagnated not only in Norway in those years, but also in other countries such as Denmark, Finland, Netherlands, Belgium, New Zealand, and Australia (Luy, 2015). One possible explanation for the structural breaks in male mortality after World War II is the progression of the tobacco epidemic. Several studies have found that smoking had a distorting effect on trends in the male life expectancy and male mortality (see e.g. Janssen et al., 2015; Beltran-Sanchez et al., 2015), and also for Norway specifically (Vollset et al., 2006). Yet, smoking is not the main force behind the sex gap in life expectancy in all countries where male life expectancy stagnated (Luy and Wegner-Siegmundt, 2015). In Norway, dietary changes with a more pronounced intake of unhealthy fats have likely contributed. This is evident by a marked increase in cardiovascular deaths for men in all age groups from the mid-1950s. Nowadays, circulatory disease mortality is no longer the first cause of death in many developed countries (Beltran-Sanchez et al., 2015). Different changes in mortality regimes for different age groups may have led to changes in the age pattern of mortality. More generally, the trend shifts for males were caused by a change in major causes of death for men below age 45 after World War II, from infectious diseases before the war to man-made diseases after the war (Meslé and Vallin, 2011). In Norway, while mortality from infectious diseases continued to decline also after World War II, the most pronounced change was the increase in cardiovascular deaths. The greater male vulnerability to cardiovascular conditions led to changes in health-related behaviours. In the historical data from Norway, the mode (M) of the distribution of deaths occurs at a considerably higher age than the average, i.e. the life expectancy at birth (e_0). The median age (Med) is placed in between these two. This is because the distribution has a long tail to the left. Horiuchi et al. (2013) state that during the last few decades, M is typically around five years higher than e_0, and Med is near the mid-point between M and e_0 in developed countries. In the Norwegian data of 2015, the difference between M and e0 is about 6 years (6.3 years for men, 5.8 years for women). Med is located almost perfectly in the middle between M and e_0. In the future, the three measures will converge as the deaths will become more concentrated around the median (see below). In 1900, the modal age was more than 20 years higher than the life expectancy, while the median age was very close to the modal age. A comparison of Figures 1 and 2 shows that the life expectancy, being a proper average of an empirical distribution and hence sensitive to extreme values, develops much more irregularly than the other two measures.

As stated earlier, Statistics Norway explicitly assumed a continued reduction in the sex gap of life expectancies. The female advantage in terms of life expectancy was 6.8 years in 1980 and 3.7 years in 2015 (Table 1a). The gap is expected to be just 2 years in 2060. Do the projections imply a similar narrowing sex gap for the modal age and the median age? The answer is yes, as can be seen from Table 1a. The sex gap in the modal age will narrow further, from 6.2 years in 1980 and 3.2 years in 2015, to 1.2 years in 2060. The gap in median ages is expected to be reduced from 7.1 (1980) and 3.5 (2015) years to 1.3 years in 2060.

Figure 1. Modal and median ages at death; historical (1900-2015) and projected (2016-2060) values

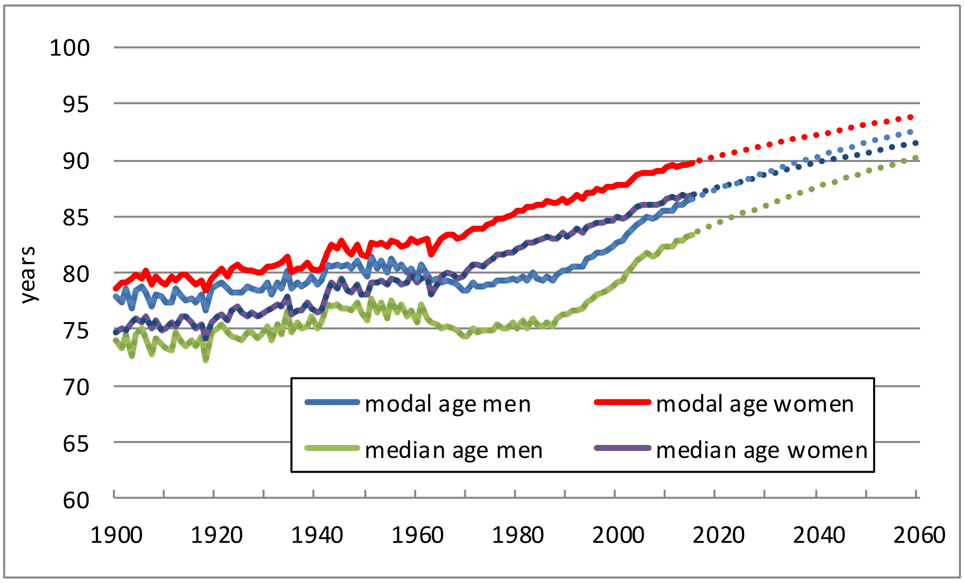


Figure 2. Life expectancy at birth; historical (1900-2015) and projected (2016-2060) values

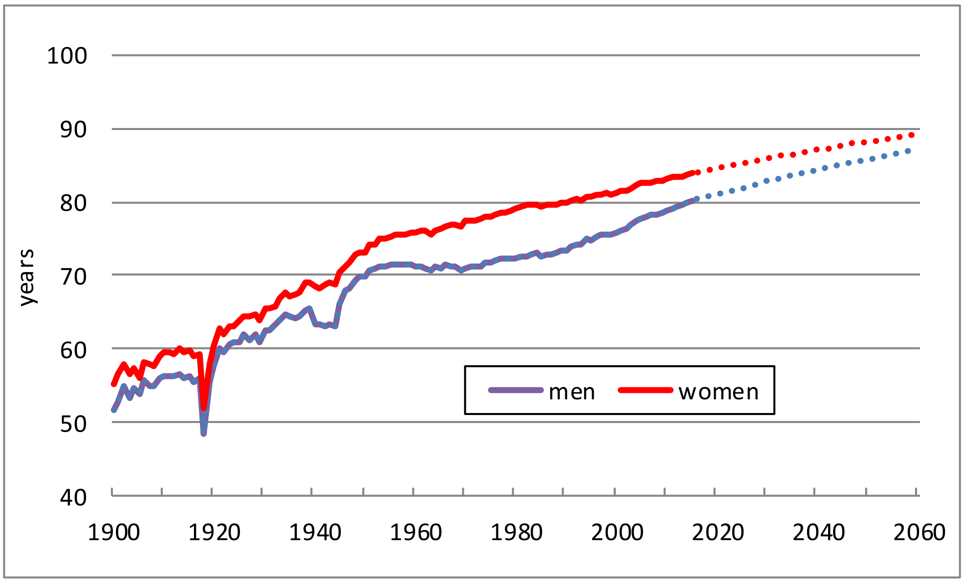
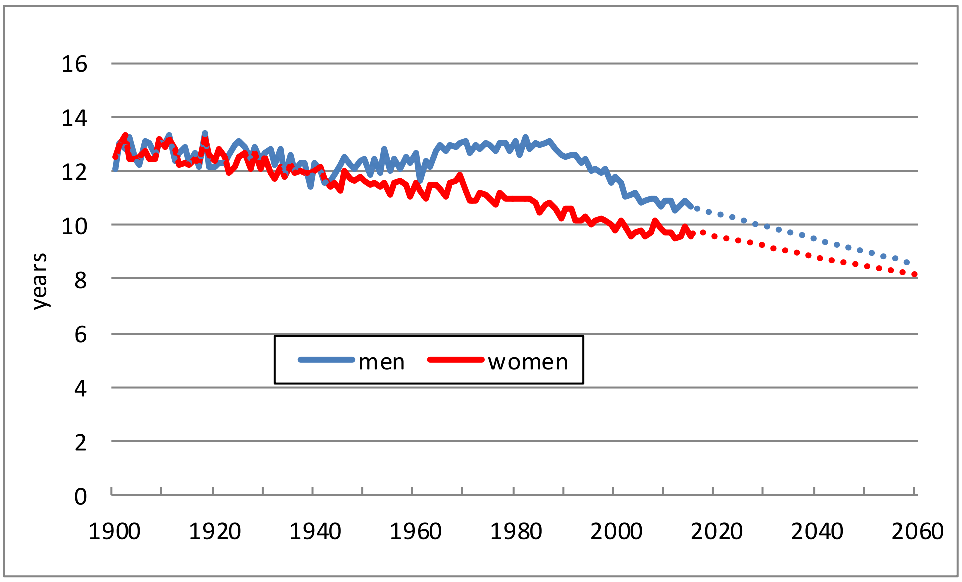


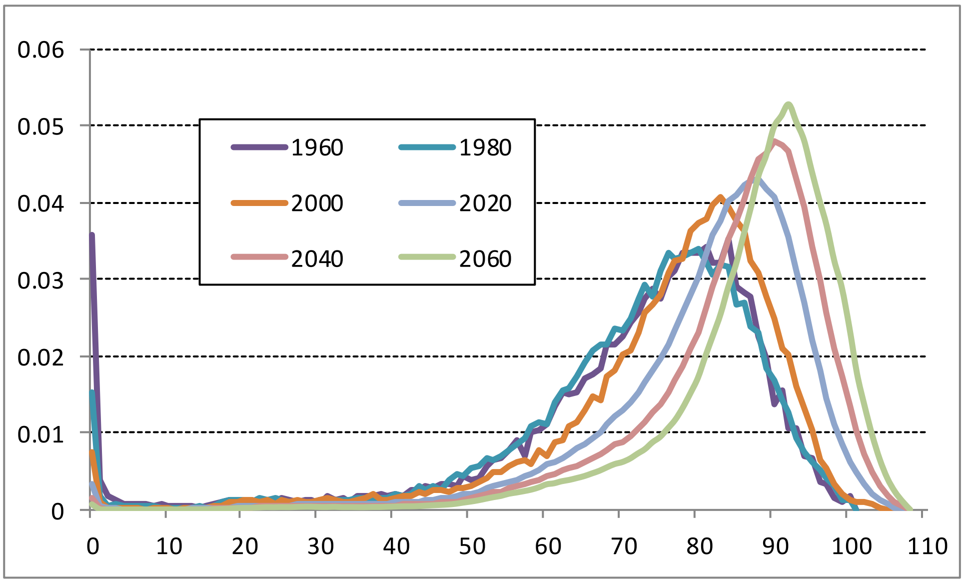
Figure 3 portrays historical and future trends in the standard deviation of the age at death for men and women since 1900, where the standard deviation is restricted to ages 30 and over. A continuous compression of old age mortality is evident, although for men the trend was interrupted in the second half of the 20th century. This compression is expected to continue to 2060. Yue (2012) analysed data from Japan, the US, and Sweden for the years 1950-2005. The standard deviation (all ages) for the US and for Sweden showed a qualitatively similar pattern for men (stable between 1970 and 1990, steep decline thereafter) and women (gradual decline after 1970). His time series are much shorter than ours, and hence he could not notice that the long-term trend for men in these two countries might be downward (as it is for Japanese men and women). Tuljapurkar and Edwards (2011) plot the historical trend in the standard deviation above age 10 for both sexes combined in the US in the period 1959-2005, and the predicted trend using Lee-Carter based mortality projections to 2050. While the historical pattern fluctuates between 15.0 and 15.8 years, the standard deviation is clearly sloping downwards to 2050, with an average fall by 0.017 years per year. In contrast, Figure 3 shows a much stronger degree of compression for Norway over the same period, with slopes equal to -0.04 for men and -0.03 for women. Canudas-Romo (2008) analyses a related dispersion indicator of the distribution of deaths for multiple industrialized countries, namely the standard deviation around the modal age (rather than around the usual mean age). His standard deviations for six developed countries for both sexes combined show a much slower fall during the second half of the century than in the first half. One explanation could be that, similar to the case of Norway, standard deviations for women fell regularly, while those for men stagnated during the first few decades after World War II.

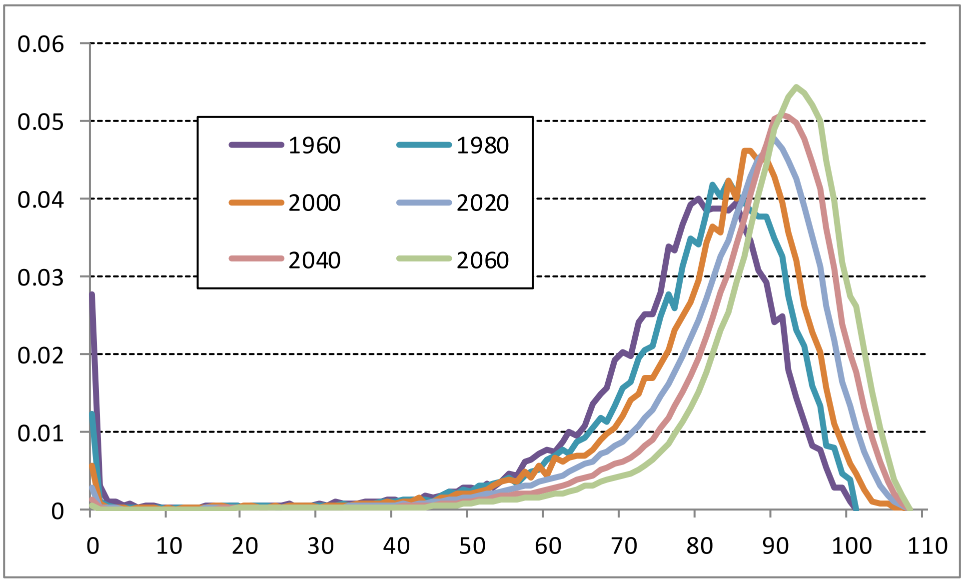
Figure 3. Standard deviation of age distribution of life table deaths for ages 30 and beyond; historical (1900-2015) and projected (2016-2060) values



What do these trends in measures of location and spread imply for the age distribution of deaths in the future? Figure 4 plots the patterns for selected years for men and women, respectively. We observe a continuation of the shift towards higher ages, accompanied by a further compression. Over time, fewer and fewer persons die at ages below 80, while it has become more and more likely to live at least until age 90. Falling death rates below the modal age – the left tail of the distribution – seem to have contributed more to compression (the distribution becoming more peaked as measured by a decline in the standard deviation) than falling death rates beyond the modal age – the right tail. For instance, men had in 1960 a chance of 1 per cent of dying at age 58 (left tail, ignoring mortality for young children). In 2060, this one per cent chance is delayed to age 76, or 18 years later. However, in the right tail we see that the "one per cent chance age" moves up by only ten years in the same time interval, from 93 years of age in 1960 to 103 years of age in 2060. Had the "one per cent chance age" in the right tail moved in tandem with that age in the left tail, and similarly for all other chances (not only 1, but also 2, 3, 4, … per cent), then the shape of the distribution would have remained unchanged, and there would have been no compression – just a shift to higher ages.

Figure 4. Age distribution of life table deaths for men (upper panel) and women (lower panel); historical (1960, 1980, 2000) and projected (2020, 2040, 2060) values





Discussion and conclusions

The 2016 Norwegian mortality projections computed by Statistics Norway expect that historical shifts towards longer longevity will continue into the future. The projections suggest a steady increase in the modal and the median age at death of men and women towards values in the range of 90-94 years in 2060. This is a continuation of the upward trend in modal and median ages at death observed since 1960 for men. For women such a trend is visible during the whole of the 20th century. Similar to the projected trend in the life expectancy, the increases in the modal and the median ages of men and women will become less steep in the future. While Statistics Norway explicitly assumed smaller differences in future life expectancies for men and women compared to current values, the projections resulted in a reduced sex gap in the median age at death and in the modal age at death as well.

Doubts have been expressed whether Lee-Carter based mortality projections are able to predict a (sufficiently strong) delay of mortality (Janssen and De Beer, 2016). Although we cannot exclude a stronger delay during the years 2016-2060 than reflected by the projections, we do not find clear support in our analysis for such a statement.

The standard deviation in the age at death (ages 30 and beyond) for men was roughly at a constant level during most parts of the previous century, but declined rapidly from the late 1980s until today. In the projections, the male standard deviation is expected to fall further also in the future, but not as steeply as before. This suggests a further compression of male mortality. For women, the drop has been less steep than that for men, but at a more or less constant rate. It is expected to continue to decline at a steady pace also in the future. Consequently, the observed gap in the standard deviations of men and women is expected to narrow. As such, also female mortality is expected to be further compressed in the future. In conclusion, the method used by Statistics Norway for projecting mortality is capable of tracking ongoing processes of mortality shifts towards higher ages, and of a compression of mortality around the modal and mean ages.

Our empirical findings are entirely based on period mortality. Some scholars argue that the observed compression of mortality may be due to, at least partly, distortions in the period age schedule (see e.g. Ediev, 2013). Cohort mortality would thus be a more appropriate perspective. However, although we have an extended time series of data of good quality, we would be able to analyse empirical data for only 16 birth cohorts (those born 1900-1915) up to age 100. In our view, this is too short a series to draw any firm conclusions.

In terms of consequences for public finances, pension costs will increase as mortality is shifted to older ages. A reform of the Norwegian public pension scheme was implemented in 2011, adjusting annual pension benefits for increases in life expectancy in an actuarial neutral way. In terms of health care costs, a higher modal age at death is likely to be associated with higher costs due to the documented increase in the prevalence of multi-morbidity at older ages (Chatterji et al., 2015). However, if future morbidity will compress parallel to the projected compression of future mortality, this will ensure that not too many people live too long with conditions in need of treatment, and thus prevent escalating health care costs.

To minimize overestimations of future mortality in official projections – with important implications for public finances and services – it may be advisable to include an assessment of the age distribution of deaths when producing such projections.

References

Aase, K. N, Tønnessen, M. & Syse, A. (2014). *The population projections - Documentation of the BEFINN and BEFREG models*. Report 2014/25. Oslo: Statistics Norway.

Bähler, C., Huber, C. A., Brüngger, B., & et al. (2015). Multimorbidity, health care utilization and costs in an elderly community-dwelling population: a claims data based observational study. *BMC Health Services Research*, 22(15):23.

Beltran-Sanchez, H., Finch, C. E., & Crimmins, E. M. (2015). Twentieth century surge of excess adult male mortality. *Proceedings of the National Academy of Sciences of the United States of America*, 112:8993–8998.

Bergeron-Boucher, M. P., Ebeling, M., & Canudas-Romo, V. (2015). Decomposing changes in life expectancy: compression versus shifting mortality. *Demographic Research,* 33(1):391–424.

Bloom, D. E., Chatterji, S., Kowal, P., & et al. (2015). Macroeconomic implications of population ageing and selected policy responses. *Lancet,* 385(9968):649–657.

Canudas-Romo, V. (2008). The modal age at death and the shifting mortality hypothesis. *Demographic Research*, 19(30):1179–1204.

Chatterji, S., Byles, J., Cutler, D., & et al. (2015). Health, functioning, and disability in older adults – present status and future implications. *Lancet*, 385(9967):563–575.

Ediev, D. (2013). Mortality compression in period life tables hides decompression in birth cohorts in low-mortality countries. *Genus*, 69(2):53–84.

Gregersen, F. A. (2014). The impact of ageing on health care expenditures: a study of steepening. *Eur Journal of Health Economics*, 15(9):979–989.

Horiuchi, S., Ouellette, N., Cheung, S. L. K., & et al. (2013). Modal age at death: lifespan indicator in the era of longevity extension. *Vienna Yearbook of Population Research*, 11:37–69.

Hyndman, R. J., Booth, H., & Yasmeen, F. (2013). Coherent mortality forecasting: the product-ratio method with functional time series models. *Demography*, 50(1):261–283.

Jagger, C., Matthews, F. E., Wohland, P., & et al. (2016). A comparison of health expectancies over two decades in England: results of the Cognitive Function and Ageing Study I and II. *Lancet*, 387(10020):779–786.

Janssen, F., & De Beer, J. (2016). Projecting future mortality in the Netherlands taking into account mortality delay and smoking. WP 18/2016. Joint Eurostat/UNECE Work Session on Demographic Projections, 2016. Accessed from: https://www.unece.org/fileadmin/DAM/stats/documents/ece/ces/ge.11/2016/WP18.pdf

Janssen, F., Rousson, V., & Paccaud, F. (2015). The role of smoking in changes in the survival curve: an empirical study in 10 European countries. *Annals of Epidemiology*, 25(4):243–249.

Kannisto, V. (2000). Measuring the compression of mortality. *Demographic Research*, 3:6.

Lee, R. D., & Carter L. R. (1992). Modeling and forecasting U.S. mortality. *Journal of the American Statistical Association*, 87(419):659–671.

Luy, M. (2015). Adult mortality in industrialized societies. In: J.D. Wright (ed.). *International encyclopedia of the social and behavioral sciences* (2nd ed., vol. 1). Oxford: Elsevier, pp. 170–180.

Luy, M., & Wegner-Siegmundt, C. (2015). The impact of smoking on gender differences in life expectancy: more heterogeneous than often stated. *European Journal of Public Health*, 25(4):706–710.

Meslé, F., & Vallin, J. (2011). Historical trends in mortality. In: R.G. Rogers, & E.G. Crimmins (eds). *International handbook of adult mortality*. New York: Springer, pp. 9–47.

Missov, T. I., Lenart, A., Nemeth, L., & et al. (2015). The Gompertz force of mortality in terms of the modal age at death. *Demographic Research*, 32(36):1031–1048.

NCD Risk Factor Collaboration (NCD-RisC). (2016). Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19.2 million participants. *Lancet*, 387(10026):1377–1396.

Norwegian Institute of Public Health. (2017). *Cause of Death Registry/Causes of death 2016: Cancer stable, dementia increasing.* Accessed from: www.fhi.no/helseregistre/dodsaarsaksregisteret

Raftery, A., Lalic, N., & Gerland, P. (2014). Joint probabilistic projection of female and male life expectancy. *Demographic Research*, 30:795–822.

Tuljapurkar, S., & Edwards, R. (2011). Variance in death and its implications for modeling and forecasting mortality. *Demographic Research*, 24:497–526.

United Nations, Department of Economic and Social Affairs, Population Division. (2013). *World population ageing*. ST/ESA/SER.A/348.

Verbrugge, L. M., Brown, D. C., & Zajacova, A. (2017). Disability rises gradually for a cohort of older Americans. *The journals of gerontology. Series B, Psychological sciences and social sciences*, 72(1):151–161.

Vollset, S. E., Tverdal, A., & Gjessing, H. K. (2006). Smoking and deaths between 40 and 70 years of age in women and men. *Annals of Internal Medicine*, 144:381–389.

Wetterstrand, W. H. (1981). Parametric models for life insurance mortality data: Gompertz' law over time. *Transactions Society Actuaries*, 33:159–179.

Wilmoth, J. R., Deegan, L. J., Lundstrõm, H., & et al. (2000). Increase of maximum life-span in Sweden, 1861-1999. *Science*, 289 (5488):2366–2368.

Yue, J. C. (2012). Mortality compression and longevity risk. *Northern American Actuarial Journal*, 16(4):434–448.

Zeng, Y., Feng, Q., Hesketh, T., & et al. (2017). Survival, disabilities in activities of daily living, and physical and cognitive functioning among the oldest-old in China: a cohort study. *Lancet*, 389(10079):1619–1629.

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