An analysis of mortality trends in developed countries, focusing on the recent slowdown in mortality improvements

Longevity Science Panel

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The Longevity Science Panel has been set up to monitor trends, generate discussion and form views on issues related to the UK's population longevity trend. The Panel is interested in the drivers that are enhancing life expectancy for example, medical advances and social change, as well as the inhibitors such as aspects of lifestyle and delays in development of treatments.

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Summary

Mortality rates have fallen or 'improved' in many developed countries. The yearly improvement is called mortality improvement rate in this report. The slowdown of mortality improvement rates since around 2010 in the UK and other countries has been widely debated. To understand this issue better, we have analysed population mortality trends of developed countries using data from the Human Mortality Database. These data have been consistently organised and adjusted, making them more suitable for coherent comparisons.

We first described the historical mortality improvement rates of these countries for age 25-95, then looked at mortality improvement trends using statistical models for the over 50s. As far as we are aware, this is the first study of its kind. Sixteen countries have data for 2011-2015 and we summarise their results here.

For age 25-50, our results are mixed. Countries such as the UK, USA, Netherland, Australia, Canada, Germany and Sweden have experienced lower mortality improvement rates in 2011-2015 when compared with the preceding decade. But other countries have experienced higher such as Belgium, Denmark, Finland, Japan and Portugal. More needs to be done to examine country-specific influences in this age group to reduce preventable deaths.

For the over 50s, we have used statistical models to analyse the historical mortality trends of various countries between 1965 and 2010 to project trends beyond 2011. We ask:

- Given the historical trends, would we have projected any slowdown in mortality improvement rates since 2011, when compared with the recent past?
- What happened since 2011 when compared with projections?

The answer to the first question is: Yes, for many countries and with a gender difference. When we look at the period from 2000, the projected mortality improvement rates in 2011-2015 were lower than the actual improvement rates in the preceding decade among men in 14 countries and women 7. These results are consistent with hypotheses for stalling mortality improvements that emerged before 2010. Examples may include unfavourable trends in obesity, diabetes, cardiovascular-related deaths, dementia deaths and frailty.

Regarding the second question, we compare the projections with actual mortality improvement rates since 2011. Again we observe a gender difference. Women in 14 countries but men in 8 have experienced lower mortality improvements than projected during 2011-2015. The UK, Spain and Germany are the 3 worst performing countries by this measure. This observation, at least for some countries, is consistent with suggestions that austerity and the unusually high winter deaths during this period may have adversely affected mortality trends.

A number of the Scandinavian populations have bucked the stalling mortality improvement trend, experiencing higher mortality improvement rates than projections.

In conclusion, part of the slowdown in mortality improvement rates of the over 50s since 2011 would have been expected from historical trends in many countries, especially among men. There has been notable slowdown, compared with projections, since 2011 in many countries especially among women. But, there are some countries with higher mortality improvement rates than projected. A better understanding of the drivers behind these complex trends will inform policies.

Introduction

In the twenty years between 1991 and 2011, life expectancy at birth for males in England and Wales grew by almost five years and by more than four years for females. In 2015, a sharp spike in the number of deaths, especially among older people, resulted in an unprecedented fall in life expectancy in England and across several European countries. In the same year, life expectancy at birth fell in the USA (Case and Deaton, 2015).

In the first published analyses of this phenomenon, contrasting viewpoints emerged. Ho and Hendi (2018) took the view that, in contrast to the USA, the simultaneous spike in mortality in 2015 in several high-income European countries was largely attributable to influenza. However, Hiam et al. (2017) focused their attention on the high rates of mortality in the elderly over 75 in England in 2015 and attributed these to the negative consequences of the UK Government's austerity policies and reductions in the funding of health and care services (Institute for Fiscal Studies, 2017). The 'austerity' explanation was subsequently challenged, mainly on the grounds that association does not prove causation and, furthermore, that, in the UK, pensioners were being better protected from spending cuts than other age groups (Fordham and Roland, 2017).

Subsequent analyses of English data by the Continuous Mortality Investigation (CMI) and insurance industry analysts showed that the stagnation in rates of mortality improvement was observable across all levels of socioeconomic class and deprivation (Palin, 2017; CMI, 2017). This contrasted with the experience of the USA, which experienced a real fall in life expectancy at birth for two consecutive years (2015 and 2016). However, the fall in USA was driven by increases in mortality in a specific range of ages and for a specific sub-population – namely, middle-aged, low educated, white adult men (Case and Deaton, 2015). In England, mortality improvements slowed across all socioeconomic strata as well as at older ages, but at a differential pace which flattened most for the most deprived groups. Thus, in England, mortality inequalities widened further for those aged 65 and over. (Palin, 2017; CMI 2017; Club Vita 2017; Longevity Science Panel 2018; Kleinow et al, 2019).

Subsequently, the ONS and a number of public organisations, industry bodies and academics have provided commentary and analysis of various dimensions of the phenomenon in England.

The emerging consensus so far is that between 2011 and 2017 (Palin, 2017; CMI 2017; Club Vita 2017; Longevity Science Panel 2018; Kleinow et al, 2019),

- The aggregated rates of mortality improvement across ages continued to improve but there was a marked slowing down in England.

- The slowdown was accompanied by increased volatility in mortality rates, year on year, making it more difficult to isolate underlying long-run trends from short-term seasonal fluctuations.

- The slowdown affected all types of neighbourhoods - rich and poor - as measured by the Index of Multiple Deprivation (IMD).

- The slowdown in rates of mortality improvement was greatest in the most deprived areas, resulting in the widening of inequalities. Women's life expectancy in the most deprived decile areas (based on IMD) has been decreasing.

- Mortality changes particularly affected older ages. In some years mortality rates increased for specific age groups, especially in winter months. This affected older women the most.

Public Health England (PHE) conducted a review of the possible factors to explain the flattening in mortality rates. They first ruled-out the contribution of potential data artefacts - in particular an abrupt change attributable to the rebasing of the population following the 2011 Census. A similar pattern of stagnation was observed in an independent industry database of pensions (Club Vita, 2017). Additionally Bajekal has assessed the impact of inter-census revisions to small-area boundaries and the introduction of a new index of deprivation 'IMD 2015' on the stability of allocation of small areas to quintiles of relative deprivation across the period from 2001 onwards (personal communication). The results showed that the allocation of small areas in IMD quintiles has been relatively stable, ruling out potential data artefacts due to census and introduction of new IMD 2015 classification.

Epidemiologists have studied the causes the slowdown in the mortality improvement (Raleigh, 2019). Excess winter mortality was particularly marked in 2015. This phenomenon was also observed in a number of other European countries. It was higher in France, Germany and Italy than in the UK, and has been attributed largely to 'flu based on corroborative information on hospital admissions, the 'flu strain in circulation A(H3N2), and low efficacy of the vaccine despite high take-up. However, the downward trend in standardised mortality rates in non-winter months has also slowed since 2011. Hence, whilst 'flu-related mortality has been exacerbated by cold winters, it is likely that other factors are also influencing the long-term stagnation (Public Health England, 2018).

Analysis of mortality by cause of death points to a reduction in improvement in mortality from cardiovascular disease (coronary heart disease and stroke) among those aged 65 and older as the main driver (Public Health England, 2018). Reductions in cardiovascular disease mortality, which is the leading cause of death, have historically driven improvements in life expectancy and any change in these rates has a large impact on trends.

Over the same period, deaths attributed to dementia increased sharply from about 2006 onwards. With more people surviving to old age, an increase in deaths from dementia is to be expected. However, changes to the coding of the underlying causes of death with the introduction of ICD10 and its revisions in 2011 and 2014 (e.g. all vascular dementias that were previously coded to circulatory diseases are now being coded to dementia), alongside a greater awareness of the condition by certifying doctors, may have also contributed to the sharp rise in dementia mortality rates. Changes in classification of causes of death do not affect the trends in overall deaths. However, any changes to prevention and treatment of dementia and other neurological diseases will affect future mortality trends.

In 2016, the causes of death contributing most to the inequalities between the most and least deprived deciles of the English population were heart disease, respiratory diseases and lung cancer, particularly at ages 55-75 (Bennet, 2018). Much of the excess mortality for disadvantaged women has been attributed to the delayed effects of the lag in the uptake of smoking in women compared to men (Leon et al, 2019).

Trends in comparator high-income countries

The slowdown in the rates of mortality improvements observed in the UK is not unique and similar changes have been seen in other European countries. Six of the largest EU countries (France, Germany, Italy, Poland, Spain, UK) saw a fall in life expectancy for both men and women between 2014 and 2015, with female life expectancy at birth falling in 23 of the 28 EU countries, while male life expectancy at birth fell in 16 EU countries (ONS, 2018, Raleigh, 2019). The European mortality monitoring network has attributed excess mortality in Europe in the particular winters of 2015, 2016 and 2017 to flu, and the particular strain prevalent, A(H3N2). There is agreement that flu has played a role in the increased volatility of recent mortality trends in many counties. But the significance of its role in the general slowdown in mortality improvement in the EU countries is unclear.

Reports regarding the over 65s in the Netherlands (Statistics Netherlands, 2019) and in Germany (Wenau et al., 2019) also show that inequalities in life expectancy by socio-economic status measures have widened in recent years. However, more in-depth analysis of mortality patterns by cause of death or inequalities has not so far been conducted.

Nevertheless, several analyses (using different start-end dates, different summary measures of mortality, different age-ranges, different sets of comparator counties) have all concluded that, among high income countries other than the US, the greatest slowdown in the rates of mortality improvements has been in the UK (Raleigh, 2018; Leon et al., 2019). For example, Leon et al (2019) compare England & Wales mortality trends with those of the median of a group of 22 comparator high income countries. They find that England & Wales mortality rates at ages 25-49 are "appreciably higher" than in the comparator group, that the trend in life expectancy for England & Wales since 2011 is among the worst performing and this is particularly the case for women.

Comparative country analyses (Raleigh, 2018) have afforded some important insights to challenge some simplistic hypotheses, e.g.:

- that countries with the highest life expectancy would experience the slowest improvements if the slowdown was because limits to mortality improvements were being approached – but this was not so for Switzerland and Japan, which did not experience a slowdown at all;

- that the larger the rates of improvement in the years prior to 2010, the greater is the slowdown – but this was not so in Italy with its high, and steady, rates of improvement;

- the higher the level of austerity, the bigger is the reduction - Greece and Spain have experienced rising life expectancy despite having higher levels of austerity cuts than the UK; and

- the differences in the gender specific trends within countries remain unexplained.

Policy response in the UK

While policy makers are alert to the call to action to reverse the adverse trends in mortality, it remains unclear what levers to pull. To reverse the trend, we need a much better understanding of the drivers of the change in rates of mortality improvement. It remains uncertain if the flattening out in the downward trend in mortality rates will persist – recent reports suggest an upturn in trends in 2018 and 2019 (Murphy, 2019; Leon et al, 2019). Most commentators in the UK point to an explanation that involves many factors, set against a backdrop of fiscal austerity, which have contributed to the recent large falls in mortality improvement in the UK. The argument that fiscal austerity has differentially affected women is supported by estimates from the House of Commons Library that, up to the 2017 autumn budget, 86% of the reduction in public spending, which the government has made through changes to taxes and benefits, is from spending which previously went to women (Keen and Cracknell, 2017).

Attempts at explaining the changes in the long-term trend in the UK must address several questions including (Raleigh, 2017):

- why are post-2010 mortality trends (both between and within years) more erratic than in preceding decades?
- why are post-2010 mortality trends worse in older women than older men?
- why is the slowdown greatest in the most deprived sections of society?
- why are similar patterns seen in many European countries?
- why is the slow-down in mortality improvement in the UK worse than in other European countries?

Industry response

The life insurance sector in the UK has released some £2bn of reserves related to annuities in 2019 alone. Much of the release of reserves was related to changes in the actuarial assumptions to allow for at least part of the slowdown in mortality improvement to continue into the near future.

If the slowdown were caused by more structural changes, such as funding cuts in health and social care, then one might assume that the slowdown would continue if these structural changes were to continue. However, if the slowdown in mortality improvement were due to more preventable or unpredictable causes, such as advancement in vaccination for circulating flu strains, then there is a chance that mortality improvement rates might climb back up. This would require insurance companies to set aside more reserves for longevity risks at a future date through their regular risk management processes.

We believe that a robust and detailed international comparison of mortality improvement trends across ages and genders would play a useful role in informing policmakers and the industry. For example, if many other developed countries have not experienced a slowdown in mortality improvement recently, so that the UK is an outlier, then this may suggest that there is scope for a reversal of the recent slowdown in mortality improvement rates in the UK. This may happen through policy changes, for example through more targeted health improvements in the more deprived population, or improved prevention of winter deaths.

Motivation

Most publications from the perspective of epidemiology, public health or demography tend to express their results in summarised statistics such as life expectancy or standardised mortality rates. While these indices are effective in summarising trends and communicating emerging issues to the public, they lack the granularity required by the insurance and financial sectors to inform the calculations for reserves (and prices) for longevity risks for portfolios of annuities or pensions. It is also difficult for policymakers to know where to focus their attention. The UK Actuarial Profession has analysed annual rates of improvement in mortality in England and Wales by age and calendar year, but international comparisons are limited to very few countries because of the need for detailed statistical analyses.

Here, we have attempted to fill this gap by analysing the mortality trends of 23 developed countries by age groups and gender to understand better the nature of the slowdown in improvement in mortality, and in some case rises in mortality, that have been observed. The detailed analysis and modelling of historical mortality data of individual ages and calendar years since 1965 will enable us to understand more fully the nature of the slowdown in mortality improvement rates and to analyse in detail the differences in the underlying trends in mortality rates across countries.

1 Data

The following twenty-three countries are considered in this analysis: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Taiwan, UK, and US. These countries were chosen as being countries with sufficiently large populations, developed economies and good quality data.

The analysis is based on population data obtained from the Human Mortality Database (HMD, 2019). The range of ages and calendar years that are available vary by country: see Table 1 [1].

We note that data availability at very advanced ages (e.g. beyond age 100) is sparse in many countries.

[1] Data downloaded in Mach 2019.

Country	Age range	Calendar years
Australia	0 - 109	1921 - 2016
Austria	0 - 109	1947 - 2017
Belgium	0 - 109	1841 - 2015
Canada	0 - 109	1921 - 2016
Denmark	0 - 109	1835 - 2016
Finland	0 - 109	1878 - 2015
France	0 - 109	1816 - 2016
Germany	0 - 109	1990 - 2017
Greece	0 - 109	1981 - 2013
Ireland	0 - 109	1950 - 2014
Italy	0 - 109	1872 - 2014
Japan	0 - 109	1947 - 2016
Korea	0 - 109	2003 - 2016
Netherlands	0 - 109	1850 - 2016
NewZealand	0 - 109	1948 - 2013
Norway	0 - 109	1846 - 2014
Portugal	0 - 109	1940 - 2015
Spain	0 - 109	1908 - 2016
Sweden	0 - 109	1751 - 2017
Switzerland	0 - 109	1876 - 2016
Taiwan	0 - 109	1970 - 2014
UK	0 - 109	1922 - 2016
USA	0 - 109	1933 - 2016

Table 1: Data range available in the Human Mortality Database for selected countries.

The focus of the analysis is on recent mortality trends; thus, data prior to 1965 are discarded. In this investigation, we analyse mortality rates and mortality improvement rates year on year by gender, single year of age and by individual calendar year for each country. In places, we use direct standardisation to create summary mortality indices and use moving averages to reduce the volatility in some of the resulting measures.

2 Descriptive analysis of the extent of slowdown across countries

This section explores the observed mortality rates in the above-mentioned 23 countries, with particular attention to after 2011. A number of mortality metrics are considered, including age specific mortality rates, standardised mortality rates, comparative mortality factors and mortality improvement rates. We undertake initial analyses at the granular level of single year of age

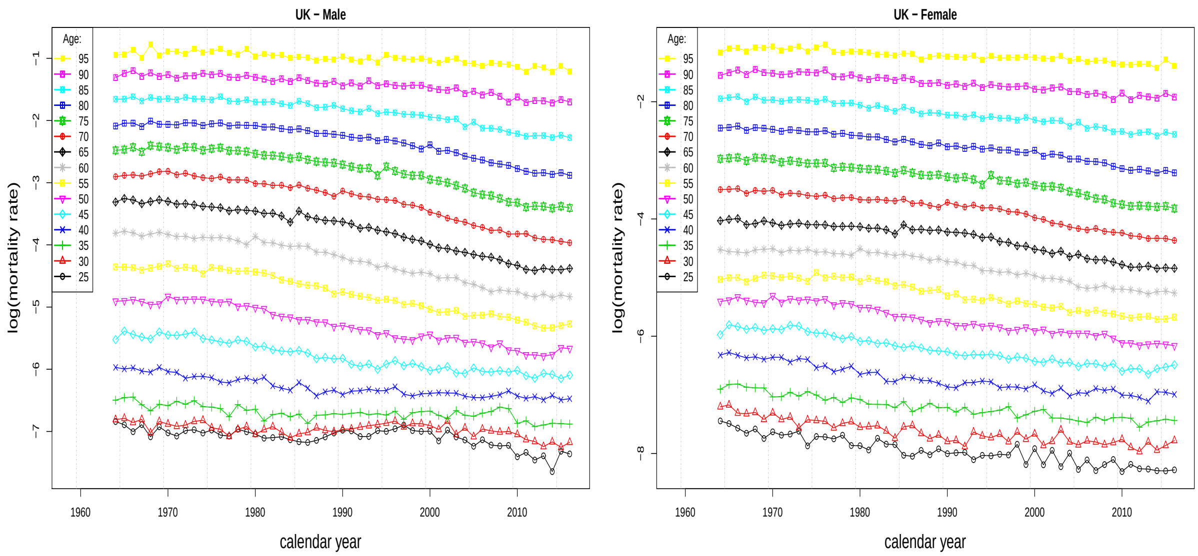

Figure 1: Observed mortality rates in UK by gender and selected single year of age, 1980 to 2017.

and single calendar year. This applies both to age and gender specific mortality rates and mortality improvement rates. We use standardisation to create mortality rates for broader age groups and we use moving averages across time to help smooth out fluctuations in the trend in mortality rates and mortality improvement rates. The exploration starts with the UK, and then moves on to compare the UK against the other 22 countries.

2.1 Recent mortality improvement trends in the UK

Figure 1 displays the crude age specific mortality rates (on the log scale) over time in the UK by gender for selected ages (The resulting crude mortality improvement rates are shown in Figure A23 in the Appendix). We note that, because of the different experience of the genders, we have used different scales on the vertical axes – this needs to be borne in mind when making comparisons between the left and right hand panels.

Figure 1 shows a steady decline of mortality rates for both genders over time, albeit with some year-to-year fluctuations. The decline seems faster at ages over 60 compared with ages under 60. Data in the upper panels for the post 2010 period indicate that the reduction of mortality rates observed in earlier years could be slowing down, for example at the ages depicted from the range 45-65.

The crude improvement rates shown in Figure A23 in the Appendix indicate that the direction and magnitude of mortality improvements fluctuate substantially from year-to-year. The youngest ages show the highest variability; this is probably due to low death counts at these ages (leading to low mortality rates in the upper panels). Nonetheless, we note that the mortality improvement rates have been positive (i.e. above the line) at most ages in most years.

Although some early patterns emerge from the crude data displayed in Figures 1 and A23, they are obscured by fluctuations. More robust patterns can be obtained by aggregating data across ages, separately for men and women. The results in terms of standardised mortality rates for the age range 25-95 are shown in Figure 2: the left hand panel shows the trends in standardized mortality rates, while the right hand panel shows the trend in smoothed mortality improvement rates (based on 5 year moving averages). Appendix A.1 provides more details on the reference population structure used as weights to standardize the rates. We make three comments on the presentation in Figure 2.

First, Figure 2 confirms the steady fall of mortality rates over time for both genders: we see the downward trend in the left hand panel and the corresponding positive values for the improvement rates in the right hand panel. Second, male mortality rates have been falling faster than those for women. We see the convergence of the 2 trends in the left hand panel and the higher annual improvement rates for men in the right hand panel. Third, post 2010, the fall in mortality rates has slowed down for both genders and the trend has become almost flat: we see this feature from both panels, noting, in the right hand panel, the dropping of the annual improvement rates down towards zero during the last 5 years of the time-period.

Figure 3 shows the smoothed annual mortality improvement rates based

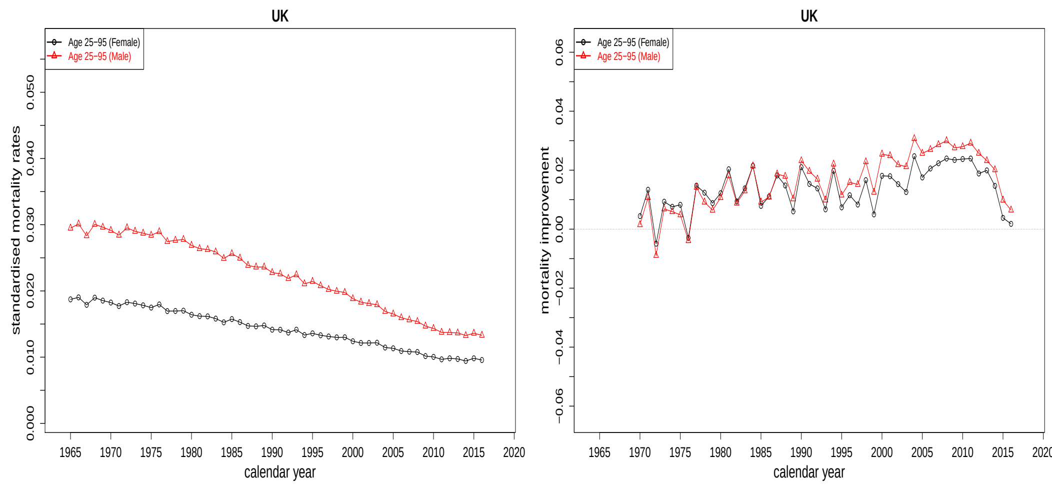

Figure 2: Observed mortality and improvements rates in UK. Left: Directly standardised mortality rates. Right: annualised mortality improvements (5-year moving averages) derived from the standardised mortality rates.

on standardized mortality rates for two broad age ranges: 25-50 and 50-95. This figure shows that, for both genders, the improvement rates have trended higher for ages 50-95 than for ages 25-50, from 1995 for women and from 1990 for men. However, both age groups show the same feature as Figure 2: a reduction in improvement rates during the period 2010-15.

Table 2 presents a more detailed summary and comparison of mortality improvements by age-bands over multiple time-periods for the two genders. The table shows that the average improvement rates have varied across time-periods and age bands.

Table 2 shows that, in the decade 2000-10, mortality improvement rates were particularly high (above 2% pa) at ages 60-84 for women and at ages 55-89 for men. We note that, looking across multiple time-periods, the average mortality improvement rates post 2010 have materially slowed down relative to the previous decades. This applies to all age groups, except 35-39 if we compare 2000-2010 with 2010-15, for both men and women.

The gap between the improvement rates for 2000-2010 and 2010-15 varies considerably across age groups. However this analysis shows broadly that the

Figure 3: Annualised mortality improvements (5-year moving averages) in the UK derived from the directly standardised mortality rates.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	1.11%	1.35%	-0.69%	0.32%	-0.30%
30-34	1.37%	1.50%	0.09%	0.29%	-1.30%
35-39	1.54%	1.30%	0.71%	0.33%	0.49%
40-44	1.69%	2.12%	0.38%	1.28%	-0.03%
45-49	1.13%	2.59%	1.20%	1.79%	-0.20%
50-54	0.37%	2.94%	1.52%	1.22%	1.14%
55-59	0.07%	2.05%	2.20%	1.77%	0.53%
60-64	0.36%	0.97%	2.81%	2.48%	0.46%
65-69	0.80%	0.84%	2.65%	2.81%	0.94%
70-74	1.18%	1.39%	1.59%	3.29%	1.13%
75-79	0.96%	1.74%	1.39%	3.07%	1.12%
80-84	0.88%	1.84%	1.40%	2.19%	1.25%
85-89	0.73%	1.62%	1.16%	1.86%	0.27%
90-95	0.39%	1.19%	0.73%	1.40%	0.06%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.55%	-0.65%	-1.26%	2.67%	-0.60%
30-34	1.05%	-0.06%	-0.76%	1.05%	0.38%
35-39	1.38%	0.43%	-0.16%	0.56%	0.88%
40-44	1.42%	1.86%	0.38%	0.47%	-0.65%
45-49	0.98%	2.55%	1.43%	1.36%	-0.18%
50-54	0.64%	3.19%	2.05%	1.87%	0.88%
55-59	0.58%	3.06%	2.60%	2.37%	1.59%
60-64	1.12%	2.01%	3.10%	2.92%	0.87%
65-69	1.08%	1.63%	3.19%	3.55%	1.48%
70-74	0.65%	1.97%	2.28%	3.89%	1.83%
75-79	0.25%	1.91%	2.09%	3.78%	1.45%
80-84	0.25%	1.45%	1.82%	2.95%	1.39%
85-89	0.31%	1.21%	1.52%	2.35%	0.84%
90-95	0.14%	1.06%	0.68%	1.43%	0.78%

(b) Male

Table 2: Average yearly mortality improvements in the UK.

trend is across all age groups and for men and women, suggesting that we need to look for explanations that might affect the whole population. Mortality increased for many of the age groups of the under 50s, suggesting that the explanation is unlikely to lie solely in changes in cardiovascular disease, dementia or flu.

The exploration carried out so far has been in terms of mortality rates and the associated mortality improvement rates. We have also considered alternative mortality measures and have reached consistent conclusions regarding the evidence for a slowdown in mortality improvements in the UK post 2010. For example, Appendix A.23 shows some details of an analysis based on smoothing and extrapolating comparative mortality factors.

2.2 Recently observed mortality improvement trends in developed countries.

This section presents mortality rates since 1965 in the 23 countries considered in this analysis. The discussion considers the trend over time for the age group 25-95, which is then split into two subgroups 25-50 and 50-95. Directly standardised mortality rates are computed separately for each country by gender and the resulting yearly changes are averaged over the different time-periods.

2.2.1 Observed mortality improvements for women.

Table 3 shows the average yearly changes over the sub-periods that make up the overall period under investigation (1965-2015) for women aged 25-95, based on the trends in the standardised mortality rates. Since all but one of the observed rates is positive, we refer in this section to 'mortality improvements'. We show the improvement rates for all countries for 2011-13 and for 2011-2015 for the subset of countries where the data series extends to 2015.

Although the average annual mortality improvement for women over 2011-2015 is positive in each country, its magnitude varies greatly across countries, ranging from 0.38% through to 3.09%, with the lowest improvement rates being experienced by UK and US, while Denmark and Korea enjoy the highest improvement rates. For the sub-period 2011-13, the range is from -0.24% to 3.12%, with the lowest improvements rates being experienced by Ireland and US, the highest being experienced by Denmark and Korea, and UK experiencing an improvement of 1.02%.

The last two columns of the table indicate that mortality improvements of women post 2013 have slowed down compared to 2011-2013, except perhaps in Belgium, Japan and Sweden; but this must be interpreted with caution because average improvements over such short time periods tend to be more vulnerable to fluctuations. When we look across longer time-periods within countries, we can see that mortality improvements of women are neither constant nor monotonic. For each country, periods of larger improvement rates are followed by periods of slower improvements.

Nevertheless, setting aside Korea (for which we have a limited time series of data), we note that in all the countries considered there is a slowdown of mortality improvement rates of women post 2010 compared to the previous decade, with the exception only of Denmark. For most countries, the largest improvements occurred during 1990-2000 or 2000-2011.

Table 4 presents the average yearly mortality improvements separately for the younger adult age group (25-50) and the older age group (50-95). Many of the comments above apply to both age groups. For example, in each group, the UK and USA are among the countries with the slowest improvement rates during the time-period 2011-2015, while Denmark and Korea are among the countries that have enjoyed higher improvement rates.

When contrasting the two age bands over the time period 2011-2015, we note that younger adult women (25-50) experienced higher rates of mortality improvement than their older counterparts in the majority of countries, with average yearly improvements as high as 4% in countries such as Denmark, Finland or Portugal. However, looking across time-periods, we note that the older women (50-95) enjoyed higher mortality improvements in some periods compared to younger adult women. For example, over the 2011-2015 the improvement for older women in the US (0.51%) is higher compare to that of younger adult women (-0.58%).

2.2.2 Observed mortality improvements for men.

As with Table 3, Table 5 shows the average yearly improvements over the sub-periods that make up the overall period under investigation (1965-2015) for men aged 25-95, based on standardized mortality rates. In this table, all rates measured at all time points are positive.

For 2011-2015, average male mortality improvement rates vary substantially across countries, with the UK and the US once again experiencing the lowest improvement rates while Denmark, Finland and Korea enjoy the highest.

The last two columns of Table 5 indicate that male mortality improvement rates for 2013-2015 tend to be lower than 2011-2013 in all countries except Belgium and Japan. Overall, the average mortality improvement rate in each country over the time-period 2011-2015 remains positive.

Like women, in most countries, men have experienced a slowdown of mortality improvements since 2010 compared to the previous decade, except in Denmark, Finland and Japan. However, looking further back in time, we note that periods of high improvement rates have historically been followed by lower improvement rates, with the exception of Denmark where the average yearly improvement rate has been monotonically increasing over the time periods considered.

Table 6 presents an analysis of male improvement rates for 2 age groups 25-50 and 50-95. Table 6 shows that, in 2011-2015 overall, younger male adults have tended to experience higher improvement rates than their

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	1.83%	1.40%	2.41%	1.89%	1.67%	0.87%
Austria	1.14%	1.99%	2.00%	2.15%	1.31%	0.75%
Belgium	1.31%	2.01%	1.62%	1.61%	0.88%	0.90%
Canada	1.73%	1.13%	0.91%	1.83%	1.55%	1.21%
Denmark	1.48%	0.34%	0.71%	1.77%	3.05%	2.63%
Finland	2.86%	0.98%	1.75%	2.18%	1.83%	1.63%
France	1.73%	2.09%	1.78%	1.99%	1.35%	0.98%
Germany			2.39%	1.56%	0.84%	0.69%
Greece			1.11%	1.91%	1.58%	
Ireland	0.61%	1.60%	1.42%	3.51%	-0.24%	
Italy	1.55%	2.01%	1.93%	2.02%	1.41%	
Japan	2.73%	2.58%	2.80%	2.36%	1.02%	1.59%
Korea					3.12%	3.09%
Netherlands	1.75%	0.83%	0.36%	1.97%	1.00%	0.56%
NewZealand	0.75%	1.08%	2.41%	2.12%	1.35%	
Norway	1.31%	0.85%	1.14%	1.89%	1.30%	
Portugal	1.02%	1.28%	1.25%	2.47%	2.27%	1.74%
Spain	1.59%	1.76%	1.86%	2.50%	1.77%	0.51%
Sweden	1.55%	1.27%	1.04%	1.49%	0.92%	1.19%
Switzerland	2.08%	1.48%	1.16%	1.78%	0.89%	0.82%
Taiwan		1.11%	2.24%	2.95%	1.92%	
UK	0.83%	1.64%	1.55%	2.30%	1.02%	0.38%
USA	1.62%	0.65%	0.28%	1.58%	0.61%	0.44%

Table 3: Average yearly mortality improvements for women over multiple time periods in 23 countries.
The underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 25-95.
The blank cells are due to missing data for some relevant calendar years.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	2.80%	2.57%	1.55%	1.61%	0.80%	0.10%
Austria	1.05%	1.92%	1.48%	2.90%	3.15%	1.94%
Belgium	1.24%	1.23%	1.06%	1.72%	1.85%	2.75%
Canada	1.45%	2.56%	1.65%	1.33%	0.93%	0.72%
Denmark	-0.43%	0.76%	2.52%	3.34%	6.75%	4.29%
Finland	2.81%	0.51%	0.83%	1.84%	3.28%	3.99%
France	1.81%	1.76%	1.13%	2.09%	2.76%	2.50%
Germany			2.05%	2.46%	2.08%	1.82%
Greece			1.04%	1.51%	1.28%	
Ireland	2.13%	2.37%	0.03%	1.76%	4.29%	
Italy	2.36%	1.90%	1.82%	2.57%	1.54%	
Japan	3.97%	2.64%	1.14%	1.24%	1.55%	2.19%
Korea					3.58%	3.15%
Netherlands	1.06%	1.28%	-0.07%	3.07%	2.74%	2.54%
New Zealand	0.63%	1.28%	2.69%	1.04%	3.83%	
Norway	0.87%	-0.05%	1.16%	2.30%	2.60%	
Portugal	1.71%	1.18%	1.50%	2.46%	4.44%	4.90%
Spain	2.88%	1.55%	1.67%	2.43%	2.07%	2.55%
Sweden	0.79%	1.23%	2.39%	3.13%	-0.58%	1.11%
Switzerland	1.43%	0.90%	2.12%	2.88%	4.12%	3.56%
Taiwan		2.49%	2.20%	2.33%	2.20%	
UK	1.47%	2.38%	1.00%	1.53%	1.71%	0.41%
USA	2.08%	1.33%	0.54%	0.30%	0.09%	-0.58%

(a) Female: Age 25-50

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	1.77%	1.35%	2.45%	1.89%	1.71%	0.90%
Austria	1.14%	1.99%	2.01%	2.12%	1.23%	0.70%
Belgium	1.31%	2.05%	1.64%	1.60%	0.82%	0.82%
Canada	1.74%	1.05%	0.87%	1.85%	1.58%	1.23%
Denmark	1.57%	0.31%	0.62%	1.70%	2.94%	2.56%
Finland	2.86%	1.00%	1.78%	2.19%	1.76%	1.50%
France	1.72%	2.11%	1.82%	1.98%	1.27%	0.89%
Germany			2.40%	1.52%	0.80%	0.65%
Greece			1.12%	1.91%	1.59%	
Ireland	0.53%	1.56%	1.48%	3.55%	-0.45%	
Italy	1.51%	2.02%	1.93%	2.00%	1.40%	
Japan	2.68%	2.58%	2.87%	2.42%	0.98%	1.55%
Korea					3.08%	3.08%
Netherlands	1.77%	0.81%	0.38%	1.91%	0.95%	0.49%
New Zealand	0.76%	1.07%	2.40%	2.16%	1.24%	1.24%
Norway	1.31%	0.89%	1.14%	1.86%	1.26%	
Portugal	0.98%	1.28%	1.23%	2.47%	2.14%	1.60%
Spain	1.52%	1.77%	1.87%	2.49%	1.73%	0.42%
Sweden	1.58%	1.27%	0.97%	1.42%	0.99%	1.19%
Switzerland	2.10%	1.50%	1.11%	1.74%	0.76%	0.71%
Taiwan		1.05%	2.24%	2.98%	1.89%	
UK	0.79%	1.61%	1.57%	2.34%	0.98%	0.38%
USA	1.59%	0.61%	0.26%	1.65%	0.65%	0.51%

(b) Female: Age 50-95

Table 4: Average yearly mortality improvements for women over multiple time periods in 23 countries. The blank cells are due to missing data for some relevant calendar years.

Panel(a): the underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 25-50.

Panel(b): the underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 50-95.

older counterparts in many countries, with countries such as Denmark, Finland, Korea and Spain experiencing an average improvement rate higher than 4% yearly. However, the picture is quite mixed, with the older adults having experienced higher improvements than younger men in Australia, Canada, Netherlands, Sweden, UK and USA over that time- period. In the US, in particular, unlike any other country, the 25 to 50 year olds experienced a worsening of mortality 2011-2015.

For most countries in the dataset, older men have experienced a slowdown of mortality improvement since 2010 compared to the previous decade, except in Denmark. For younger adults however, many countries such as Belgium, Denmark, Finland, France, Japan, New Zealand, Portugal, Spain and Sweden have experienced an increase in yearly mortality improvement rates on average over 2011-2015 compared to the previous decade.

Looking further back in time, within the two broad age groups considered, we note that mortality improvement is neither constant nor monotonic, except for the case of Denmark where the average improvement rates have tended to increase monotonically for both of the two age groups over 1965-2015.

2.2.3 Observed mortality improvements: a comparison of men and women

Putting Tables 3 and 5 side-by-side, a number of comments can be made regarding mortality improvement rates for men relative to those for women.

Over 1965-1980, women aged 25–95 enjoyed better mortality improvement rates overall than men in all of the 19 countries where data are available. During that time-period, the gender gap in average annual mortality improvement rates varied substantially between countries, ranging from a small differential of 0.26% in the UK through to almost 1.5

Similarly, putting Tables 4 and 6 side-by-side (separately for each of the two age groups) shows that over the time-period, 1965-1980, women enjoyed higher mortality improvement rates on average in the older age group, but men's improvements accelerated faster than women's during subsequent time

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	1.26%	1.61%	2.73%	2.42%	2.11%	1.54%
Austria	0.74%	1.83%	2.15%	2.20%	1.52%	1.16%
Belgium	0.55%	1.54%	1.57%	2.19%	1.28%	1.79%
Canada	0.93%	1.19%	1.54%	2.58%	2.00%	1.61%
Denmark	0.25%	0.39%	1.18%	2.00%	2.93%	2.63%
Finland	1.45%	0.98%	1.77%	2.31%	2.60%	2.47%
France	1.08%	1.70%	1.63%	2.24%	1.92%	1.58%
Germany			2.21%	2.01%	1.34%	1.03%
Greece			0.57%	1.78%	1.40%	
Ireland	-0.14%	1.22%	1.41%	3.98%	0.62%	
Italy	0.57%	1.76%	1.79%	2.33%	2.01%	
Japan	2.36%	1.58%	1.47%	1.79%	1.78%	2.11%
Korea					3.28%	3.21%
Netherlands	0.29%	0.41%	1.06%	2.70%	1.83%	1.56%
New Zealand	0.15%	1.60%	2.45%	2.95%	1.39%	
Norway	0.27%	0.51%	1.42%	2.51%	2.15%	
Portugal	0.70%	0.91%	0.85%	2.17%	1.94%	1.91%
Spain	0.97%	1.06%	1.27%	2.44%	2.40%	1.21%
Sweden	0.36%	1.29%	1.44%	2.00%	1.93%	1.62%
Switzerland	1.25%	0.95%	1.69%	2.29%	1.71%	1.34%
Taiwan		0.93%	1.59%	2.15%	0.97%	
UK	0.57%	1.77%	2.01%	2.87%	1.56%	0.98%
USA	1.13%	0.92%	1.16%	2.02%	0.84%	0.64%

Table 5: Average yearly mortality improvements for men over multiple time periods in 23 countries.
The underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 25-95.
The blank cells are due to missing data for some relevant calendar years.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	1.68%	2.47%	1.34%	2.04%	1.85%	0.02%
Austria	0.24%	2.49%	2.33%	2.68%	4.08%	3.63%
Belgium	1.07%	1.65%	0.38%	2.65%	3.36%	3.30%
Canada	1.17%	2.46%	1.94%	1.90%	1.56%	0.42%
Denmark	-0.75%	-0.23%	2.08%	2.62%	5.71%	4.97%
Finland	2.13%	0.77%	2.22%	2.62%	3.20%	5.00%
France	0.76%	1.22%	1.53%	2.79%	3.56%	2.70%
Germany			2.16%	2.92%	3.56%	2.26%
Greece			-0.25%	1.03%	2.99%	
Ireland	0.63%	2.94%	0.76%	2.39%	1.73%	
Italy	1.43%	1.77%	1.89%	3.48%	3.41%	
Japan	2.57%	2.80%	0.57%	1.79%	3.42%	3.53%
Korea					4.59%	4.73%
Netherlands	0.90%	1.32%	0.98%	3.15%	2.18%	1.54%
New Zealand	1.29%	2.05%	2.09%	1.85%	2.03%	
Norway	0.73%	0.92%	1.00%	2.82%	1.85%	
Portugal	0.73%	0.68%	-0.34%	3.41%	4.90%	4.85%
Spain	1.28%	-0.43%	1.51%	4.06%	5.36%	4.55%
Sweden	-0.51%	2.66%	2.87%	2.39%	0.74%	1.15%
Switzerland	1.25%	0.50%	2.21%	3.23%	3.04%	2.92%
Taiwan		0.45%	1.07%	1.47%	1.84%	
UK	1.20%	1.84%	0.64%	1.33%	1.49%	0.69%
USA	1.33%	0.60%	1.73%	0.97%	0.32%	-0.57%

(a) Male: Age 25-50

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013	2011-2015
Australia	1.23%	1.56%	2.81%	2.44%	2.13%	1.63%
Austria	0.76%	1.79%	2.13%	2.17%	1.40%	1.05%
Belgium	0.51%	1.54%	1.63%	2.16%	1.18%	1.72%
Canada	0.91%	1.12%	1.52%	2.62%	2.02%	1.68%
Denmark	0.30%	0.41%	1.12%	1.96%	2.82%	2.53%
Finland	1.39%	1.00%	1.73%	2.28%	2.55%	2.31%
France	1.09%	1.75%	1.63%	2.20%	1.80%	1.51%
Germany			2.21%	1.96%	1.24%	0.97%
Greece			0.62%	1.82%	1.27%	
Ireland	-0.18%	1.16%	1.45%	4.05%	0.54%	
Italy	0.52%	1.77%	1.79%	2.27%	1.94%	
Japan	2.34%	1.51%	1.51%	1.80%	1.69%	2.03%
Korea					3.20%	3.12%
Netherlands	0.26%	0.37%	1.06%	2.68%	1.82%	1.56%
New Zealand	0.08%	1.57%	2.47%	2.99%	1.36%	
Norway	0.24%	0.49%	1.44%	2.50%	2.15%	
Portugal	0.69%	0.93%	0.93%	2.06%	1.71%	1.70%
Spain	0.94%	1.16%	1.24%	2.34%	2.26%	1.05%
Sweden	0.40%	1.22%	1.37%	1.98%	1.98%	1.65%
Switzerland	1.24%	0.99%	1.65%	2.23%	1.67%	1.27%
Taiwan		0.96%	1.63%	2.20%	0.87%	
UK	0.54%	1.77%	2.07%	2.95%	1.57%	0.99%
USA	1.12%	0.95%	1.11%	2.09%	0.89%	0.75%

(b) Male: Age 50-95

Table 6: Average yearly mortality improvements for men over multiple time periods in 23 countries. The blank cells are due to missing data for some relevant calendar years.

Panel(a): the underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 25-50.

Panel(b): the underlying yearly mortality improvements are derived from standardised mortality rates corresponding to age band 50-95.

periods. Thus, over the period 2011-2015, the average yearly mortality improvement rate for men was higher than for women in all the countries shown, with the exception of Denmark and Greece.

In the younger adult group (age 25-50), women also enjoyed higher improvement rates on average than men during 1965-1980 (except in New Zealand). Although men have been catching up during subsequent time periods, there remain many countries where women have enjoyed better mortality improvement than men during the most recent period of 2011-2015.

3 Analysis based on stochastic mortality trend models

Since the picture is variable and fluctuating, in order to determine more scientifically the extent to which mortality improvement trends have changed since 2010, we build a stochastic trend model that best describes the trends for each country-gender combination for the period 1965-2010 and then assess the extent to which the subsequent mortality experience, i.e. the period from 2010 to 2015, has departed from what we might have projected from the long-run model forecasts.

Thus, in this section, we use stochastic mortality projection models to explore the extent of the slowdown of mortality improvements over the most recent years for the set of countries identified in Table 1. This process involves two stages. At the first stage, a number of mortality projection models are calibrated to each population by gender, excluding the most recent years (e.g. using data up to 2010 only). At the second stage, the calibrated models from the first stage are used to forecast mortality rates over the most recent years (e.g. 2011-2015). The projected mortality rates and resulting improvement rates are then compared in detail against the observed experience.

The next few sections present the models considered, outline the fitting and projection method used, look at model selection and then present the results comparing the projected versus observed experience over the most recent period (either 2011-13 or 2011-2015 depending on the extent of country-level data).

3.1 Mortality projection models

In order to choose the best fitting model, we have considered a set of 9 well-known and widely used mortality projection models from the literature in this analysis. These models have tended to perform best when fitted to older adult age groups and because of this restriction we focus from now on mortality rates at ages over 50.

This set of models includes the Age-Period-Cohort (APC) model (Currie, 2006), the Lee-Carter (LC) model (Lee and Carter, 1992) and its extension, the Renshaw-Haberman model (RH), with cohort effects (Renshaw and Haberman, 2006), the two-factor Cairns-Blake-Dowd (CBD5) model (Cairns et al., 2006) and its extensions (CBD6, CBD7, CBD8; see Cairns et al. (2009)), the Plat model (Plat, 2009), and the two-dimensional P-spline model (Currie et al., 2004). Many of these models can be fitted through R packages (Camarda, 2012; Hyndman et al., 2014; Villegas et al., 2018).

An outline of the mathematical structure of the models implemented as part of this analysis is given in Table 7. Each model provides a mathematical formulation of the central mortality rate as a function of age and time where $m_{x,t}$ represents the central mortality rates at age x (over 50) and calendar year t.

In terms of broad structure, the LC model is a non-linear model where the terms on the right hand side can be regarded as representing the sum of an average age effect, α_x, and a term that represents a product of a time trend, k_t, and an age gradient, β_x. The RH model additionally includes a term that represents a cohort effect relating to year of birth $t - x$. The APC model is a

Model	Structure
LC	$\log m_{x,t} = \alpha_x + \beta_x \kappa_t$
APC	$\log m_{x,t} = \alpha_x + \kappa_t + \gamma_{t-x}$
RH	$\log m_{x,t} = \alpha_x + \beta_x \kappa_t + \gamma_{t-x}$
CBD5	$\log m_{x,t} = \kappa_{0,t} + (x - \overline{x})\kappa_{1,t}$
CBD6	$\log m_{x,t} = \kappa_{0,t} + (x - \overline{x})\kappa_{1,t} + \gamma_{t-x}$
CBD7	$\log m_{x,t} = \kappa_{0,t} + (x - \overline{x})\kappa_{1,t} + ((x - \overline{x})^2 - \sigma^2)\kappa_{2,t} + \gamma_{t-x}$
CBD8	$\log m_{x,t} = \kappa_{0,t} + (x - \overline{x})\kappa_{1,t} + (x - \overline{x})\gamma_{t-x}$
Plat1	$\log m_{x,t} = \alpha_x + \kappa_{0,t} + (x - \overline{x})\kappa_{1,t} + \gamma_{t-x}$
P-splines 2D	$\log m_{x,t} = \sum_r \mathcal{B}_r(x,t)\theta_r$

Table 7: Mortality projection models implemented in analysis; $m_{x,t}$ denotes the central mortality rate at age x and calendar year t. The symbols α and β indicate the age components, κ represents the period component, and γ the cohort component, $\mathcal{B}$ the B-spline basis, and θ the spline coefficients.

specific case of the RH model. These three models are from the same family. Next, the CBD models also form a family and take advantage of the finding that at these older ages the data often suggest that the structure of the model may be simplified with linear predetermined terms replacing the estimated age gradient β_x. CBD 5 is the simplest with a linear age term. CBD 6 includes a cohort term like RH, and the Plat model adapts CBD 6 by including α_x. CBD 7 includes a quadratic age term and CBD 8 is a more complex version of CBD 6. The 2-dimensional spline model is a different form of model and uses a combination of P-splines to provide a smooth representation of the mortality surface by age and time.

3.1.1 Fitting the models and Forecasting

The models in Table 7 can be fitted based on the methodology of generalized linear models (GLM) under the Poisson assumption about the distribution of numbers of deaths in cells defined by age, x, and time, t:

$$D_{x,t} \sim Poisson(E_{x,t} \times m_{x,t}) \tag{1}$$

where $D_{x,t}$, $E_{x,t}$ and $m_{x,t}$ represent the death counts, exposed to risk and central mortality rates at age x and calendar year t.

Among these models the simplest to fit is CBD5. Indeed upon specification of the death and exposure data, the two unknown period components $\kappa_{0,t}$ $\kappa_{1,t}$ in CBD5 can be fitted using standard functions designed to fit a GLM.

A key feature of these models is that, apart from CBD5 and P-splines, none of the seven other models listed in Table 7 is identifiable. That is, different sets of parameters estimates can yield the same estimate of the mortality rates. Looking at the LC model for example, the two sets of parameters $(\alpha_x, \beta_x, \kappa_t)$ and $(\alpha_x - a\beta_x, \beta_x, \kappa_t + a)$ yield identical fitted values of the mortality rates $m_{x,t}$ for any value of a.

The modern approach to address this identifiability issue in mortality projection models is to impose appropriate constraints on the model components. For LC model for example, the following two constraints suffice:

$$\sum_x \beta_x = 1 \quad \text{and} \quad \sum_t \kappa_t = 0 \tag{2}$$

More details on standard identifiability constraints applied to mortality projection models can be found in Cairns et al. (2009).

Beside identifiability issues, the five models containing an explicit cohort component in Table 7 (i.e. CBD6, CBD7, CBD8, RH, Plat) involve an extra layer of challenge regarding the estimation of the cohort components. Indeed the youngest and oldest cohorts in the data have too few observation to be estimated reliably. Forcing estimation in such circumstances would yield estimates with very high uncertainty. We address this problem here by constraining the estimated cohort components of the four youngest cohorts (i.e. born from 1957 to 1960) to be identical; we similarly apply the same constraint to the four oldest cohorts in the data (i.e. born from 1870 to 1873).

Upon fitting the models containing an explicit period or cohort component, these components are projected and combined (according to the formulas in Table 7) to obtain forecast of the mortality rates.

In this work, the period components are forecasted using multivariate random walks with drifts, and the cohort components are forecasted using ARIMA models (Cairns et al., 2006; Richards et al., 2019). To fit an ARIMA one must first decide about the different order (d), the auto-regressive order (p), and the order of the moving average (q). For each value of $d \in \{0, 1\}$, the auto-regressive and moving average orders were optimised (over $p \in \{0, 1, 2, 3\}$, $q \in \{0, 1, 2, 3\}$) using Akaike Information Criteria with correction for small sample size. More details on models selection are provided in Section 3.1.2 below.

Although the P-splines model does not require constraints or explicit cohort components, care is needed regarding the underlying smoothing methodology. Indeed, the performance of this method is driven by a number of parameters, the most influential ones being the spacing of the B-spline knots, the penalty function and the smoothing parameters.

The P-splines implemented in this work use cubic B-splines with a 5-years knot spacing in age and in time, with a second order difference penalty function (Currie et al., 2004). The smoothing parameters can be estimated using information criteria such as the Bayesian Information Criteria (BIC) – see Section 3.1.2. However, this can yield unstable models with unreasonable forecasts. In this work, we have used the adjusted version of BIC that takes into account overdispersion in order to select optimal values of the smoothing parameters (Djeundje and Currie, 2010).

One attractive feature of P-splines is that the penalty function allows us to fit the model and forecast simultaneously, once the smoothing parameters have been specified. Note that the difference order of the penalty has an influential impact on the direction of the forecast. In practice, however, the second order difference penalty is known to yield forecasts that fit well with the observed data provided care is taken to avoid under-smoothing (Djeundje and Currie, 2010)

3.1.2 Model comparison and selection

Upon calibrating the 9 mortality projection models as described in Section 3.1.1 (for each country, separately for men and women), we decided to select 3 models for each population in order to investigate further the extent of the slow-down in recent mortality improvements. The choice of three models for each population provides scope for analysing the sensitivity of results to the choice of model.

In general, the comparison and selection of models aiming at forecasting future trends involves a number of steps. At first sight, a good model should fit the data well. Adherence of models to the data can be compared using statistical metrics such as the deviance, or by analysing plots of the residuals.

However, by focusing only on this fitting requirement, the most complex models with large number of parameters will tend to be preferred. There are statistical criteria that attempt to provide reasonable balance between the conflicting characteristics of fidelity to the data and parsimony. These include the Bayesian Information Criteria (BIC):

$$\texttt{BIC} = \texttt{Dev} + \log(n) \times \texttt{ED} \tag{3}$$

where n represents the sample size, $\texttt{Dev}$ is the deviance residual from fitting the model, and $\texttt{ED}$ is the effective dimension of the model. Models with lower BIC tend to provided a balance of adherence to data and simplicity.

In this analysis we have found that, when it comes to forecasting mortality rates into the future, the best models (according to the BIC criterion) among those listed in Table 7 can yield unreasonable forecasts. In particular, for mortality projection models involving a cohort component, an automatic optimisation of the orders of the ARIMA for the forecasting of the cohort component often yield unreasonable forecasts of mortality rates.

Thus, in this analysis, although an exploration of various fitting statistics was carried out, the following three criteria were also included in model selection:

- Consistency: for the past few decades, population mortality rates are known to be decreasing steadily over time. Thus, models exhibiting sudden jumps or shocks in fitted or projected mortality rates, as well as models yielding monotonically increasing mortality forecasts over time are discarded.

- Stability: Any model exhibiting a high level of uncertainty in any of its underlying components is discarded.

- Parsimony: Increasing complexity that does not yield new insights is pointless. Thus, if forecasts from several models are closely similar, the simplest model among them is preferred.

For each country-gender combination, three models were retained and used to explore further the direction of recent mortality improvements. For each population, the LC model was chosen to be one of these three models; the other two models were chosen based on goodness of fit to the observed data and the three criteria above.

The LC serves as a benchmark and it was retained for two major reasons. First, it is the most widely used model for mortality forecasting investigations. Second, throughout the analysis, the LC model was found to behave very well with respect to the three criteria set above. The other two models retained in each case vary from country-to-country as well as by gender within the same country.

3.2 Results

As mentioned earlier, the 9 models were fitted to each country separately for males and females using data for ages 50 to 95 and for calendar years 1965

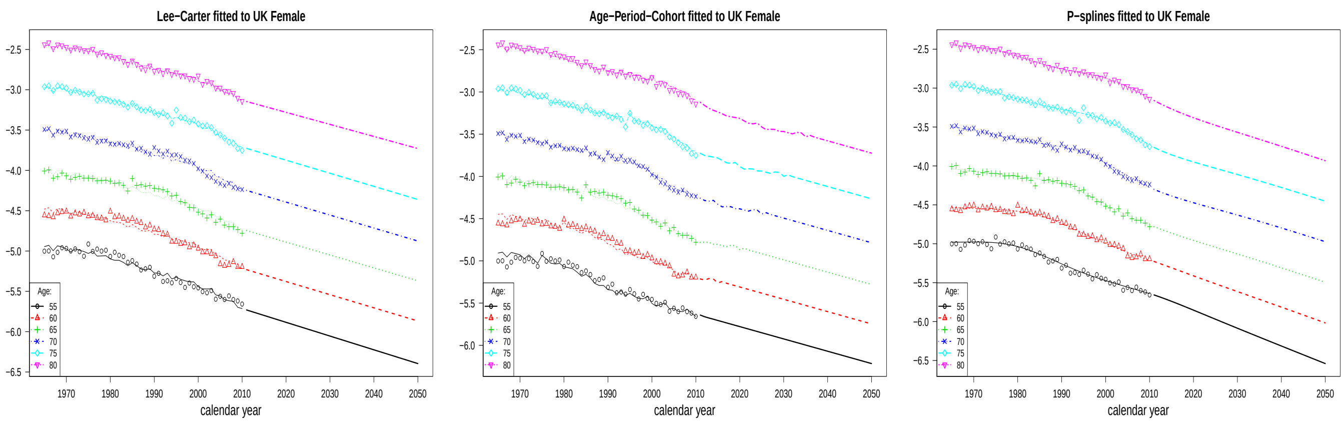

Figure 4: Mortality rates (log scale) from selected models fitted to UK females.

to 2010. For some countries, however, data were available for later years only (e.g. from 1981 for Greece, 1990 for Germany) and in these cases the models were calibrated using the data available from that starting year up to 2010. Korea was excluded from this part of the analysis due to the data being available only over a short time period, and noting that the stochastic mortality models require large data sets over an extended time-period in order to provide both a good fit to the observed data and credible forecasts.

3.2.1 Results for the UK

As noted above, three stochastic mortality models (out of nine) have been selected for men and women separately. Profile views from these models are shown are shown in Figure 4 for women and Figure 4 for men. We note that these selected models may not necessarily be the best fitting models in terms of the Deviance, AIC or BIC. Instead, these models have been retained based on the selection criteria described in Section 3.1.2.

In order to summarize the results, the projected age specific mortality rates (by single year of age and single year of calendar time) from 2011 onwards are used to compute the projected standardised mortality rates for ages 50-64, 65-79, 80-95 and for the full age range 50-95; from these standardised mortality rates, projected mortality improvement rates could be derived. These improvement rates have then been compared to the mortality improvement

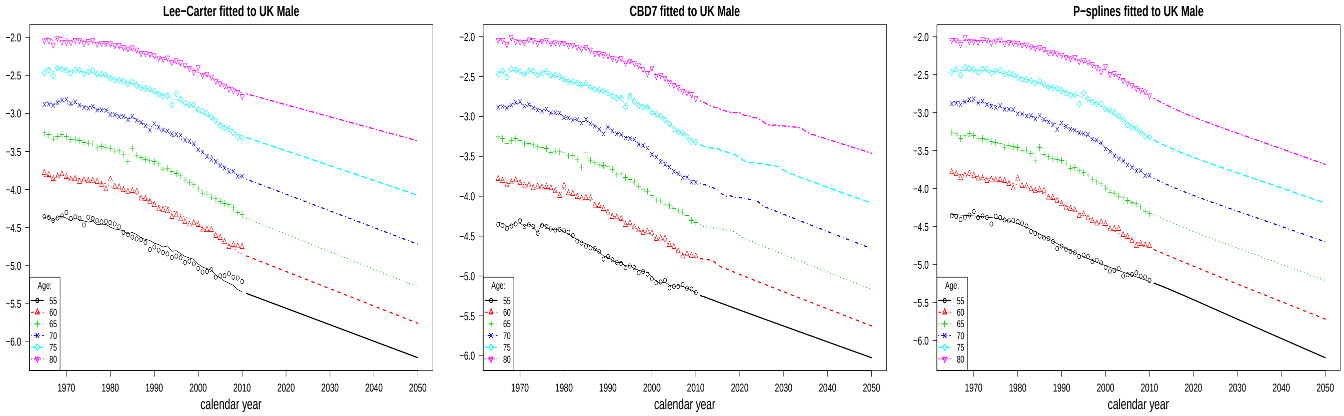

Figure 5: Mortality rates (log scale) from selected models fitted to UK males.

	LC	APC	P-splines	Observed
50-64	1.65%	1.04%	1.94%	1.22%
65-79	1.58%	1.85%	2.39%	1.13%
80-95	1.13%	2.11%	2.60%	-0.24%
50-95	1.34%	1.89%	2.45%	0.38%

(a) Female

	LC	CBD7	P-splines	Observed
50-64	2.21%	1.72%	2.37%	1.30%
65-79	1.97%	1.99%	2.73%	1.62%
80-95	1.11%	1.42%	2.79%	0.50%
50-95	1.53%	1.65%	2.71%	0.99%

(b) Male

Table 8: Average yearly mortality improvements in the UK: Expected vs Observed over the time period 2011-2015).

rates observed since 2010. The results for UK men and women are shown in Table 8.

These tables show that, although the projected mortality improvements vary from one model to another, the average improvement experience since 2010 is lower compared to the predictions from any of the three models selected for men and women. This comment applies to each gender overall (age 50-95) as well as to all of the age-subgroups shown (except for the APC model at ages 50-64 for women).

3.2.2 Comparative results for females in 22 countries

The three models selected for each of the 22 countries by gender can be found in Appendix B. From these selected models, tables comparing average expected improvements against experience (equivalent tables to Tables 8) were computed for each country. These can also be found in Appendix B.

Figure 6 compares mortality improvement experience over the time period 2011-2015 to the projected improvements derived from the LC model forecasts; a dot above the identity line means that observed improvement is larger than predicted improvement from LC forecast. Thus Figure 6 shows that, in all countries except Denmark, the average yearly mortality improvements post 2010 have been worse than was anticipated by the LC model calibrated to the 1965-2010 data. Further, we note that the observed improvements are relatively close to the forecasts in some countries (e.g. Portugal, Sweden and Canada). Thus the evidence for a slowdown is marginal in these countries.

The UK is among a group of countries (including Germany and Spain) that have experienced worse mortality improvements on average than rates we anticipated from the LC model.

Some countries are omitted from Figure 6 because their data for 2014 or 2015 are unavailable. An equivalent figure but covering a comparison of mortality improvements over 2011-2013 is given in Figure 7 with all the 22 countries shown as compared with the LC model predictions. Two countries stand out: Denmark at the one end with a greater improvement in mortality than projected and Ireland, at the other extreme, with much worse mortality than anticipated. We place more emphasis on the results in Figure 6 than those in Figure 7 because of the higher variability in the mortality improvements over shorter time periods.

Overall from Figure 6 to Figure 7, many countries have shifted slightly up indicating that the experience post 2013 tends to be heavier compared to 2011-2013 for those countries. But this must be taken with caution due to high variability in the average observed improvements over such short time periods.

Horizontally however the shift from Figure 6 to Figure 7 is negligible because the projected mortality rates have been smoothed via random walk

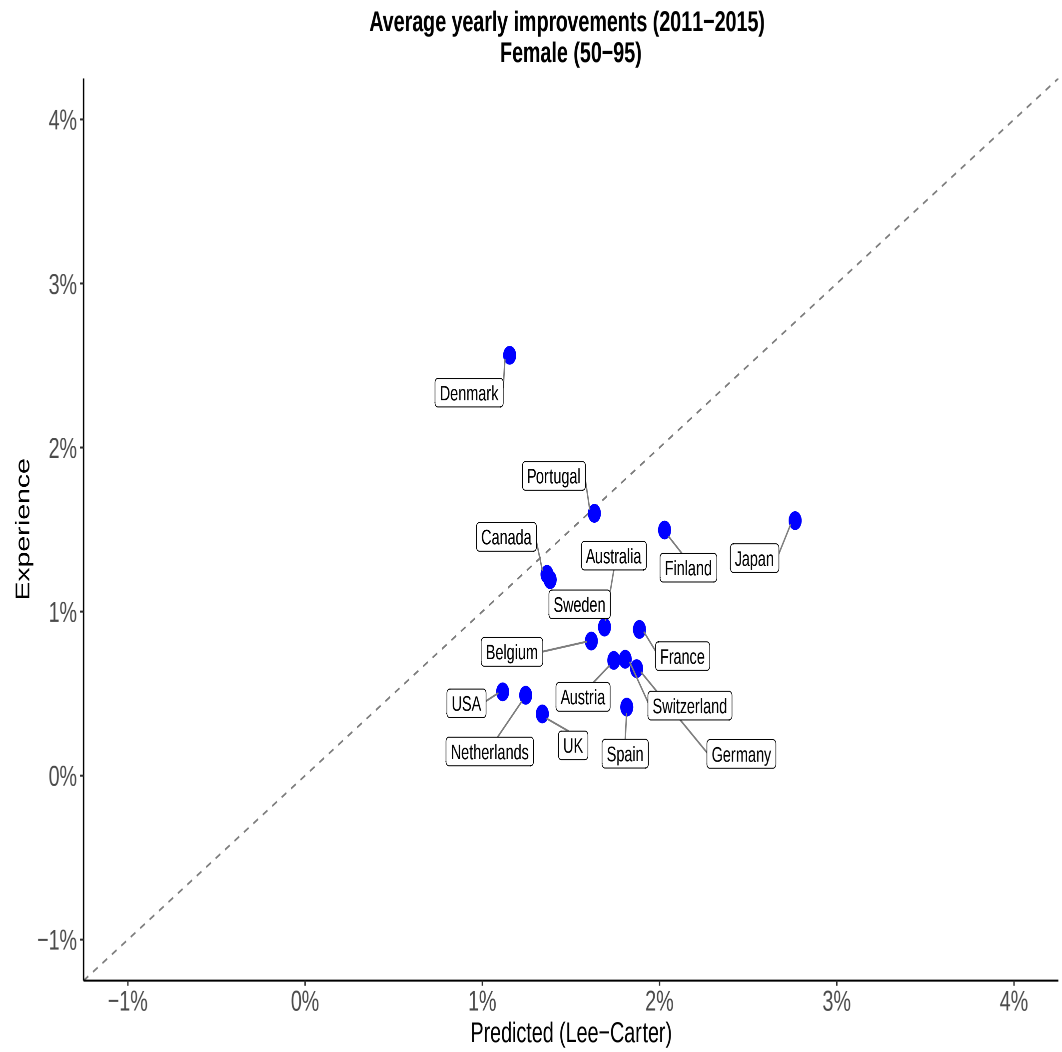

Figure 6: Comparison of actual versus expected mortality improvements for females over the time period 2011-2015. The expected improvements are derived from Lee-Carter forecast of mortality rates. Some countries are omitted from this graphic because data was not available for some calendar year 2014 or 2015. Since all countries had data over 2011-2013, an equivalent graphic comparing all 22 countries is shown in Figure 7.

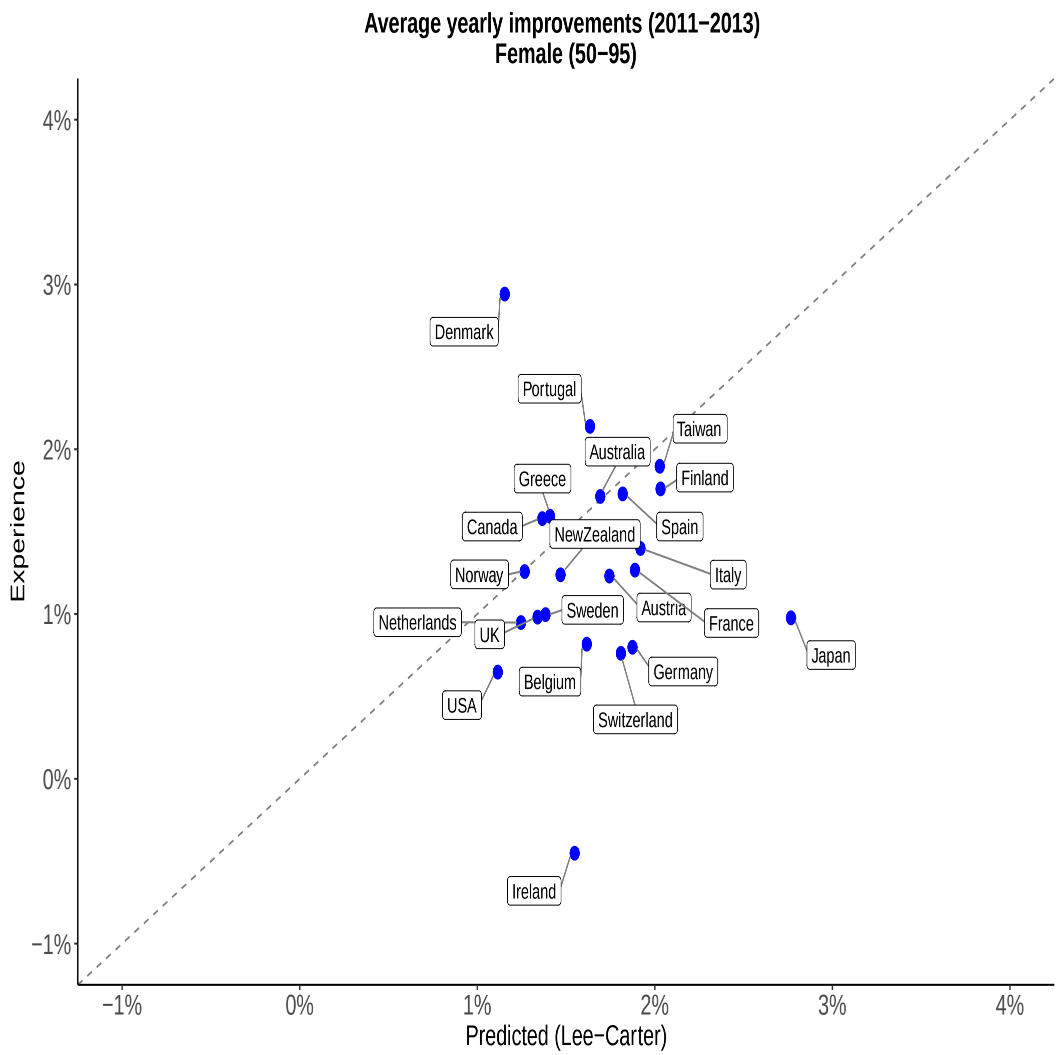

Figure 7: Comparison of actual versus expected mortality improvements for females over the time period 2011-2013. The expected improvements are derived from the forecasting of mortality rates from LC model fitted to data up to 2010.

within the LC model.

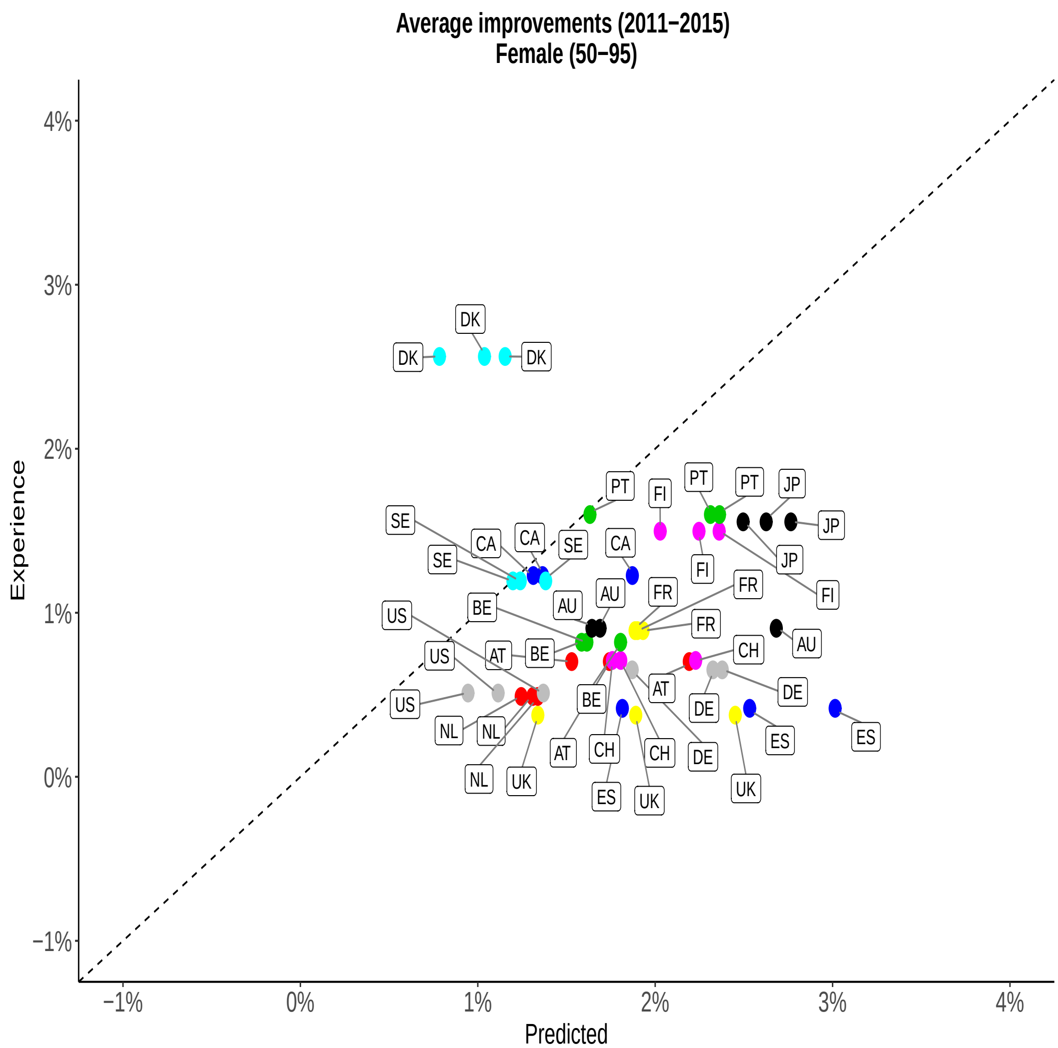

Figure 8: Comparison of actual versus expected mortality improvements for females in 22 countries. For each country, three different models were used to forecast the mortality rates over the time period 2011-2015. Thus each country appears three times on this graphic. Some countries are missing from the graphic because data was not available for calendar year 2013 or 2014.

So far in this section, the discussion has revolved around the output from the LC model. Figure 8 illustrates the results involving the three models selected for each population. Each country appears three times in this graphic presentation. The spread of the locations of each country is an indication of the uncertainty arising from model choice. The magnitude of this uncertainty varies broadly across countries, ranging from countries such as Netherlands where the spread is narrow through to countries such as Spain or the UK where the spread is wide.

Overall, all the models indicate that the mortality improvement experience over 2011-2015 was lower than anticipated by any of the three models selected for each country, apart from Denmark. The models confirm that Denmark alone stands out with higher mortality improvements over 2011-2015 compared to those anticipated by any of the selected models.

3.2.3 Comparative results for males in 22 countries

Regarding men, Figure 9 compares the observed and projected mortality improvements over the time period of 2011-2015; the projected were derived from mortality forecasts from the LC model.

Overall the direction of observed mortality improvements relative to those projected on the basis of the LC model is balanced: with about half of the countries experiencing a higher improvement on average than projected from the LC model and half lower. This suggests that on aggregate, it is women who are experiencing the slowdown in mortality improvement far more than men.

As with women, men in Denmark stand out with substantially higher mortality improvements on average than projected, followed by Finland. At the other end of the spectrum, the USA, UK and Germany are among the countries with the lowest mortality improvements on average for men compared to that projected from the LC model.

Some countries are missing from this graphic due to data being missing for 2014 or 2015. A similar comparative graphic showing all the countries over 2011-2013 is shown in Figure 10. The horizontal shift from Figure 9 to Figure 10 is negligible because the projected mortality rates have been smoothed via the time series component of the LC model.

Figure 11 compares the observed improvements against the predicted values derived from three models for each population. As is the case for

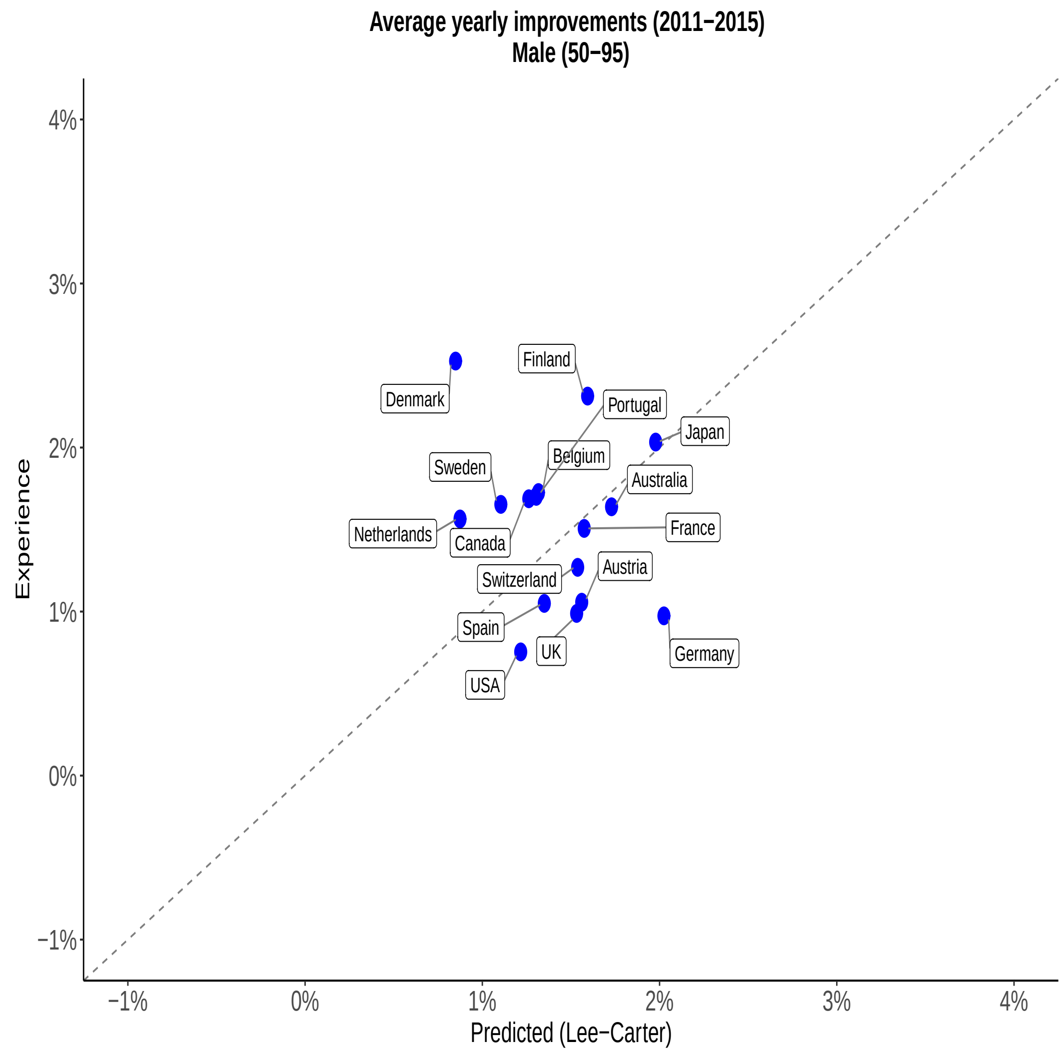

Figure 9: Comparison of actual versus expected mortality improvements for males. The expected are derived from the forecasting of mortality rates from LC model fitted to data up to 2010. Some countries are missing from this graphic because data was not available for calendar year 2014 or 2015. Since all the countries has data over 2011-2013, an equivalent graphic (but for 2011-2013) with all the 22 countries is shown in Figure 10.

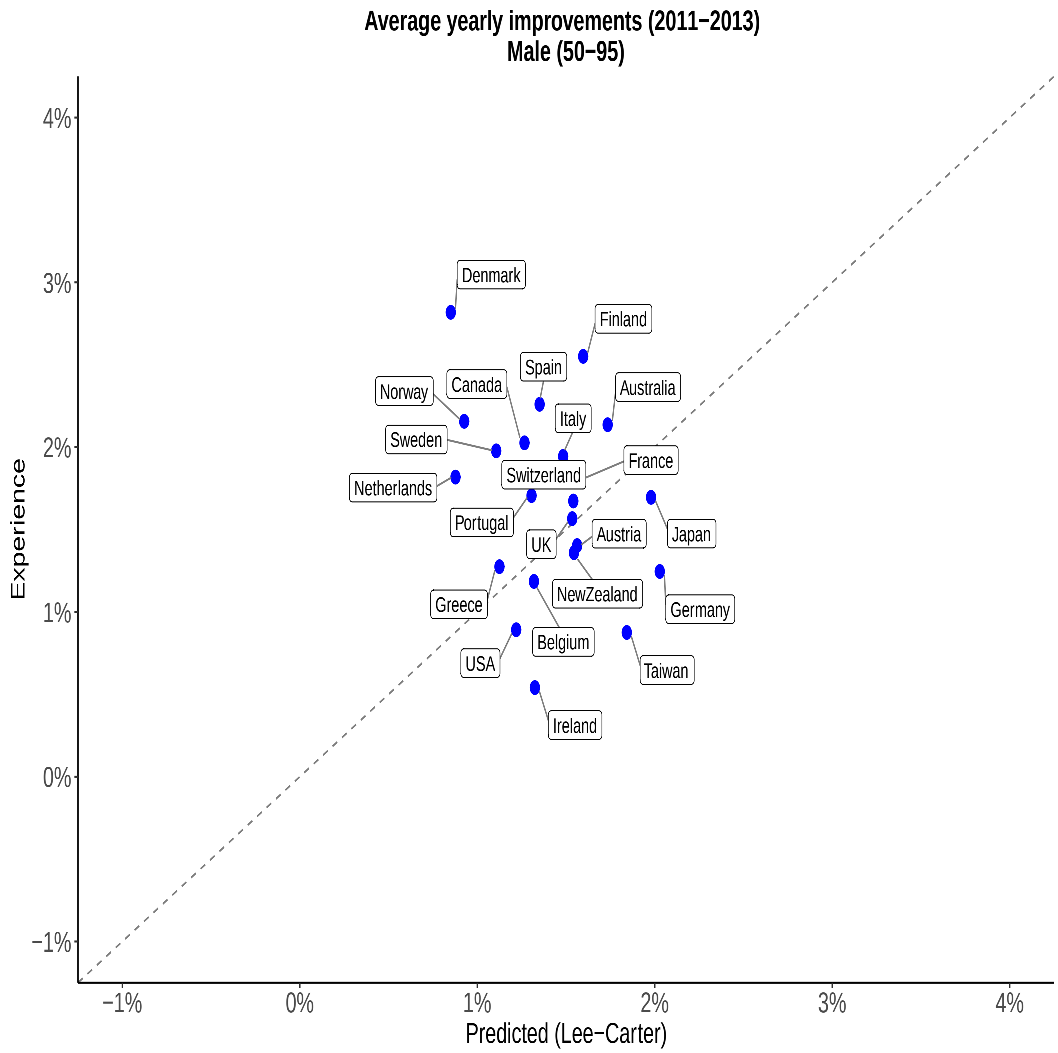

Figure 10: Comparison of actual versus expected mortality improvements for males. The expected improvements are derived from the LC forecasts of mortality rates.

women, the variability due to models is broad, ranging from countries with lower variability such as the US through to countries such as Spain or Netherlands, which demonstrate higher variability.

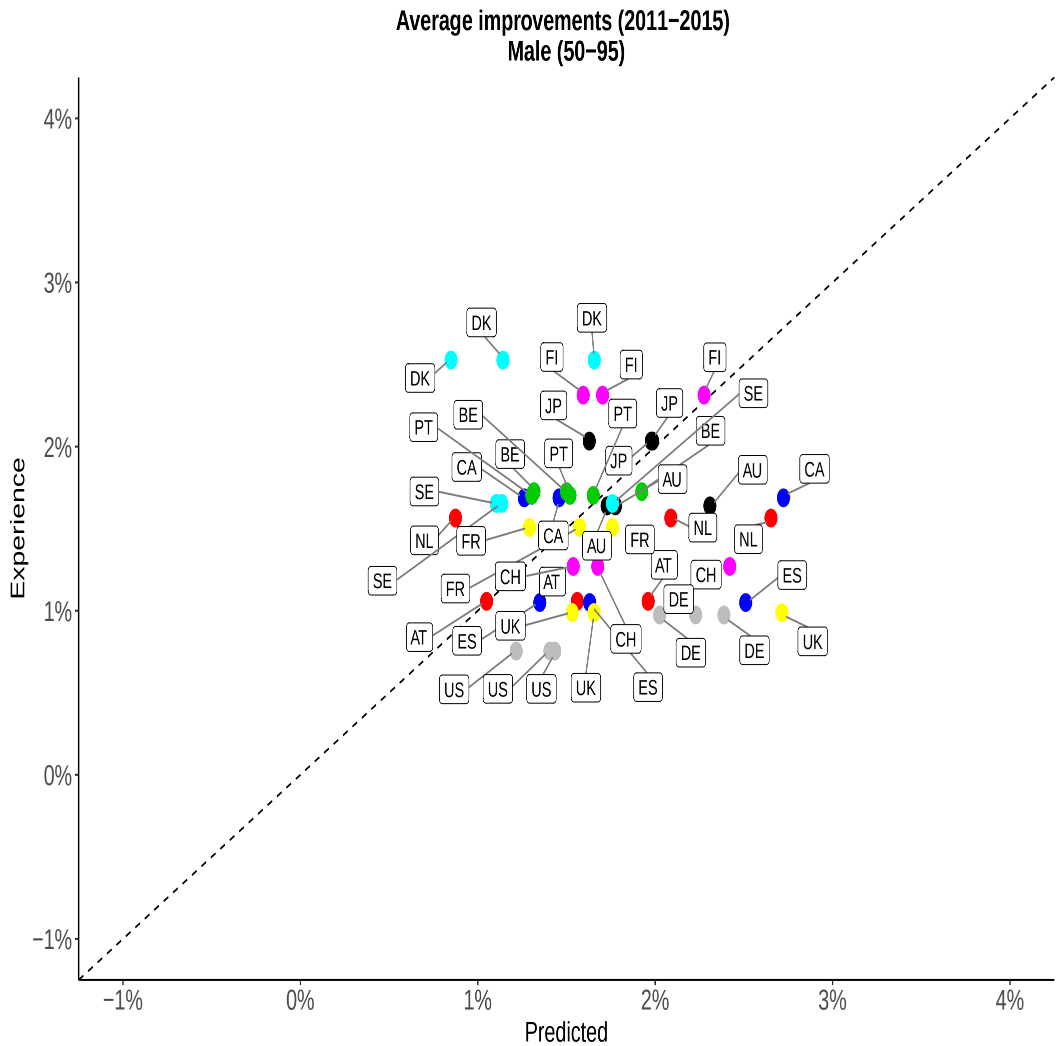

Figure 11: Comparison of actual versus expected mortality improvements for females. The expected are derived from the forecasting of mortality rates from LC model fitted to data up to 2010. Some countries are missing from this graphic because data was not available calendar year 2014 or 2015.

3.3 Would we have projected the recent slowdown in international mortality improvement rates among over 50s, given historical mortality trends up to 2010?

One way to answer this question is through the following steps:

- For each country, analyse historical data of 1965-2010 using various statistical models as described above.
- From the analysis above, project mortality rates from 2011 onwards and derive their mortality improvement rates.
- Shortlist 3 models based on our criteria mentioned previously.
- For each model, derive the difference between projected and observed rates in the preceding decade.
- Finally, average the differences derived from the 3 models to compare between countries.

If the projected rates are lower than observed in the preceding decade, it shows that a slowdown would have been projected from historical data. This would suggest that the slowdown is influenced by hypotheses that predate 2010.

For illustration, we use a difference of 0.25% p.a. mortality improvement rate as a cut-off point to differentiate countries whose projections are lower or higher than observed. The results of 16 countries with reliable data up to 2015 are shown in Tables 9 and 10.

We observe a group of countries with projected 2011-2015 improvement rates that are lower than the observed figures in the preceding decade by more than 0.25% p.a.. This group consists of women in 7 countries and men in 14. Countries with both men and women in this group are the UK, USA, Netherlands, Denmark, Portugal, Canada and Austria. Countries with only

	Projected 2011-2015 rates minus actual 2000-2010 rates[1]	Actual 2011-2015 rates minus projected 2011-2015 rates[2]
Denmark	**-0.71%**	*1.57%*
Netherlands	**-0.61%**	**-0.81%**
USA	**-0.51%**	**-0.63%**
UK	**-0.44%**	**-1.52%**
Portugal	**-0.37%**	**-0.50%**
Canada	**-0.33%**	**-0.29%**
Austria	**-0.30%**	**-1.12%**
Sweden	-0.15%	-0.08%
France	-0.08%	**-1.01%**
Spain	-0.03%	**-2.04%**
Finland	0.02%	**-0.71%**
Belgium	0.07%	**-0.85%**
Australia	0.11%	**-1.10%**
Switzerland	0.19%	**-1.22%**
Japan	0.20%	**-1.07%**
Germany	*0.67%*	**-1.54%**
	Negative means projected rate is lower than observed in 2000-2010	*Negative means observed rate is lower than projected for 2011-2015*

Table 9: Women over 50s: Comparison of projected mortality improvement rates with observed from different periods.

Bold = less than -0.25%

Italic = higher than 0.25%

1: Three statistical models were first chosen for each country. Then for each model, the difference between projected rates and observed in preceding decade was calculated. The average results of the 3 models are shown in the table.

2: As above, except that for each model, the difference between observed rates and projected rates in the same period of 2011-2015 was calculated.

	Projected 2011-2015 minus actual 2000-2010[1]	Actual 2011-2015 minus Projected 2011-2015[2]
UK	**-0.98%**	**-0.98%**
Canada	**-0.81%**	-0.13%
Netherlands	**-0.81%**	**-0.31%**
Denmark	**-0.74%**	*1.31%*
USA	**-0.74%**	**-0.60%**
France	**-0.66%**	-0.03%
Sweden	**-0.65%**	*0.32%*
Austria	**-0.65%**	**-0.47%**
Belgium	**-0.59%**	0.15%
Portugal	**-0.57%**	0.21%
Australia	**-0.51%**	**-0.30%**
Spain	**-0.51%**	**-0.78%**
Finland	**-0.43%**	*0.46%*
Switzerland	**-0.35%**	**-0.61%**
Japan	0.06%	0.17%
Germany	*0.25%*	**-1.24%**
	Negative means projected rate is lower than observed in 2000-2010	*Negative means observed rate is lower than projected for 2011-2015*

Table 10: Men over 50s: Comparison of projected mortality improvement rates with observed from different periods.

Bold = less than -0.25%

Italic = higher than 0.25%

1: Three statistical models were first chosen for each country. Then for each model, the difference between projected rates and observed in preceding decade was calculated. The average results of the 3 models are shown in the table.

2: As above, except that for each model, the difference between observed rates and projected rates in the same period of 2011-2015 was calculated.

men in this group are Sweden, France, Spain, Finland, Belgium, Australia and Switzerland. The results of these countries are consistent with hypotheses for slowdown in mortality improvements that would have started before 2010. These hypotheses may include the worsening trends of obesity and diabetes, widening socio-economic inequality and reducing role of mortality improvements related to circulatory diseases (Raleigh, 2019).

Similarly, we observe another group with projected 2011-2015 improvement rates that are within 0.25% p.a. from than their respective figures from the preceding decade. This group includes Japanese men and women; and women in Sweden, France, Spain, Finland, Belgium, Australia and Switzerland.

Finally, German men and women have been projected to have mortality improvement rates in 2011-2015 that are higher than observed in the preceding decade.

3.4 Has there been more slowdown in mortality improvement rates than the projections discussed above?

We follow the steps in the analyses above, except that we derive the difference between observed and projected rates over the same period of 2011-2015. The results show what actually happened when compared with projections in each country during the period. If the observed mortality rates were lower than projected, the difference may be associated with events that happened after 2011, such as austerity and high 2014/2015 winter deaths.

We observe a remarkable gender difference, where women in 14 countries but men in 8 have experienced lower mortality improvement rates than projected, by more than 0.25% p.a., during 2011-2015 (Tables 9, 10).

When combined with the previous analysis, we may divide the slowdown in mortality improvements into 2 parts - projected slowdown and further slowdown relative to projections. For example, men in the UK have experienced lower mortality improvement rates in 2011-2015 than that in the preceding decade, by about 2% (Table 6). The projected slowdown is about 1% p.a. and further slowdown compared with projection is about 1% p.a. (Table 10). This 'double slowdown' could be shown in the UK, Netherlands, USA, Austria and other populations (Tables 9, 10).

Both genders in Denmark and men in Sweden and Finland have experienced higher mortality improvement rates in 2011-2015 than projections, by more than 0.25%.

Japanese men and Swedish women have experienced mortality improvement rates that are within 0.25% p.a. of their projected figures.

3.5 Attempt to rank countries based on the modelling results

Countries can be compared and ranked in many ways. An example is shown in Table 11 where comparison and ranking are in terms of the gap between the observed improvements and projected improvements (averaged over the 3 models used), separately for men and women, for the period 2010-15. This indicates that countries such as Denmark, Japan and Sweden come top of the rankings, experiencing higher improvement rates compared to projections. The UK, Germany and Spain are at the bottom of the rankings.

2011-2015	Female Gap (rank)	Male Gap (rank)
Australia	-1.10% (11)	-0.30% (9)
Austria	-1.12% (12)	-0.47% (11)
Belgium	-0.85% (8)	0.15% (6)
Canada	-0.29% (3)	-0.13% (8)
Denmark	1.57% (1)	1.31% (1)
Finland	-0.71% (6)	0.46% (2)
France	-1.01% (9)	-0.03% (7)
Germany	-1.54% (15)	-1.24% (16)
Japan	-1.07% (10)	0.17% (5)
Netherlands	-0.81% (7)	-0.31% (10)
Portugal	-0.50% (4)	0.21% (4)
Spain	-2.04% (16)	-0.78% (14)
Sweden	-0.08% (2)	0.32% (3)
Switzerland	-1.22% (13)	-0.61% (13)
UK	-1.52% (14)	-0.98% (15)
USA	-0.63% (5)	-0.60% (12)

Table 11: Average gap between the observed and projected improvement rates over 2011-2015, where data are available. For each country, this gap has been calculated as the average discrepancy between the observed and projected improvement rates from each of the three selected models.

2011-2013	Female Gap (rank)	Male Gap (rank)
Australia	-0.32% (6)	0.17% (11)
Austria	-0.62% (13)	-0.15% (13)
Belgium	-0.91% (17)	-0.45% (17)
Canada	0.04% (2)	0.22% (8)
Denmark	1.96% (1)	1.59% (1)
Finland	-0.52% (9)	0.68% (2)
France	-0.68% (14)	0.25% (7)
Germany	-1.43% (20)	-1.00% (21)
Greece	-0.37% (7)	0.20% (9)
Ireland	-2.56% (22)	-1.84% (22)
Italy	-0.74% (15)	0.45% (5)
Japan	-1.70% (21)	-0.18% (14)
Netherlands	-0.42% (8)	-0.08% (12)
NewZealand	-0.55% (11)	-0.54% (19)
Norway	-0.07% (4)	0.57% (4)
Portugal	0.02% (3)	0.19% (10)
Spain	-0.74% (16)	0.41% (6)
Sweden	-0.30% (5)	0.62% (3)
Switzerland	-1.21% (19)	-0.20% (15)
Taiwan	-0.56% (12)	-0.89% (20)
UK	-0.93% (18)	-0.43% (16)
USA	-0.53% (10)	-0.49% (18)

Table 12: Average gap between observed and projected improvement rates over 2011-2013. For each country, this gap has been calculated as the average discrepancy between the observed and projected improvement rates from each of the three selected models.

4 Concluding remarks

This study analyses population mortality trends across developed countries, to see whether we can better understand reports of stalling improvements in recent years. We first analysed and described historical mortality rates and resulting improvements, then looked at mortality improvement patterns using statistical projection models.

The descriptive analyses have provided average mortality improvement rates split for countries, genders and various grouping of ages (see Appendices for 5-year age groups). These will allow other researchers and practitioners to inform or validate their work.

As far as we are aware, this is the first study of international trends using statistical models to detect historical trends and project from 2011 onwards. It allows us to understand if the post-2011 slowdown in mortality improvements as widely discussed (Leon, 2019; Raleigh, 2019) could have been projected from historical trends. Additionally, we can evaluate what actually happened after 2011 compared with projections.

4.1 Descriptive analyses for age 25-50

Our results are mixed for the 25-50 age group. Countries such as the UK, USA, Netherland, Australia, Canada, Germany and Sweden have experienced slower mortality improvement rates in 2011-2015 when compared with that in 2000-2010. But other countries have experienced higher such as Belgium, Denmark, Finland, Japan and Portugal. More needs to be done to examine country-specific and global influences in this age group for the purposes of public policies and insurance risk management.

4.2 Statistical projections for age 50-95: Given the international historical trends, would we have projected the recent slowdown in mortality improvement rates?

Yes, at least partly for many countries. We have observed projected improvement rates that are lower than the figures observed in the preceding decade. There is a gender bias with men being affected more than women. Men in 14 countries and women in 7 would have projected a slowdown in mortality improvement in rates, with projected 2011-2015 rates lower than those observed in 2000-2010. They include men and women in the UK, USA, Netherlands, Denmark, Portugal, Canada and Austria. Countries with only male populations in this group are Sweden, France, Spain, Finland, Belgium, Australia and Switzerland.

This observation is consistent with several hypotheses for the slowdown in mortality improvements that would have emerged before 2010 (for references see Leon, 2019 and Raleigh, 2019). Hypotheses have been developed based on specific countries, such as socio-economic divide in the UK. They may also be relevant for other countries. Other examples of hypotheses are:

- Worsening trends in diabetes and obesity in the UK, USA and other OECD countries.
- Inequality in mortality among different socio-economic groups has widened such that adverse mortality trends in the more deprived are affecting the overall mortality trend.
- Improvements in circulatory disease mortality are slowing in several countries, potentially related to stabilising smoking prevalence and cholesterol levels, especially among men, in addition to worsening diabetes and obesity trends mentioned above.
- Rising death rates related to dementia and Alzheimer diseases, but this

needs to be treated with care because of changes in coding practices in causes of death.

- Cohort effects. In the UK, people born between 1926 and 1935, aged 65 to 84 between 2000 and 2010, have experienced higher mortality improvement rates than people born before or after them. Some European countries have similar cohorts too. The survival of this cohort could have led to a subset of frail individuals. This when combined with younger cohorts with lower mortality improvement rates would stall overall mortality improvement rates.

4.3 Has there been more slowdown in mortality improvement rates than the projections just discussed?

We observe a remarkable gender difference, where women in 14 countries but men in 8 countries have experienced lower mortality improvements than projected, by more than 0.25% p.a., during 2011-2015 in 16 countries. This observation is consistent with suggestions that austerity measures in response to the 2008 recession and excess winter deaths such as the unusually high 2014/2015 winter deaths have adversely affected mortality trends (for references see Leon, 2019, Public Health England 2018, Raleigh, 2019).

Both austerity and excess winter deaths would risk exacerbating the unfavourable trends in obesity, diabetes, circulatory diseases-related deaths, dementia deaths and frailty mentioned above. Disadvantaged group may be impacted more increasing their mortality rates disproportionally such that overall mortality improvements are stalled (Public Health England, 2018). As women are notably affected more than men in our analyses, we suggest that austerity has disproportionately impacted women in these countries (Keen and Cracknell, 2017).

A number of the Scandinavian populations including both genders in

Denmark and men in Sweden and Finland have experienced mortality improvement rates in 2011-2015 that are greater than average projections by more than 0.25% p.a.. These countries were less affected by austerity and were among the 5 countries least affected by the 2014/2015 excess winter deaths. So, our results are consistent with the suggestion that austerity and excess winter deaths are linked to the recent slowdown in mortality improvement.

The UK, Spain and Germany are the 3 worst performing countries when assessed by the gap between actual experience against projection in 2011-2015. The UK and Spain have been cited to be more affected by austerity (Raleigh, 2019) and among the 6 worst affected countries by the 2014/2015 excess winter deaths in the European Union's 15 countries (EU MOMO, 2015). So their results are consistent with the potential roles of austerity and winter deaths.

However, Germany's experience is less consistent with the austerity and winter deaths hypotheses. It has been thought to be less affected by austerity (Raleigh, 2019) and was not one of the 6 worst-hit countries by the 2014/2015 winter deaths. One may expect its post-2011 mortality trends to be more aligned with projections, but the observed trends are worse than projections. Additionally, Portugal has been thought to be more impacted by austerity (Raleigh, 2019) and was the worst-hit country by the 2014/2015 winter deaths according to EU MOMO, 2015. We would expect Portugal to have experienced lower mortality improvement rates than projected, but this is not the case for Portuguese men. These suggest that there are forces other than austerity and the 2014/2015 winter deaths that might have influenced the recent slowdown.

4.4 Further work

The slowdown in mortality improvement is an important public health and policy issue that warrant further work, for example:

- Throughout the analysis, 2010 was set as a reference year. Although this is convenient for countries such as UK, the exact timing of the change in the overall direction of mortality improvements can vary from country to country; further analysis would help to investigate this.

- Also, the stochastic mortality projection models implemented in this analysis were fitted to the data above age 50, as most of these models were originally developed to forecast pensioners' mortality. Further work would help to study the suitability of some of these models for younger ages and hence whether this part of the analysis could be extended down to ages below age 50.

- Our analyses are consistent with suggestions that there are forces that would have contributed to the slowdown in mortality improvement rates even before 2010 and additional forces after. More analyses on health and socio-economic trends in each country and between countries would help to clarify potential drivers of historical trends and future trajectories.

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Appendix

A Complement to the descriptive analysis of the extend of slowdown of mortality improvements.

A.1 Standard population

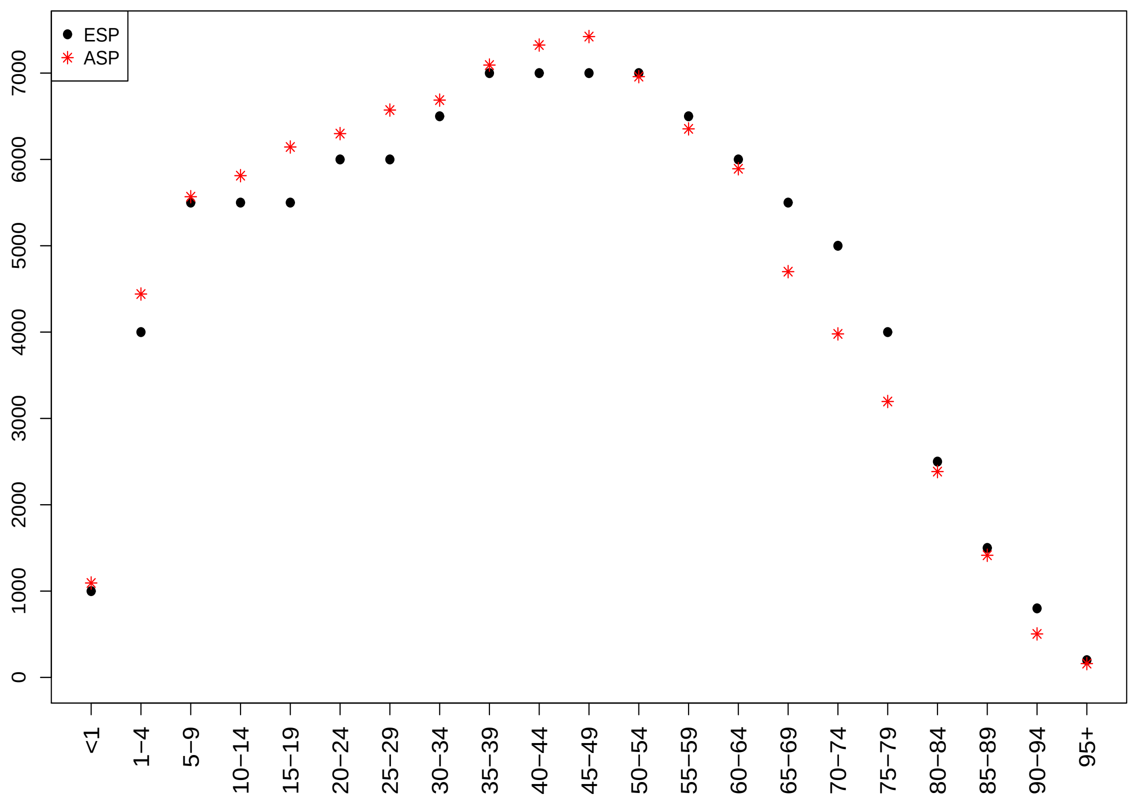

Figure A1: Comparison of the distribution of the 2010 aggregated population (ASP) from the 23 countries involved is this project, against the 2013 European Standard Population (ESP). Mortality rates were standardised using ASP by single ages as weights.

A.2 Observed mortality rates and improvements in Australia.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	1.82%	-0.89%	-2.22%	0.59%	-0.81%
30-34	0.59%	0.09%	-0.80%	1.86%	-4.33%
35-39	1.65%	0.74%	-0.70%	0.73%	-0.23%
40-44	1.47%	1.70%	1.15%	1.17%	-1.00%
45-49	2.08%	2.55%	1.83%	1.07%	-0.29%
50-54	1.85%	1.98%	2.11%	0.39%	0.15%
55-59	1.67%	2.30%	1.96%	1.57%	0.44%
60-64	2.18%	1.96%	3.41%	2.08%	0.81%
65-69	1.53%	1.55%	2.92%	2.31%	1.14%
70-74	2.14%	1.38%	2.99%	2.34%	2.14%
75-79	2.18%	1.24%	3.07%	2.61%	0.93%
80-84	1.66%	1.32%	2.50%	2.04%	1.45%
85-89	1.36%	0.79%	1.71%	1.61%	1.08%
90-95	0.82%	0.25%	1.37%	0.59%	0.97%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-0.91%	-0.69%	0.44%	5.13%	-0.28%
30-34	1.69%	-1.26%	-0.35%	3.59%	1.03%
35-39	1.49%	0.86%	0.10%	1.35%	0.40%
40-44	1.82%	1.74%	-0.18%	1.20%	-1.23%
45-49	1.21%	3.84%	1.94%	0.37%	0.56%
50-54	1.35%	3.91%	3.21%	0.86%	0.34%
55-59	1.68%	3.17%	3.73%	2.09%	0.38%
60-64	2.00%	2.45%	4.08%	2.69%	0.40%
65-69	1.33%	2.33%	3.79%	3.18%	1.89%
70-74	1.42%	2.25%	3.32%	3.60%	1.85%
75-79	1.01%	1.58%	3.13%	3.29%	1.73%
80-84	0.73%	0.98%	2.58%	2.40%	1.76%
85-89	1.28%	0.32%	1.90%	1.94%	1.27%
90-95	0.23%	-0.63%	0.76%	0.43%	2.04%

(b) Male

Table A1: Average yearly mortality improvements in Australia.

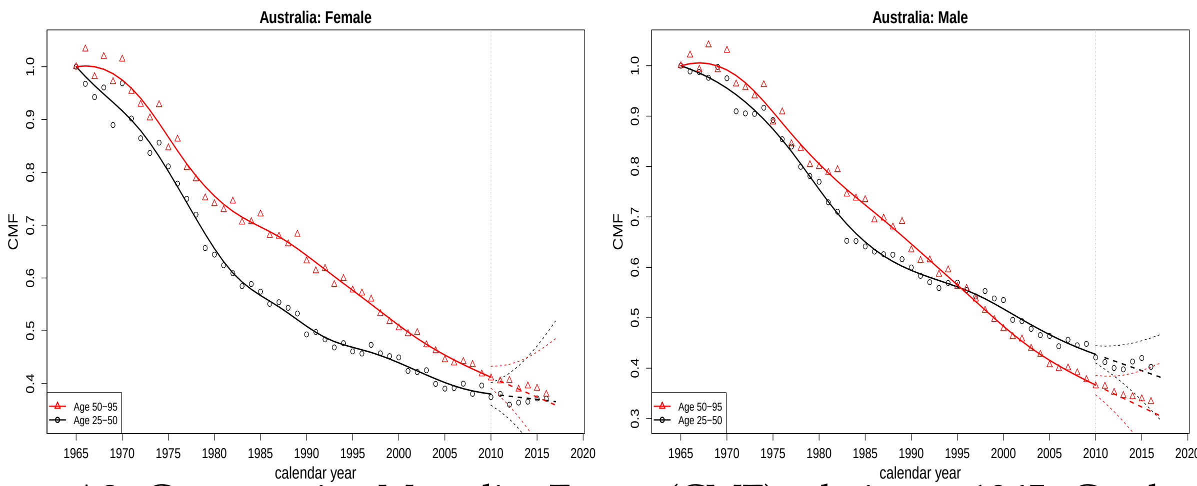

Figure A2: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.3 Observed mortality rates and improvements in Austria.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29	-1.11%	0.43%	-2.30%	-3.34%	-2.02%
30-34	-1.00%	1.23%	0.32%	-1.67%	-10.48%
35-39	-0.40%	2.02%	0.03%	0.54%	-2.31%
40-44	0.18%	-0.41%	-0.01%	2.98%	-0.54%
45-49	0.11%	0.91%	0.41%	1.40%	3.16%
50-54	0.45%	0.72%	0.06%	2.44%	0.97%
55-59	0.56%	1.47%	0.90%	1.25%	1.18%
60-64	0.95%	2.30%	2.07%	0.12%	1.68%
65-69	1.59%	1.77%	2.88%	1.68%	-0.50%
70-74	1.26%	2.79%	2.68%	2.76%	-0.61%
75-79	0.77%	2.63%	2.35%	2.66%	1.31%
80-84	0.64%	2.04%	2.28%	2.38%	1.68%
85-89	0.18%	1.09%	1.66%	1.85%	0.77%
90-95	-0.79%	1.29%	0.76%	1.42%	-0.02%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29	-0.81%	1.85%	0.29%	-0.12%	-0.34%
30-34	0.08%	-0.22%	1.71%	0.65%	2.65%
35-39	-0.09%	1.51%	2.54%	1.88%	-0.12%
40-44	-0.95%	1.31%	2.06%	3.35%	1.21%
45-49	-1.15%	2.45%	1.71%	1.90%	3.75%
50-54	-0.50%	2.63%	0.98%	1.69%	4.08%
55-59	0.30%	2.11%	2.44%	1.30%	2.14%
60-64	1.29%	1.25%	2.89%	1.27%	2.81%
65-69	1.15%	1.35%	2.20%	2.54%	1.28%
70-74	0.53%	2.56%	2.23%	3.13%	-0.16%
75-79	-0.04%	2.26%	1.90%	2.87%	1.95%
80-84	-0.14%	1.80%	2.11%	2.47%	1.76%
85-89	-0.28%	0.80%	1.83%	1.43%	0.80%
90-95	-0.39%	0.58%	1.03%	0.56%	0.38%

(b) Male

Table A2: Average yearly mortality improvements in Austria.

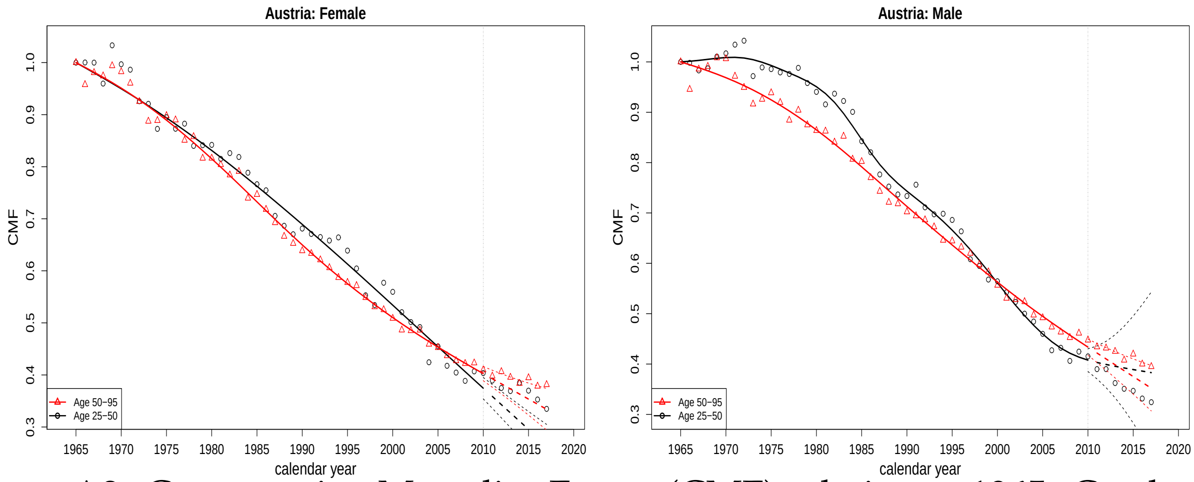

Figure A3: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.4 Observed mortality rates and improvements in Belgium.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	-2.17%	0.95%	-2.94%	-4.57%	1.69%
30-34	-1.52%	-0.22%	-0.44%	-2.38%	-6.36%
35-39	-0.27%	-0.94%	-0.04%	0.48%	1.60%
40-44	-0.21%	-0.55%	0.28%	1.92%	1.07%
45-49	0.94%	0.57%	0.12%	1.06%	1.43%
50-54	0.77%	2.36%	0.07%	0.49%	2.94%
55-59	0.66%	1.98%	0.85%	0.36%	-0.45%
60-64	1.05%	2.10%	1.36%	0.12%	-0.72%
65-69	1.56%	2.06%	2.44%	0.43%	1.62%
70-74	1.54%	2.48%	1.94%	2.07%	-0.17%
75-79	1.35%	2.53%	1.94%	2.32%	1.21%
80-84	0.84%	2.29%	1.58%	2.10%	1.69%
85-89	0.59%	1.49%	1.32%	1.35%	0.79%
90-95	-0.17%	0.82%	0.84%	0.99%	-0.40%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	-0.82%	-0.02%	-2.17%	0.91%	5.82%
30-34	-0.83%	-0.16%	-0.24%	1.64%	0.45%
35-39	-0.56%	1.41%	-0.17%	1.25%	1.64%
40-44	0.22%	0.61%	0.15%	2.34%	1.22%
45-49	1.18%	1.56%	-0.26%	2.43%	2.67%
50-54	0.38%	2.73%	0.09%	2.00%	3.34%
55-59	0.92%	2.69%	1.00%	1.82%	1.55%
60-64	0.52%	2.52%	2.44%	1.34%	1.39%
65-69	0.66%	1.98%	2.26%	2.28%	1.32%
70-74	0.01%	2.06%	2.09%	2.96%	1.37%
75-79	-0.34%	1.80%	2.00%	2.78%	1.94%
80-84	-0.20%	0.93%	1.22%	2.44%	2.35%
85-89	0.29%	0.39%	1.10%	1.24%	1.58%
90-95	-0.51%	-0.20%	0.38%	0.75%	0.39%

(b) Male

Table A3: Average yearly mortality improvements in Belgium.

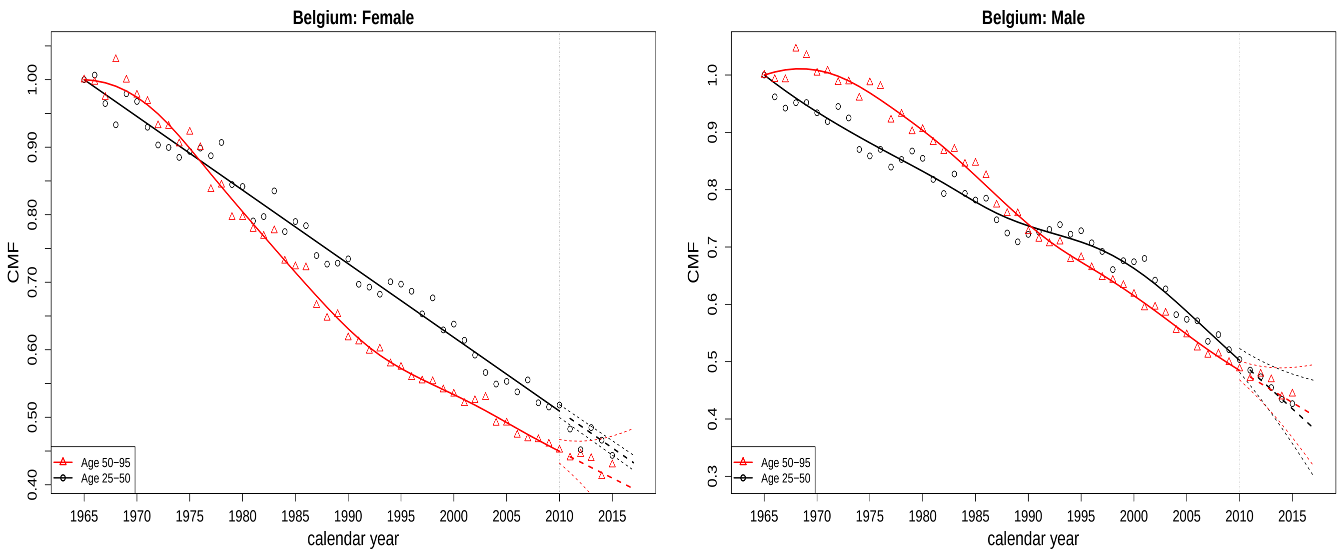

Figure A4: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.5 Observed mortality rates and improvements in Canada.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.01%	2.11%	0.71%	-0.23%	-3.42%
30-34	1.27%	0.77%	1.10%	-0.42%	-2.37%
35-39	0.66%	2.29%	0.79%	0.88%	-1.60%
40-44	1.05%	2.47%	0.73%	1.67%	0.00%
45-49	0.82%	2.12%	1.98%	0.78%	0.46%
50-54	1.06%	2.23%	0.94%	1.06%	0.56%
55-59	1.06%	1.57%	1.23%	1.50%	0.30%
60-64	1.58%	1.61%	1.40%	1.78%	0.21%
65-69	1.51%	1.51%	1.26%	1.81%	0.97%
70-74	1.56%	1.16%	1.13%	1.86%	1.01%
75-79	1.92%	1.23%	1.19%	2.07%	1.36%
80-84	1.55%	0.74%	0.99%	2.09%	1.66%
85-89	1.50%	0.70%	0.24%	1.86%	1.96%
90-95	0.66%	0.09%	-0.08%	1.18%	1.78%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-0.09%	1.62%	2.71%	0.87%	-3.20%
30-34	0.81%	-0.10%	2.10%	1.73%	-3.82%
35-39	0.59%	0.60%	1.75%	1.92%	-1.47%
40-44	1.62%	2.72%	0.93%	2.05%	-0.21%
45-49	0.97%	3.04%	1.71%	1.68%	0.73%
50-54	0.96%	3.22%	2.38%	1.22%	1.30%
55-59	0.96%	2.79%	2.60%	1.88%	1.12%
60-64	1.31%	2.09%	2.66%	2.46%	0.61%
65-69	0.63%	2.00%	2.40%	3.02%	1.03%
70-74	0.60%	1.49%	2.10%	3.31%	1.64%
75-79	0.61%	1.07%	1.70%	3.15%	2.02%
80-84	0.46%	0.30%	1.28%	2.84%	2.35%
85-89	0.71%	0.09%	0.58%	2.33%	2.16%
90-95	0.29%	-0.16%	-0.02%	1.24%	1.63%

(b) Male

Table A4: Average yearly mortality improvements in Canada.

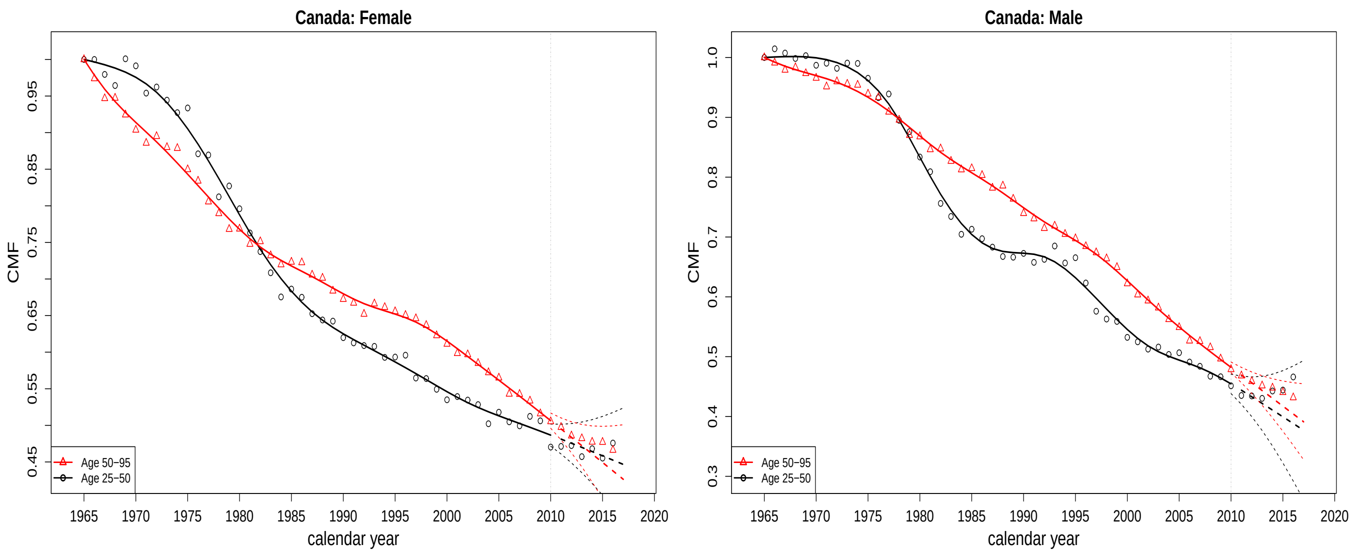

Figure A5: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.6 Observed mortality rates and improvements in Denmark.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-8.04%	-1.81%	-4.22%	-6.18%	-26.46%
30-34	-3.65%	-0.56%	-1.36%	-4.27%	-17.85%
35-39	-3.48%	-2.37%	1.05%	0.76%	-5.52%
40-44	-2.89%	-1.99%	1.26%	1.36%	3.75%
45-49	-1.99%	-0.01%	0.60%	1.31%	2.89%
50-54	-1.36%	-1.03%	2.01%	0.96%	3.22%
55-59	-0.82%	-1.67%	1.93%	1.26%	2.67%
60-64	0.00%	-0.76%	0.55%	2.85%	0.60%
65-69	1.14%	-1.12%	-0.13%	3.13%	2.26%
70-74	1.57%	0.13%	-0.35%	2.57%	2.85%
75-79	1.96%	0.48%	0.23%	1.31%	3.71%
80-84	1.99%	0.66%	0.49%	1.13%	2.19%
85-89	1.62%	0.50%	0.49%	0.71%	1.72%
90-95	0.05%	0.53%	0.74%	0.97%	0.60%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-3.78%	-0.88%	-0.22%	-0.83%	-4.37%
30-34	-2.39%	-3.15%	2.91%	2.32%	-3.01%
35-39	-2.76%	-1.93%	1.88%	-0.82%	1.05%
40-44	-2.61%	-1.57%	0.75%	1.60%	3.02%
45-49	-0.86%	-0.33%	0.61%	1.94%	3.44%
50-54	-1.04%	0.52%	2.32%	0.19%	5.72%
55-59	-0.39%	0.42%	2.11%	0.91%	2.53%
60-64	-0.16%	0.22%	2.59%	1.94%	1.42%
65-69	-0.06%	0.00%	1.79%	3.10%	1.86%
70-74	-0.33%	0.37%	1.26%	2.59%	3.33%
75-79	-0.13%	0.30%	0.93%	2.57%	3.53%
80-84	0.35%	0.18%	0.60%	1.78%	2.55%
85-89	0.56%	0.08%	0.03%	1.03%	1.85%
90-95	-0.15%	-0.02%	-0.37%	0.60%	0.03%

(b) Male

Table A5: Average yearly mortality improvements in Denmark.

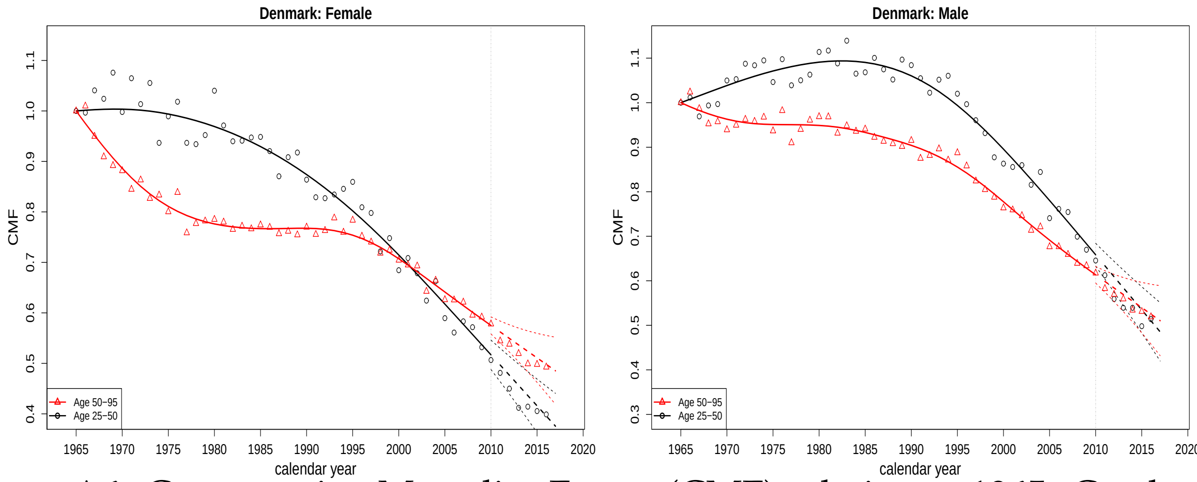

Figure A6: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.7 Observed mortality rates and improvements in Finland.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	-4.44%	-3.19%	-8.72%	-12.22%	-6.20%
30-34	-1.60%	-4.27%	-2.16%	-9.94%	-6.80%
35-39	-0.08%	-1.10%	-2.02%	-1.07%	-2.02%
40-44	-0.28%	-2.93%	-1.34%	1.13%	1.15%
45-49	1.79%	-2.25%	-0.52%	0.99%	1.10%
50-54	1.91%	-0.67%	-0.31%	-0.55%	3.06%
55-59	2.15%	1.87%	0.24%	0.20%	2.58%
60-64	2.35%	1.46%	1.64%	0.50%	1.55%
65-69	2.60%	1.27%	2.26%	0.76%	0.15%
70-74	2.80%	1.34%	2.83%	2.67%	1.22%
75-79	2.79%	1.58%	2.40%	2.87%	1.65%
80-84	2.07%	0.85%	1.91%	2.84%	1.75%
85-89	1.61%	-0.04%	1.12%	2.04%	1.32%
90-95	0.49%	-0.46%	0.19%	1.22%	0.09%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	0.01%	0.15%	-0.05%	-2.23%	3.87%
30-34	-1.25%	-1.70%	1.34%	-0.14%	1.87%
35-39	0.15%	-1.61%	1.52%	1.10%	3.21%
40-44	1.59%	-0.75%	1.53%	2.37%	5.36%
45-49	1.62%	0.74%	1.16%	2.33%	3.08%
50-54	1.06%	2.21%	0.99%	1.42%	5.08%
55-59	1.31%	2.43%	2.48%	0.83%	4.09%
60-64	1.16%	1.75%	3.65%	1.89%	2.66%
65-69	0.80%	1.68%	2.79%	2.21%	2.56%
70-74	0.77%	1.64%	2.56%	3.29%	1.81%
75-79	0.94%	1.16%	1.73%	2.87%	2.44%
80-84	0.67%	0.25%	0.95%	2.11%	3.37%
85-89	0.51%	-1.03%	0.36%	1.91%	0.56%
90-95	-2.58%	-2.00%	0.01%	0.95%	0.14%

(b) Male

Table A6: Average yearly mortality improvements in Finland.

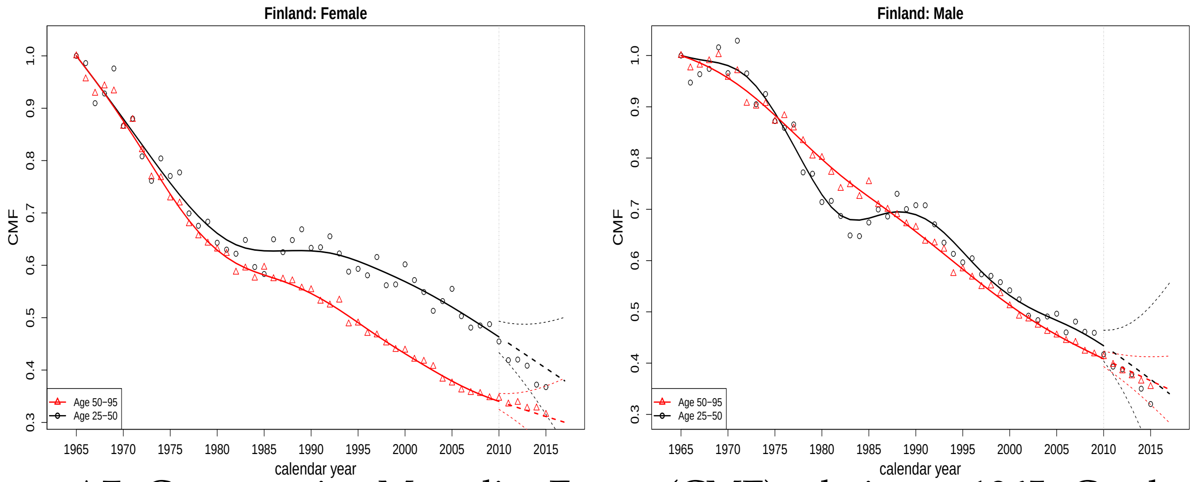

Figure A7: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.8 Observed mortality rates and improvements in France.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.68%	0.26%	3.32%	1.94%	0.62%
30-34	1.15%	0.83%	1.62%	3.37%	-0.29%
35-39	1.48%	1.03%	1.06%	2.80%	2.76%
40-44	1.36%	1.79%	0.78%	2.33%	3.41%
45-49	1.46%	2.04%	0.27%	1.29%	1.97%
50-54	1.50%	2.31%	1.19%	0.45%	2.55%
55-59	1.57%	2.08%	1.49%	0.36%	0.64%
60-64	1.96%	2.35%	1.84%	1.03%	-0.24%
65-69	2.24%	2.55%	1.80%	1.54%	0.60%
70-74	2.03%	2.67%	1.92%	2.43%	0.54%
75-79	1.71%	2.73%	2.21%	2.70%	1.51%
80-84	1.36%	2.38%	2.10%	2.44%	1.93%
85-89	0.96%	1.72%	1.72%	2.00%	1.31%
90-95	0.47%	0.80%	1.19%	1.53%	0.21%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.29%	-0.72%	3.07%	2.64%	2.72%
30-34	1.00%	-1.23%	2.98%	2.35%	2.49%
35-39	1.22%	-0.43%	1.99%	2.31%	2.69%
40-44	0.59%	1.13%	1.07%	3.27%	2.80%
45-49	0.01%	2.34%	0.68%	2.70%	2.94%
50-54	0.14%	2.43%	1.77%	1.34%	3.85%
55-59	0.98%	1.76%	2.44%	0.83%	2.12%
60-64	1.23%	1.65%	2.53%	1.74%	0.37%
65-69	1.17%	2.20%	1.74%	2.73%	0.99%
70-74	0.80%	2.38%	1.63%	3.23%	1.33%
75-79	0.74%	2.43%	1.83%	2.73%	2.31%
80-84	0.65%	1.65%	1.51%	2.37%	2.38%
85-89	0.54%	0.97%	1.38%	1.94%	1.59%
90-95	0.04%	0.47%	0.54%	1.44%	0.68%

(b) Male

Table A7: Average yearly mortality improvements in France.

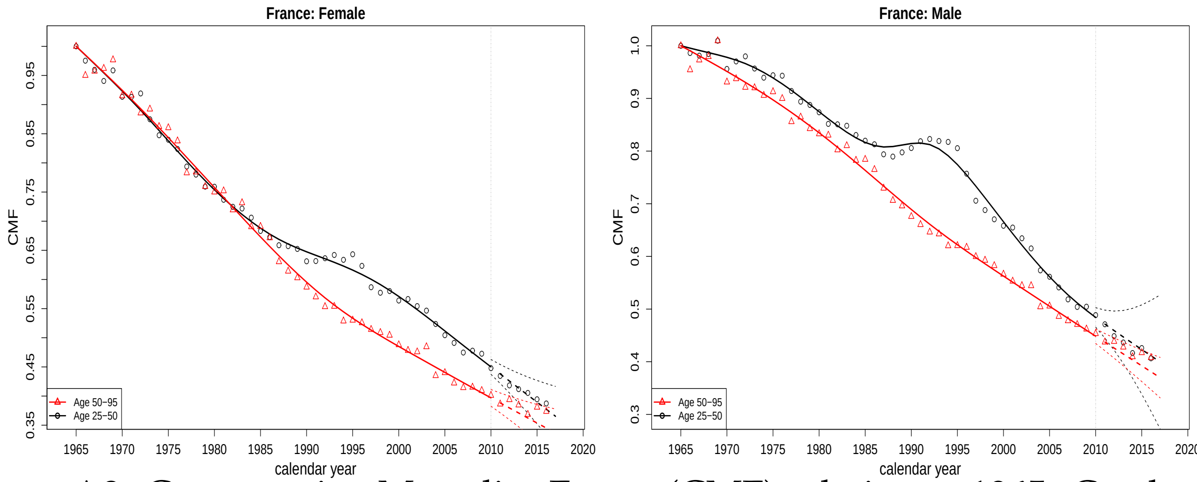

Figure A8: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.9 Observed mortality rates and improvements in Germany.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29			2.57%	1.70%	2.12%
30-34			3.11%	1.80%	-0.85%
35-39			3.20%	2.75%	0.68%
40-44			1.80%	2.99%	1.87%
45-49			1.51%	2.19%	1.95%
50-54			1.00%	1.18%	2.38%
55-59			2.29%	0.89%	0.58%
60-64			2.90%	0.74%	0.16%
65-69			2.74%	2.07%	-0.46%
70-74			2.39%	2.78%	-0.45%
75-79			2.43%	2.32%	2.27%
80-84			2.54%	1.33%	1.73%
85-89			2.13%	0.69%	1.14%
90-95			1.61%	0.48%	-0.13%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29			2.61%	2.26%	4.47%
30-34			3.84%	1.95%	1.15%
35-39			3.25%	3.06%	1.01%
40-44			1.23%	3.72%	2.05%
45-49			1.50%	2.77%	2.77%
50-54			2.20%	1.44%	3.17%
55-59			2.88%	1.10%	1.84%
60-64			2.87%	1.82%	0.53%
65-69			2.25%	2.74%	0.25%
70-74			2.01%	2.92%	0.84%
75-79			2.21%	2.48%	2.18%
80-84			2.37%	1.63%	1.82%
85-89			1.76%	1.09%	0.78%
90-95			1.04%	0.84%	-0.01%

(b) Male

Table A8: Average yearly mortality improvements in Germany.

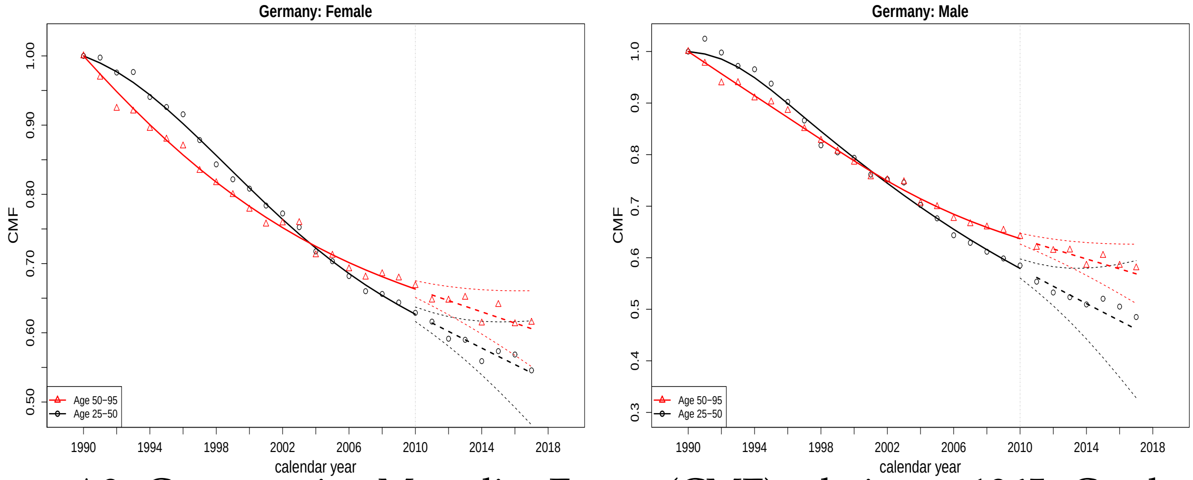

Figure A9: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.10 Observed mortality rates and improvements in Greece.

	1965-1980	1981-1990	1990-2000	2000-2010	2011-2013
25-29		-2.59%	-1.90%	-1.72%	-9.26%
30-34		-0.01%	0.08%	0.00%	-7.91%
35-39		-2.47%	-0.52%	-0.94%	0.49%
40-44		0.13%	-0.04%	-0.46%	0.15%
45-49		-0.27%	-0.34%	1.18%	-0.41%
50-54		2.54%	0.08%	-0.05%	-0.03%
55-59		1.75%	1.54%	0.60%	-1.36%
60-64		3.21%	1.73%	0.68%	1.25%
65-69		1.82%	2.15%	2.49%	-1.95%
70-74		1.35%	2.10%	3.55%	2.17%
75-79		1.03%	1.27%	2.88%	3.05%
80-84		0.16%	0.79%	2.04%	2.34%
85-89		-0.29%	0.27%	0.92%	1.16%
90-95		-1.65%	-1.19%	0.51%	0.77%

(a) Female

	1965-1980	1981-1990	1990-2000	2000-2010	2011-2013
25-29		-1.01%	-1.36%	0.00%	9.67%
30-34		-1.27%	-1.33%	-0.68%	5.29%
35-39		-1.94%	-1.13%	0.82%	3.93%
40-44		-1.66%	-1.11%	-0.07%	3.02%
45-49		-0.29%	-0.94%	0.79%	-0.61%
50-54		0.89%	-0.62%	0.60%	-0.01%
55-59		1.63%	0.53%	0.30%	-0.46%
60-64		1.81%	1.04%	0.53%	-0.73%
65-69		1.16%	1.50%	2.00%	-3.57%
70-74		0.82%	0.84%	2.67%	1.63%
75-79		0.49%	0.68%	2.34%	1.99%
80-84		0.49%	0.42%	1.71%	2.81%
85-89		-0.03%	0.10%	1.74%	-0.32%
90-95		-1.05%	-0.35%	0.60%	4.72%

(b) Male

Table A9: Average yearly mortality improvements in Greece.

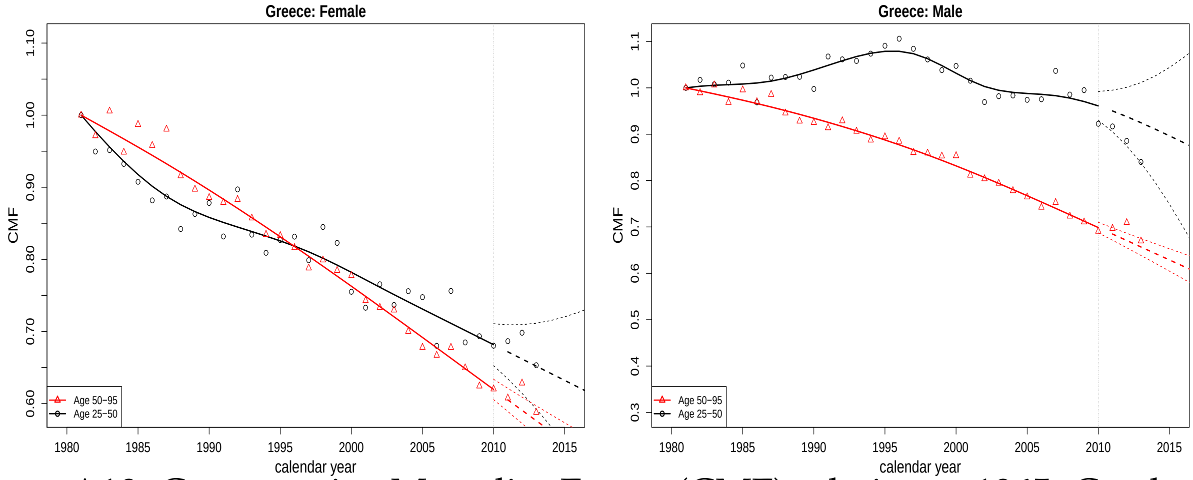

Figure A10: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.11 Observed mortality rates and improvements in Ireland.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	-2.73%	-15.06%	-13.90%	-8.88%	-21.73%
30-34	-5.08%	-6.26%	-9.78%	-4.51%	-9.23%
35-39	-3.60%	-6.47%	-8.64%	-2.46%	-6.88%
40-44	-2.42%	1.94%	-1.91%	-1.29%	4.16%
45-49	0.47%	-0.90%	-3.04%	0.89%	2.24%
50-54	-0.44%	1.44%	0.24%	0.47%	2.42%
55-59	-0.33%	1.32%	2.07%	2.58%	0.21%
60-64	-0.22%	0.88%	2.22%	2.63%	0.88%
65-69	-0.29%	1.22%	2.49%	2.79%	1.67%
70-74	-0.01%	1.93%	1.70%	3.68%	0.96%
75-79	-0.03%	1.28%	1.56%	4.28%	2.11%
80-84	0.31%	1.55%	1.04%	3.74%	0.21%
85-89	-0.04%	0.74%	0.52%	3.03%	0.04%
90-95	-0.33%	-0.09%	-0.32%	2.10%	1.54%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	-2.68%	-3.61%	-7.07%	1.60%	-0.14%
30-34	0.24%	-2.95%	-5.17%	0.97%	-3.57%
35-39	-2.26%	0.62%	-1.64%	-2.01%	3.67%
40-44	-0.57%	0.27%	-2.51%	-0.88%	1.83%
45-49	-0.67%	1.76%	0.00%	2.07%	2.21%
50-54	-0.78%	3.34%	1.38%	1.76%	0.89%
55-59	-0.64%	1.85%	1.74%	3.43%	-0.16%
60-64	-0.02%	1.29%	2.85%	3.71%	2.60%
65-69	-0.65%	1.20%	3.02%	4.06%	2.67%
70-74	-0.92%	1.39%	1.68%	5.18%	1.46%
75-79	-1.04%	0.78%	1.37%	5.10%	2.06%
80-84	-0.76%	0.46%	0.90%	3.40%	2.93%
85-89	-0.81%	-0.10%	-0.48%	3.54%	-0.94%
90-95	-2.25%	-0.65%	-0.11%	1.50%	2.81%

(b) Male

Table A10: Average yearly mortality improvements in Ireland.

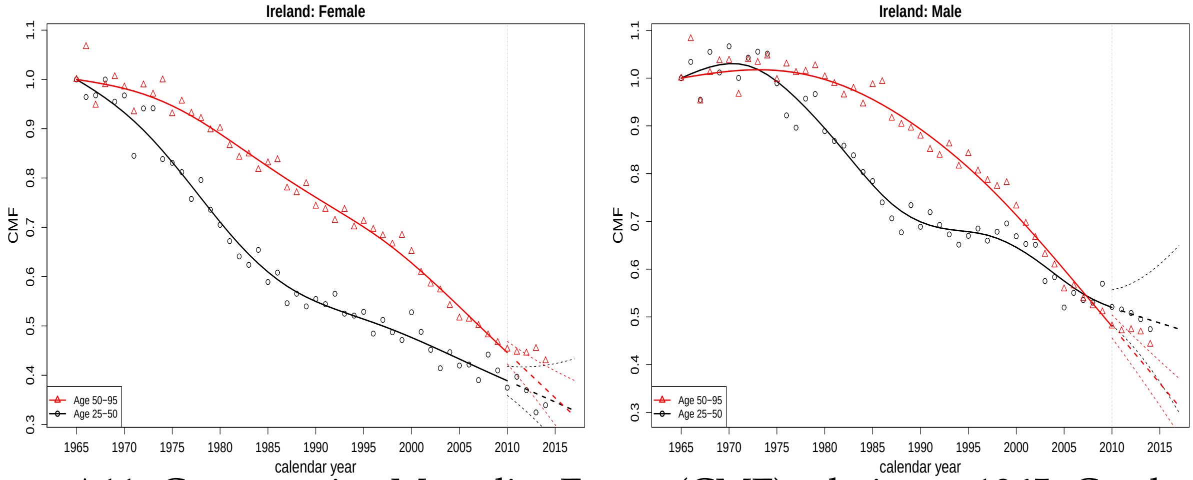

Figure A11: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.12 Observed mortality rates and improvements in Italy.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	2.61%	-0.24%	1.13%	3.91%	-1.19%
30-34	2.39%	0.46%	1.29%	3.31%	3.20%
35-39	2.36%	1.03%	1.29%	3.00%	0.58%
40-44	2.11%	1.61%	1.03%	2.22%	2.84%
45-49	1.76%	2.23%	1.94%	1.72%	2.54%
50-54	1.72%	2.54%	1.84%	1.56%	2.31%
55-59	1.36%	2.13%	1.95%	1.73%	0.68%
60-64	1.47%	2.12%	2.31%	2.00%	0.76%
65-69	1.68%	2.04%	2.60%	2.58%	0.25%
70-74	1.41%	2.30%	2.48%	3.00%	1.03%
75-79	1.36%	2.34%	2.20%	2.72%	2.54%
80-84	1.03%	2.29%	2.00%	2.26%	2.16%
85-89	0.52%	1.69%	1.63%	1.44%	1.75%
90-95	0.03%	1.16%	1.01%	0.99%	1.44%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	1.70%	-3.01%	2.04%	4.28%	4.60%
30-34	2.31%	-1.92%	1.76%	4.25%	4.71%
35-39	2.01%	0.13%	0.02%	4.29%	2.57%
40-44	1.54%	2.09%	1.38%	3.35%	3.22%
45-49	0.61%	3.41%	2.28%	2.59%	3.24%
50-54	0.16%	3.68%	2.50%	2.90%	1.48%
55-59	0.43%	2.63%	3.02%	3.07%	2.34%
60-64	0.63%	1.84%	3.47%	2.97%	1.88%
65-69	0.46%	1.68%	2.67%	3.43%	1.81%
70-74	0.04%	2.00%	1.97%	3.59%	2.30%
75-79	-0.19%	2.03%	1.64%	2.92%	2.74%
80-84	-0.07%	1.69%	1.63%	1.96%	2.73%
85-89	-0.01%	1.18%	1.18%	1.28%	1.76%
90-95	-0.29%	0.95%	0.34%	0.72%	1.40%

(b) Male

Table A11: Average yearly mortality improvements in Italy.

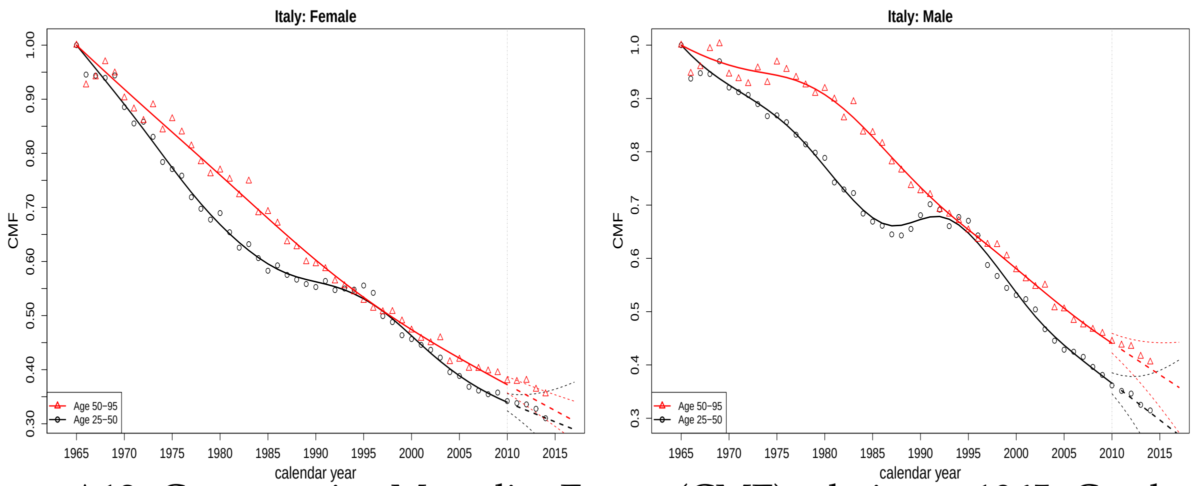

Figure A12: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.13 Observed mortality rates and improvements in Japan.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	4.92%	2.88%	0.53%	0.86%	0.56%
30-34	4.47%	2.91%	0.29%	0.71%	3.04%
35-39	4.11%	2.61%	0.99%	0.25%	1.93%
40-44	3.78%	2.25%	1.31%	1.09%	1.97%
45-49	3.55%	2.55%	1.08%	1.46%	1.49%
50-54	3.41%	2.51%	0.86%	1.61%	1.20%
55-59	3.47%	2.52%	1.65%	1.70%	1.52%
60-64	3.34%	2.82%	1.98%	1.84%	1.92%
65-69	3.40%	3.15%	2.17%	2.55%	1.40%
70-74	3.11%	3.49%	2.72%	2.75%	1.76%
75-79	2.75%	3.43%	3.07%	2.83%	2.29%
80-84	2.02%	2.77%	3.49%	2.84%	1.78%
85-89	1.33%	1.94%	3.15%	2.40%	1.68%
90-95	0.67%	1.22%	2.53%	1.69%	0.81%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	4.12%	1.72%	0.93%	0.65%	2.95%
30-34	3.89%	2.17%	-0.53%	1.26%	2.94%
35-39	3.22%	2.57%	-0.08%	1.64%	3.26%
40-44	2.48%	2.81%	0.80%	1.47%	3.83%
45-49	1.46%	3.08%	0.74%	1.93%	3.30%
50-54	2.11%	2.04%	0.73%	2.33%	2.96%
55-59	2.86%	0.67%	1.53%	1.82%	3.07%
60-64	2.91%	0.96%	1.28%	1.64%	2.57%
65-69	2.70%	2.07%	0.77%	2.49%	1.48%
70-74	2.35%	2.43%	1.24%	2.57%	1.58%
75-79	1.97%	2.10%	1.89%	1.96%	2.63%
80-84	1.66%	1.49%	1.74%	1.80%	2.38%
85-89	1.06%	0.95%	1.70%	1.37%	1.76%
90-95	0.47%	0.49%	1.15%	0.91%	1.08%

(b) Male

Table A12: Average yearly mortality improvements in Japan.

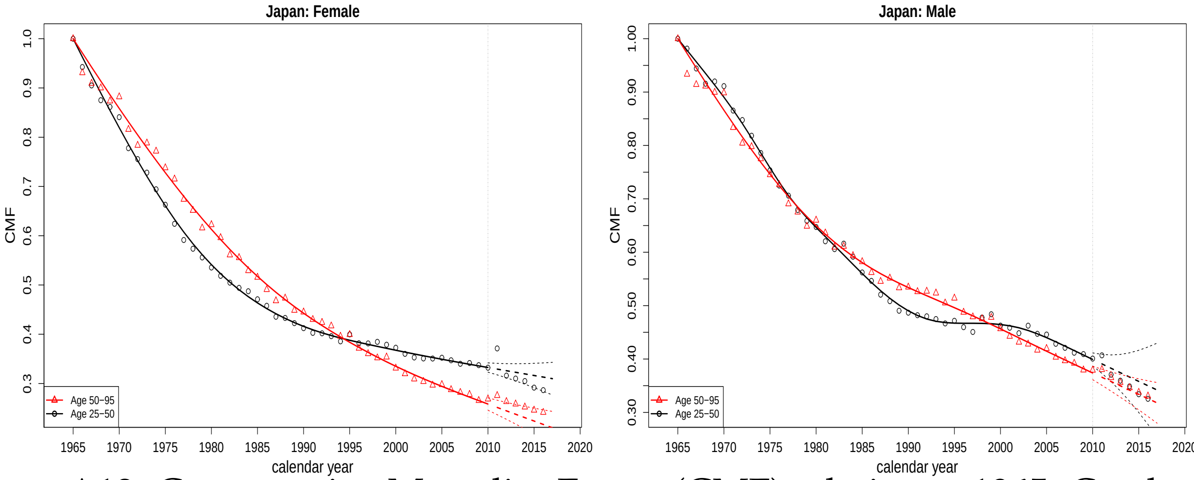

Figure A13: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.14 Observed mortality rates and improvements in Korea.

	1965-1980	1980-1990	1990-2000	2003-2010	2011-2016
25-29				-2.72%	6.39%
30-34				-1.35%	2.48%
35-39				0.33%	2.94%
40-44				2.50%	2.06%
45-49				2.32%	3.42%
50-54				3.31%	2.59%
55-59				4.68%	2.44%
60-64				5.06%	3.41%
65-69				5.65%	4.59%
70-74				5.87%	5.03%
75-79				5.29%	4.33%
80-84				4.43%	3.33%
85-89				3.50%	1.88%
90-95				2.46%	1.28%

(a) Female

	1965-1980	1980-1990	1990-2000	2003-2010	2011-2016
25-29				1.44%	4.35%
30-34				2.48%	3.45%
35-39				4.64%	4.48%
40-44				4.57%	4.77%
45-49				4.16%	4.97%
50-54				4.16%	3.98%
55-59				3.24%	3.98%
60-64				4.75%	3.38%
65-69				4.95%	4.06%
70-74				3.79%	5.07%
75-79				3.02%	3.75%
80-84				2.65%	2.46%
85-89				1.96%	2.31%
90-95				0.86%	1.20%

(b) Male

Table A13: Average yearly mortality improvements in Korea.

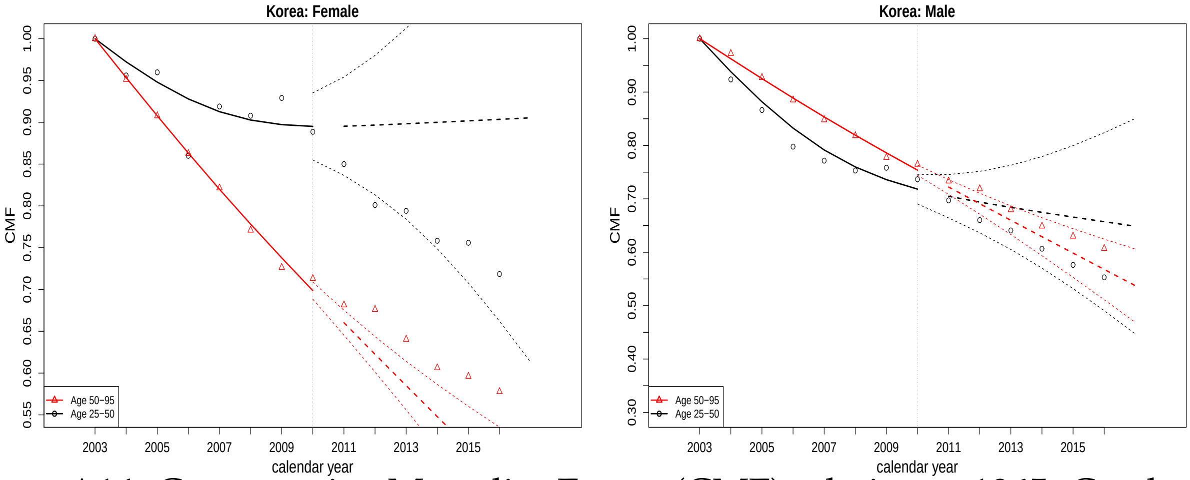

Figure A14: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.15 Observed mortality rates and improvements in Netherlands.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.05%	-0.99%	-1.12%	-0.18%	-6.14%
30-34	0.11%	-0.04%	0.06%	-0.08%	-2.77%
35-39	0.21%	-0.47%	-0.71%	2.71%	-1.06%
40-44	0.61%	0.56%	-1.06%	3.11%	1.92%
45-49	0.78%	0.91%	-0.96%	2.55%	2.14%
50-54	0.80%	1.27%	0.49%	1.07%	1.47%
55-59	0.93%	0.57%	0.29%	0.55%	0.84%
60-64	1.16%	0.61%	0.69%	1.57%	0.15%
65-69	1.71%	0.87%	0.31%	1.89%	0.04%
70-74	1.92%	1.32%	0.57%	2.53%	0.25%
75-79	1.70%	1.23%	0.70%	2.31%	1.27%
80-84	1.58%	0.93%	0.29%	2.04%	1.24%
85-89	1.29%	0.31%	0.12%	1.82%	0.22%
90-95	0.72%	0.02%	-0.14%	1.33%	-0.45%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.17%	-0.96%	-0.03%	2.55%	-2.44%
30-34	0.71%	-0.80%	0.67%	1.96%	-2.73%
35-39	0.97%	-0.02%	0.49%	2.77%	0.99%
40-44	0.52%	0.47%	0.12%	2.56%	-0.18%
45-49	0.50%	1.64%	0.58%	2.86%	1.65%
50-54	-0.03%	1.92%	1.73%	2.26%	2.36%
55-59	0.60%	1.08%	1.98%	2.29%	2.17%
60-64	0.32%	1.79%	2.49%	2.95%	1.30%
65-69	0.08%	0.99%	1.79%	3.33%	2.26%
70-74	-0.69%	0.92%	1.68%	3.76%	1.71%
75-79	-0.41%	0.39%	1.30%	2.95%	3.08%
80-84	-0.22%	-0.19%	0.60%	2.73%	1.55%
85-89	0.09%	-0.77%	0.25%	2.06%	0.55%
90-95	0.04%	-0.40%	-0.47%	1.15%	0.18%

(b) Male

Table A14: Average yearly mortality improvements in Netherlands.

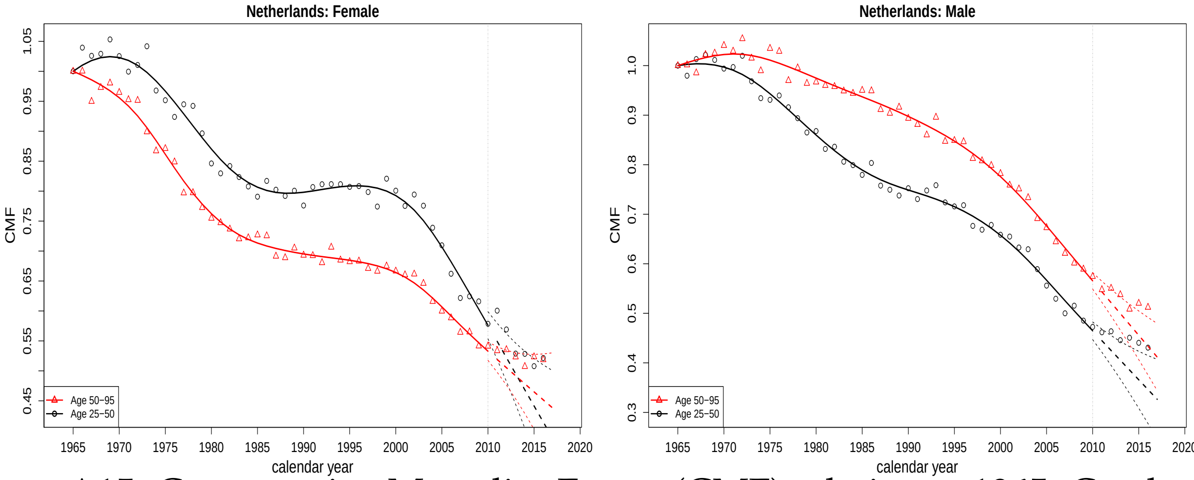

Figure A15: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.16 Observed mortality rates and improvements in NewZealand.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013
25-29	-10.11%	-8.53%	-7.41%	-11.29%	1.25%
30-34	-8.91%	-9.09%	-2.74%	-5.99%	-2.95%
35-39	-1.75%	-1.98%	-1.89%	-0.94%	-1.67%
40-44	-2.39%	-1.26%	-0.28%	-1.00%	3.52%
45-49	-2.48%	-1.06%	1.58%	-0.71%	0.21%
50-54	-0.55%	-0.67%	1.56%	1.02%	-3.94%
55-59	-0.40%	-0.56%	0.79%	2.29%	-0.45%
60-64	-0.65%	0.64%	1.73%	2.63%	-0.36%
65-69	-0.56%	1.24%	1.73%	2.59%	2.14%
70-74	-0.09%	1.47%	2.65%	2.40%	2.63%
75-79	0.67%	1.73%	2.70%	2.39%	-0.69%
80-84	0.56%	0.42%	2.61%	1.83%	2.12%
85-89	0.76%	0.48%	1.33%	1.36%	0.80%
90-95	-0.11%	-1.04%	1.06%	0.47%	1.10%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2013
25-29	-7.01%	-5.52%	0.28%	1.93%	-2.29%
30-34	-3.25%	-2.06%	-1.79%	0.14%	-1.39%
35-39	-1.53%	-1.88%	-0.54%	0.15%	-0.76%
40-44	-0.26%	0.68%	-0.05%	-1.35%	-0.48%
45-49	0.65%	2.48%	1.08%	-0.40%	0.58%
50-54	0.64%	2.72%	3.26%	1.16%	0.77%
55-59	0.38%	2.10%	2.80%	2.58%	1.28%
60-64	0.16%	2.38%	3.85%	3.70%	1.04%
65-69	-0.07%	1.74%	3.17%	3.11%	1.87%
70-74	-0.12%	1.91%	2.97%	3.54%	0.27%
75-79	-0.17%	1.67%	2.51%	3.65%	1.15%
80-84	-0.45%	0.78%	1.71%	2.58%	1.86%
85-89	-0.84%	-0.20%	0.85%	1.98%	-0.78%
90-95	-3.50%	-2.11%	-0.07%	0.81%	2.39%

(b) Male

Table A15: Average yearly mortality improvements in New Zealand.

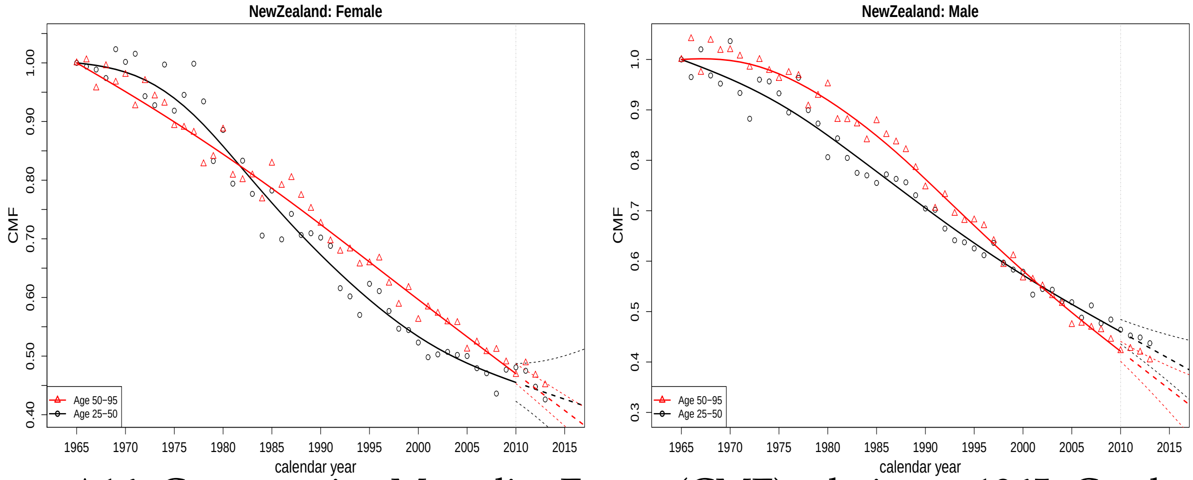

Figure A16: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.17 Observed mortality rates and improvements in Norway.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	-2.76%	-13.16%	-9.97%	-5.89%	3.18%
30-34	-2.99%	-7.50%	-2.31%	-3.65%	-6.06%
35-39	-2.03%	-8.59%	-4.51%	-2.25%	-3.15%
40-44	-0.14%	-2.89%	-1.16%	0.14%	0.66%
45-49	-0.72%	-1.86%	-1.57%	0.80%	0.23%
50-54	0.02%	0.73%	-0.79%	0.34%	0.22%
55-59	0.69%	-0.01%	0.01%	0.54%	1.53%
60-64	1.04%	-0.53%	0.85%	0.90%	3.12%
65-69	1.81%	1.11%	1.39%	1.22%	1.50%
70-74	1.79%	0.29%	0.94%	1.54%	2.74%
75-79	1.90%	1.01%	1.67%	1.97%	1.64%
80-84	1.58%	1.21%	1.00%	2.11%	1.60%
85-89	1.37%	0.42%	0.80%	1.68%	1.63%
90-95	0.22%	0.32%	0.17%	1.36%	1.14%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	-1.29%	-4.50%	-6.80%	-2.41%	4.01%
30-34	-1.35%	-3.20%	-4.07%	-1.13%	-2.74%
35-39	-0.18%	-2.40%	-3.39%	-0.11%	-6.74%
40-44	-0.42%	-0.83%	-0.37%	0.67%	2.12%
45-49	-0.04%	-0.02%	2.17%	2.46%	2.19%
50-54	-0.24%	2.10%	1.78%	2.62%	2.05%
55-59	-0.20%	0.91%	2.48%	1.26%	3.30%
60-64	-0.05%	1.26%	3.46%	2.41%	2.54%
65-69	-0.23%	0.59%	2.60%	2.63%	3.61%
70-74	-0.18%	0.31%	2.06%	3.27%	1.95%
75-79	-0.20%	0.64%	1.62%	2.88%	2.80%
80-84	0.22%	-0.03%	0.88%	2.44%	2.72%
85-89	0.50%	-0.38%	0.14%	2.06%	2.26%
90-95	0.55%	-0.50%	-1.41%	0.76%	-0.13%

(b) Male

Table A16: Average yearly mortality improvements in Norway.

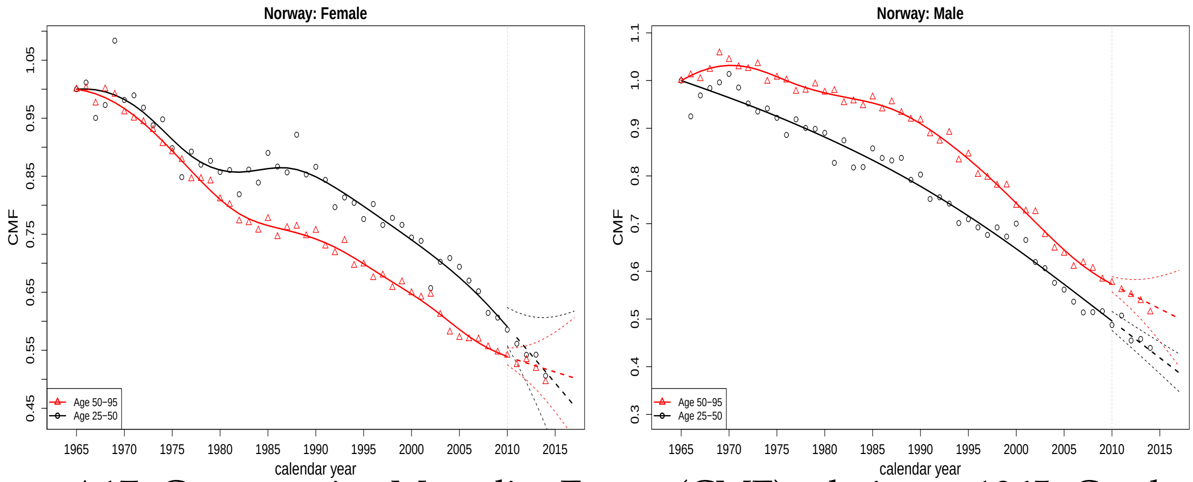

Figure A17: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.18 Observed mortality rates and improvements in Portugal.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	0.67%	-1.32%	0.30%	0.76%	2.72%
30-34	1.02%	-1.15%	-2.00%	2.22%	6.38%
35-39	1.09%	-0.46%	0.13%	0.58%	5.77%
40-44	0.98%	0.43%	0.75%	1.84%	3.10%
45-49	0.78%	0.80%	0.74%	0.97%	2.07%
50-54	1.13%	0.68%	-0.08%	1.31%	2.05%
55-59	1.11%	1.28%	1.57%	2.55%	1.64%
60-64	1.35%	1.43%	1.46%	2.93%	-0.19%
65-69	1.32%	1.34%	1.77%	3.30%	1.32%
70-74	1.19%	2.12%	1.33%	3.31%	2.57%
75-79	1.00%	1.72%	1.57%	3.69%	2.61%
80-84	0.73%	1.33%	1.39%	2.21%	3.16%
85-89	0.60%	0.63%	0.57%	1.68%	1.26%
90-95	-0.39%	-0.01%	0.29%	1.36%	-1.30%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2015
25-29	-0.24%	-1.23%	0.31%	7.61%	3.03%
30-34	-0.10%	-1.55%	-1.03%	6.86%	5.71%
35-39	0.70%	-0.73%	-2.40%	4.81%	7.27%
40-44	0.44%	0.49%	-1.30%	1.67%	5.84%
45-49	0.11%	1.22%	-0.45%	0.67%	2.67%
50-54	0.13%	1.26%	1.34%	0.57%	2.48%
55-59	0.64%	0.48%	1.53%	1.02%	0.90%
60-64	0.44%	0.77%	1.75%	2.08%	0.49%
65-69	0.58%	0.96%	1.35%	2.73%	1.70%
70-74	0.58%	1.48%	1.15%	3.10%	2.22%
75-79	0.31%	1.39%	1.12%	2.97%	2.66%
80-84	0.28%	0.73%	0.83%	1.85%	3.06%
85-89	0.28%	0.44%	0.46%	1.34%	0.75%
90-95	-0.89%	-0.88%	-1.24%	0.68%	-0.37%

(b) Male

Table A17: Average yearly mortality improvements in Portugal.

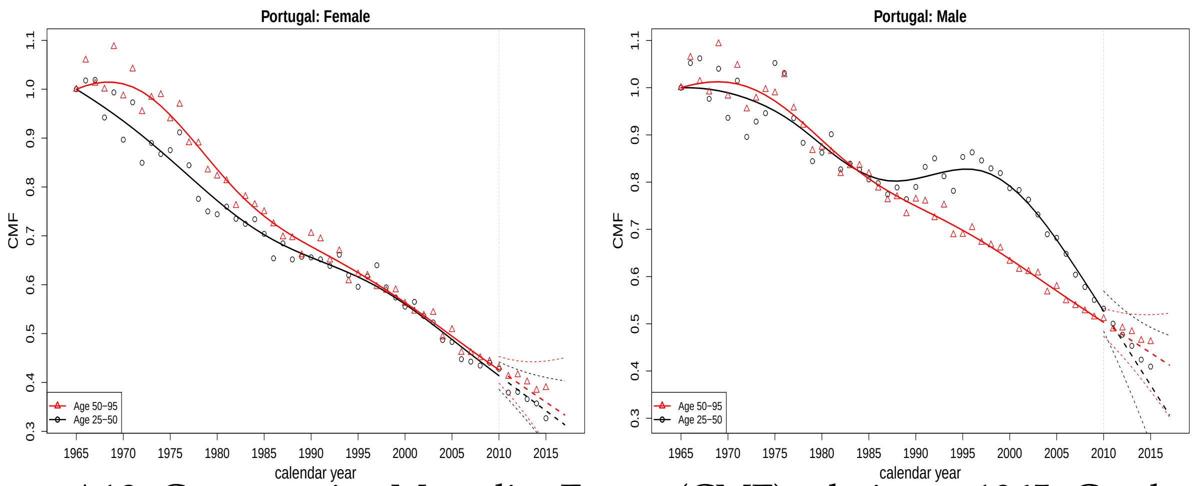

Figure A18: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.19 Observed mortality rates and improvements in Spain.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	3.18%	-2.48%	3.65%	3.14%	0.25%
30-34	3.05%	-0.26%	0.97%	4.77%	1.08%
35-39	2.79%	0.57%	0.15%	2.98%	1.75%
40-44	2.81%	1.51%	0.63%	1.70%	3.50%
45-49	2.38%	2.07%	1.16%	1.28%	2.34%
50-54	2.07%	2.07%	1.90%	0.51%	0.56%
55-59	2.21%	2.33%	2.25%	0.60%	0.42%
60-64	2.27%	2.56%	2.45%	2.12%	-0.67%
65-69	2.30%	2.48%	2.30%	2.78%	0.22%
70-74	2.22%	2.39%	2.59%	3.17%	1.72%
75-79	1.82%	2.45%	2.30%	3.19%	2.12%
80-84	1.34%	1.94%	1.90%	2.93%	2.01%
85-89	0.81%	1.10%	1.48%	2.37%	1.20%
90-95	-0.23%	0.17%	0.95%	1.62%	0.76%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	0.98%	-4.80%	4.84%	6.13%	2.26%
30-34	1.04%	-3.68%	2.09%	7.11%	0.68%
35-39	1.46%	-1.11%	0.49%	6.07%	4.33%
40-44	1.02%	0.13%	0.52%	3.67%	5.30%
45-49	1.09%	0.79%	1.17%	2.51%	4.63%
50-54	0.73%	1.11%	1.21%	1.69%	2.69%
55-59	0.94%	1.30%	1.81%	1.79%	1.93%
60-64	1.28%	1.49%	1.62%	2.25%	0.92%
65-69	1.35%	1.33%	1.74%	2.83%	1.02%
70-74	1.01%	1.33%	1.49%	2.92%	1.68%
75-79	1.08%	1.53%	1.32%	3.04%	1.67%
80-84	1.16%	1.43%	1.29%	2.41%	2.18%
85-89	0.66%	0.53%	0.93%	2.01%	1.31%
90-95	-0.02%	-0.03%	0.06%	1.15%	1.42%

(b) Male

Table A18: Average yearly mortality improvements in Spain.

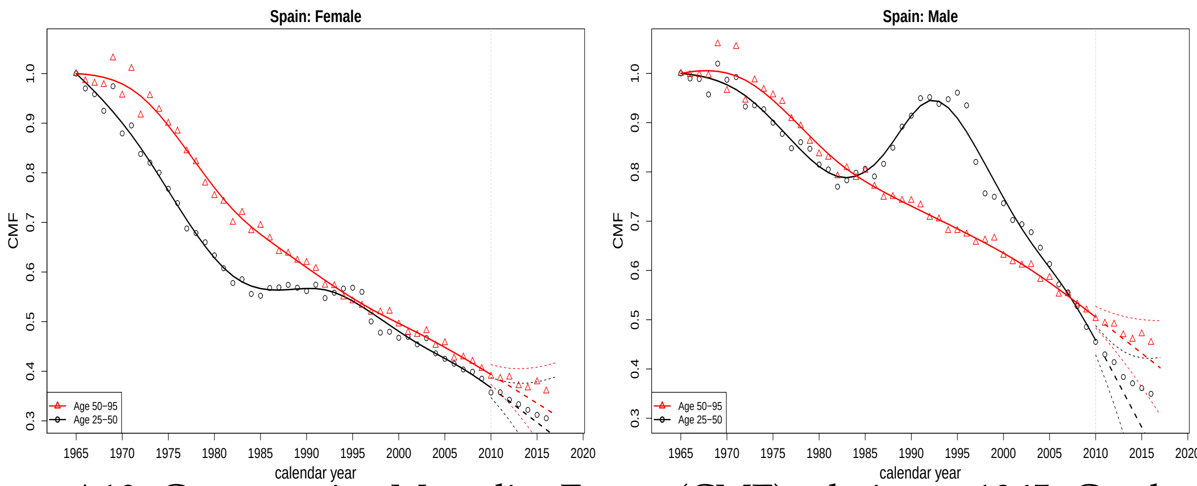

Figure A19: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.20 Observed mortality rates and improvements in Sweden.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29	-1.23%	-3.27%	-1.13%	-7.24%	-7.87%
30-34	-1.95%	-0.19%	0.71%	-4.24%	-6.15%
35-39	-0.22%	-0.67%	-0.10%	0.47%	-3.26%
40-44	-1.90%	0.58%	1.50%	2.50%	-1.36%
45-49	0.42%	-0.48%	1.12%	2.37%	-0.56%
50-54	0.80%	1.20%	0.17%	1.53%	0.63%
55-59	0.57%	0.48%	-0.43%	1.41%	1.45%
60-64	1.24%	0.99%	0.08%	0.94%	1.60%
65-69	1.69%	1.11%	0.96%	1.10%	1.01%
70-74	1.90%	1.50%	1.20%	1.35%	0.62%
75-79	1.80%	1.74%	1.58%	1.57%	0.97%
80-84	1.44%	1.45%	0.87%	1.79%	0.63%
85-89	1.16%	0.96%	0.96%	1.38%	0.83%
90-95	0.76%	0.08%	0.22%	0.52%	0.60%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2017
25-29	-2.35%	-0.16%	1.30%	-3.28%	-3.15%
30-34	-1.58%	0.55%	3.09%	-1.88%	-3.78%
35-39	-0.84%	2.14%	2.69%	2.10%	-5.31%
40-44	-1.46%	1.71%	2.39%	2.57%	-1.20%
45-49	-1.20%	2.16%	1.24%	1.74%	2.22%
50-54	-0.66%	2.78%	2.33%	1.36%	2.55%
55-59	0.12%	1.74%	2.90%	1.85%	2.62%
60-64	-0.15%	1.63%	2.23%	1.82%	1.90%
65-69	0.36%	1.82%	2.26%	2.47%	2.02%
70-74	0.13%	1.64%	1.93%	2.77%	2.15%
75-79	0.22%	1.31%	1.71%	2.27%	2.56%
80-84	0.27%	0.93%	1.27%	2.01%	1.98%
85-89	0.17%	0.43%	0.31%	1.55%	0.95%
90-95	-0.46%	0.07%	-0.32%	0.78%	-0.06%

(b) Male

Table A19: Average yearly mortality improvements in Sweden.

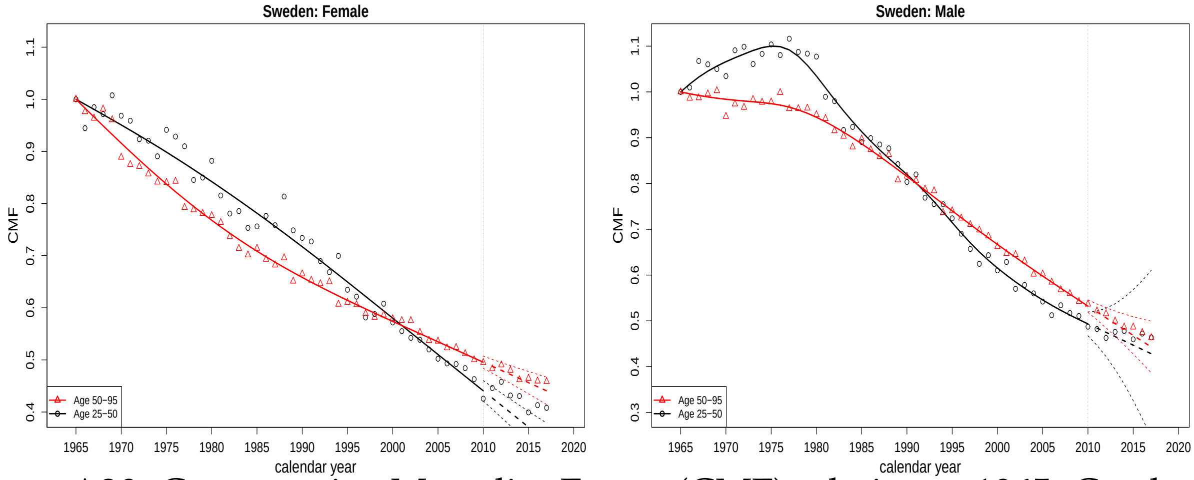

Figure A20: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.21 Observed mortality rates and improvements in Switzerland.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-2.10%	-5.99%	-3.93%	-2.80%	-17.69%
30-34	-1.77%	-3.67%	-0.31%	-0.84%	-6.29%
35-39	-0.18%	-0.07%	-0.20%	1.32%	-0.89%
40-44	-0.12%	0.08%	-0.55%	0.50%	-0.28%
45-49	0.41%	0.15%	1.68%	0.37%	1.97%
50-54	0.34%	1.00%	0.18%	1.19%	2.97%
55-59	1.54%	1.95%	0.09%	0.59%	2.08%
60-64	1.59%	1.42%	0.12%	0.48%	1.60%
65-69	2.18%	1.63%	1.45%	1.83%	-0.11%
70-74	2.26%	1.76%	1.63%	1.65%	0.98%
75-79	2.09%	2.11%	1.53%	2.46%	1.19%
80-84	1.85%	1.52%	1.38%	1.79%	1.75%
85-89	0.95%	0.96%	0.81%	1.65%	1.34%
90-95	0.25%	0.01%	0.05%	1.08%	1.12%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-0.55%	-2.76%	2.72%	2.45%	-1.91%
30-34	-0.36%	-2.25%	2.83%	1.59%	0.60%
35-39	-0.64%	-2.29%	0.77%	1.80%	-0.43%
40-44	1.05%	-1.08%	-0.12%	1.86%	3.45%
45-49	1.19%	0.73%	0.92%	1.65%	3.15%
50-54	1.19%	2.26%	1.56%	1.86%	2.00%
55-59	0.97%	2.03%	1.95%	1.67%	2.91%
60-64	1.25%	1.21%	2.10%	2.61%	1.93%
65-69	1.27%	1.32%	2.41%	2.23%	2.21%
70-74	0.82%	1.45%	2.12%	3.36%	1.85%
75-79	0.71%	1.13%	1.68%	2.76%	3.15%
80-84	0.53%	0.86%	1.38%	2.27%	2.43%
85-89	0.65%	-0.10%	1.16%	1.38%	1.72%
90-95	0.18%	-0.47%	-0.12%	0.88%	0.99%

(b) Male

Table A20: Average yearly mortality improvements in Switzerland.

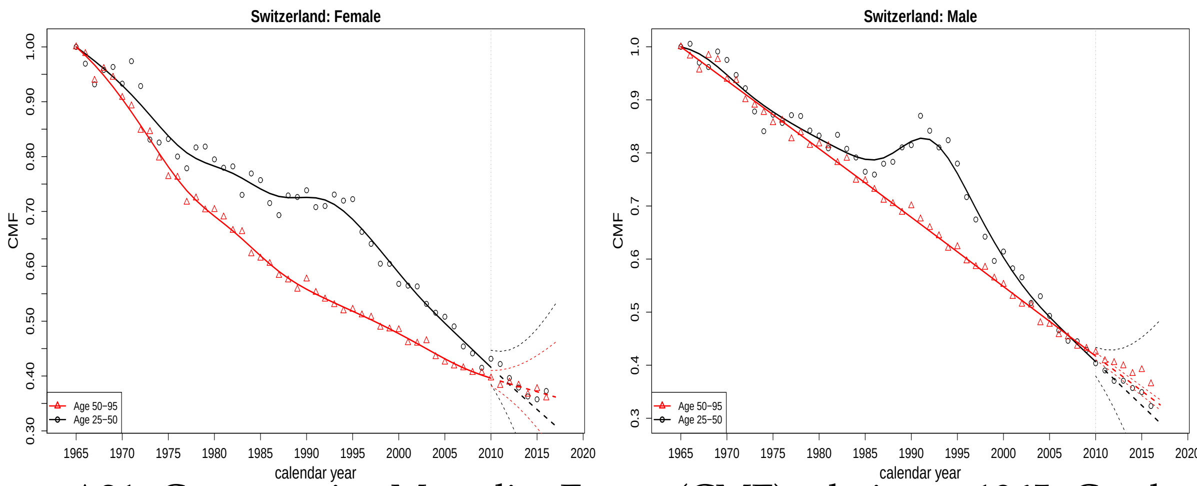

Figure A21: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.22 Observed mortality rates and improvements in Taiwan.

	1970-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	2.84%	0.09%	2.56%	1.78%	1.98%
30-34	3.61%	0.62%	1.63%	1.55%	1.68%
35-39	2.59%	0.98%	1.78%	2.79%	-1.46%
40-44	1.79%	2.32%	0.92%	1.66%	1.27%
45-49	1.03%	2.71%	1.78%	1.73%	1.13%
50-54	1.23%	2.40%	1.70%	2.50%	-0.59%
55-59	0.48%	2.04%	1.42%	2.91%	0.24%
60-64	2.51%	1.85%	2.30%	3.55%	1.21%
65-69	2.45%	1.48%	2.87%	3.82%	0.22%
70-74	2.84%	1.43%	2.86%	3.49%	1.88%
75-79	1.56%	0.62%	2.76%	2.82%	1.37%
80-84	1.07%	0.49%	2.62%	2.87%	1.35%
85-89	0.34%	0.37%	1.43%	2.74%	0.84%
90-95	0.76%	0.17%	0.24%	1.39%	0.93%

(a) Female

	1970-1980	1980-1990	1990-2000	2000-2010	2011-2014
25-29	1.96%	-0.14%	2.73%	2.95%	5.76%
30-34	2.16%	-0.03%	1.13%	2.43%	3.24%
35-39	0.52%	-0.13%	0.10%	1.82%	-0.02%
40-44	-0.24%	0.24%	0.45%	0.93%	1.49%
45-49	0.62%	0.48%	0.75%	0.75%	-0.35%
50-54	2.06%	0.43%	0.91%	1.47%	-0.22%
55-59	1.88%	0.97%	0.56%	1.61%	1.17%
60-64	2.80%	1.74%	0.40%	2.30%	0.84%
65-69	3.05%	2.06%	1.69%	2.05%	0.84%
70-74	3.08%	1.71%	2.10%	1.78%	0.75%
75-79	2.54%	1.30%	2.31%	1.75%	0.57%
80-84	0.89%	0.86%	1.84%	2.56%	0.00%
85-89	-0.03%	-0.37%	1.36%	2.45%	-0.48%
90-95	1.20%	-3.03%	-0.06%	1.94%	-1.33%

(b) Male

Table A21: Average yearly mortality improvements in Taiwan.

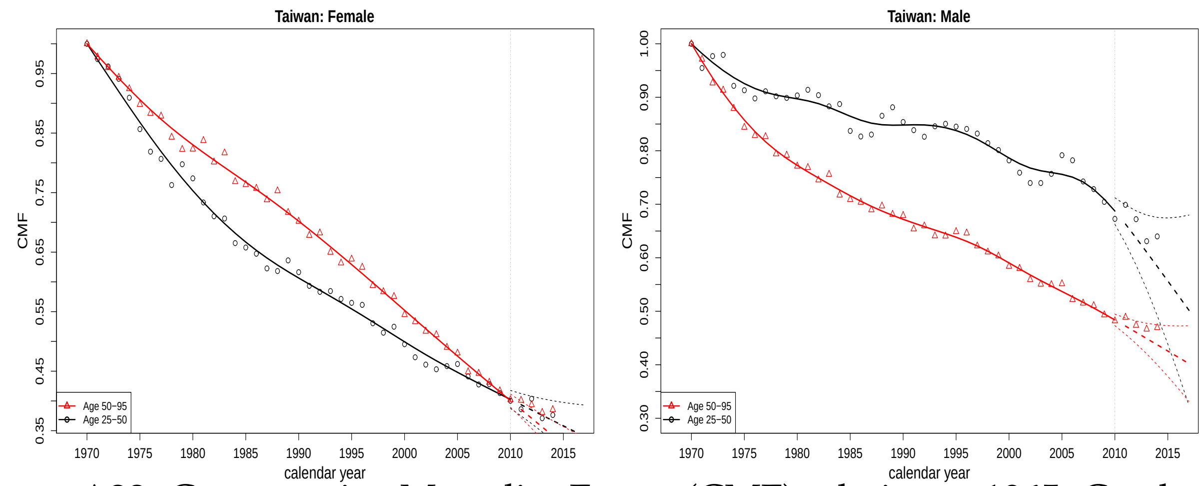

Figure A22: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.23 Observed mortality rates and improvements in UK.

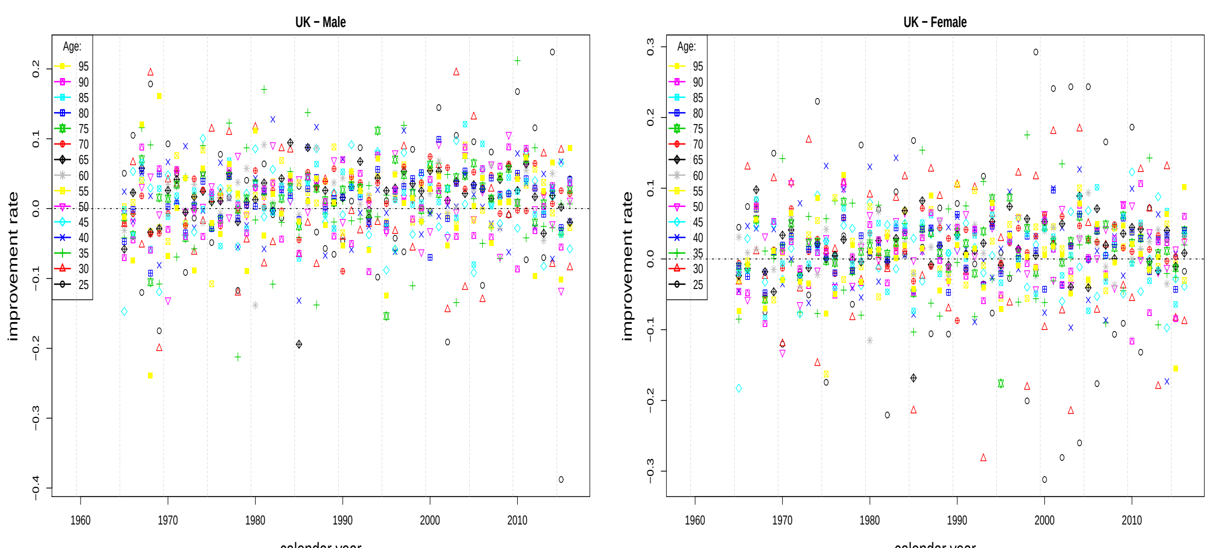

Figure A23: Observed mortality improvement rates in UK by gender and selected single year of age, 1980 to 2017.

Figure A24 displays the comparative mortality factor by gender relative to 1965. The smoothed lines were added by fitting one-dimensional P-splines to data up to 2010. The fitted lines were then projected past 2010 using a second order difference penalty.

These graphics show that mortality experience post 2010 in the UK tends to be greater than what would have been anticipated based on 1965-2010 trends, especially for the age band 50-95.

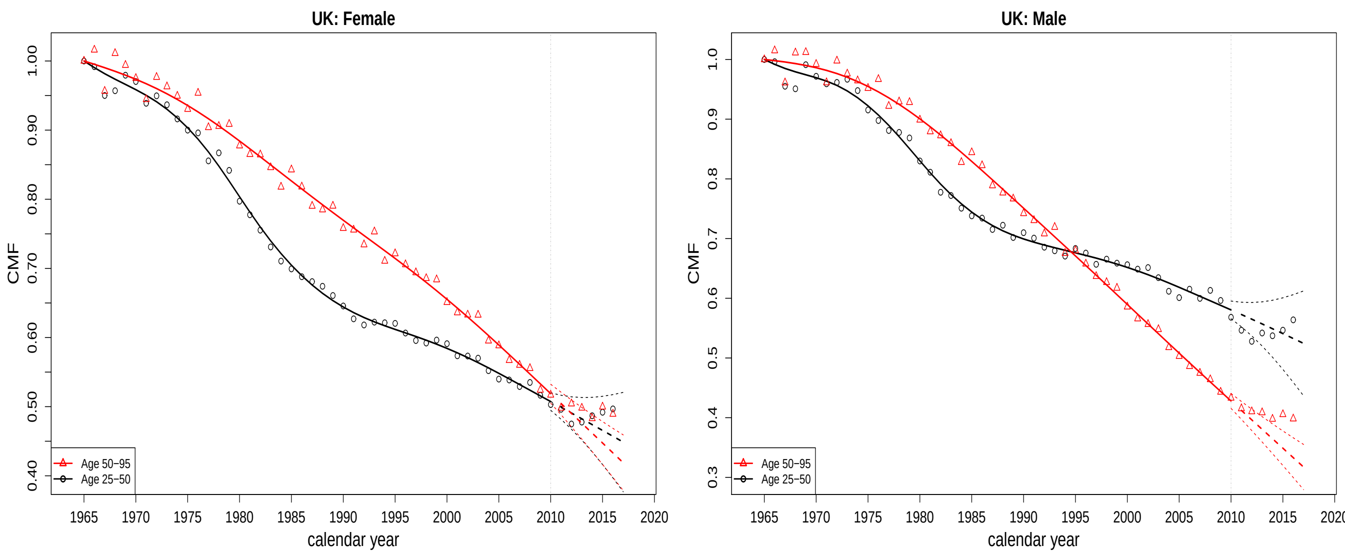

Figure A24: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines).
The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965.
The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

A.24 Observed mortality rates and improvements in USA.

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	1.47%	0.44%	1.81%	-0.52%	-3.33%
30-34	2.38%	-0.16%	1.38%	0.10%	-3.96%
35-39	2.40%	0.96%	0.01%	0.91%	-2.75%
40-44	1.94%	1.80%	-0.21%	0.88%	-0.88%
45-49	1.62%	1.53%	0.49%	0.00%	0.30%
50-54	1.58%	1.32%	1.30%	0.09%	-0.30%
55-59	1.00%	0.66%	1.18%	1.47%	-1.24%
60-64	1.39%	0.49%	0.93%	2.03%	-0.36%
65-69	1.26%	0.21%	0.63%	2.03%	0.91%
70-74	1.40%	0.59%	0.60%	1.90%	0.72%
75-79	1.84%	0.64%	0.38%	1.66%	0.88%
80-84	1.64%	0.77%	0.11%	1.92%	0.63%
85-89	1.56%	0.65%	-0.23%	1.61%	1.00%
90-95	1.07%	0.23%	-0.63%	1.03%	1.73%

(a) Female

	1965-1980	1980-1990	1990-2000	2000-2010	2011-2016
25-29	-0.56%	0.32%	3.05%	-0.65%	-3.74%
30-34	0.50%	-1.43%	3.57%	0.18%	-4.32%
35-39	1.17%	-1.25%	2.59%	1.47%	-3.93%
40-44	1.51%	0.58%	1.00%	1.82%	-1.45%
45-49	1.52%	1.64%	0.84%	1.04%	0.71%
50-54	1.56%	2.11%	1.69%	0.34%	0.24%
55-59	1.33%	1.62%	2.05%	0.95%	-0.28%
60-64	1.60%	1.57%	2.12%	1.88%	-0.87%
65-69	1.11%	1.40%	1.90%	2.36%	0.37%
70-74	0.79%	1.46%	1.70%	2.62%	0.62%
75-79	0.86%	0.92%	1.46%	2.37%	0.98%
80-84	0.77%	0.57%	0.93%	2.62%	1.06%
85-89	0.79%	0.34%	0.12%	2.19%	1.40%
90-95	0.44%	-0.06%	-0.53%	1.12%	2.53%

(b) Male

Table A22: Average yearly mortality improvements in USA.

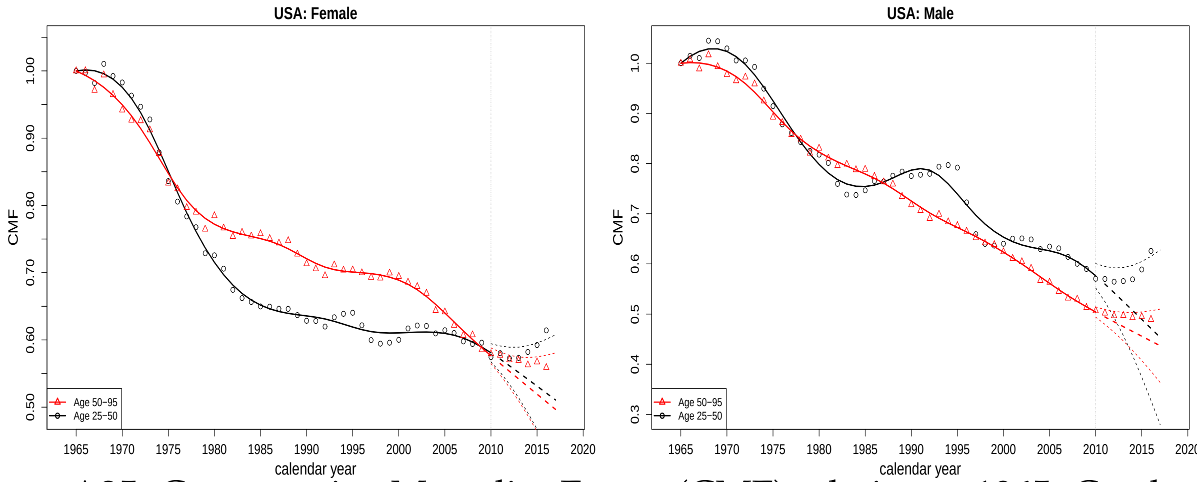

Figure A25: Comparative Mortality Factor (CMF) relative to 1965: Crude CMF (dots and triangles), fitted (continuous lines), projection with 95% confidence intervals (dash lines). The crude CMFs were calculated as the ratio of (*i*) expected number deaths for each calendar year assuming the structure of the population in 1965 and (*ii*) the aggregated death counts observed in 1965. Thus, a CMF lower than one indicates that mortality was lighter relative to 1965. The smooth lines were fitted using the method of P-splines applied to data up to 2010. These smoothed lines were then projected beyond 2010 using a second order difference penalty.

B Complement to the slowdown of mortality improvements via mortality forecasting models.

B.1 Mortality projection models applied to Australia.

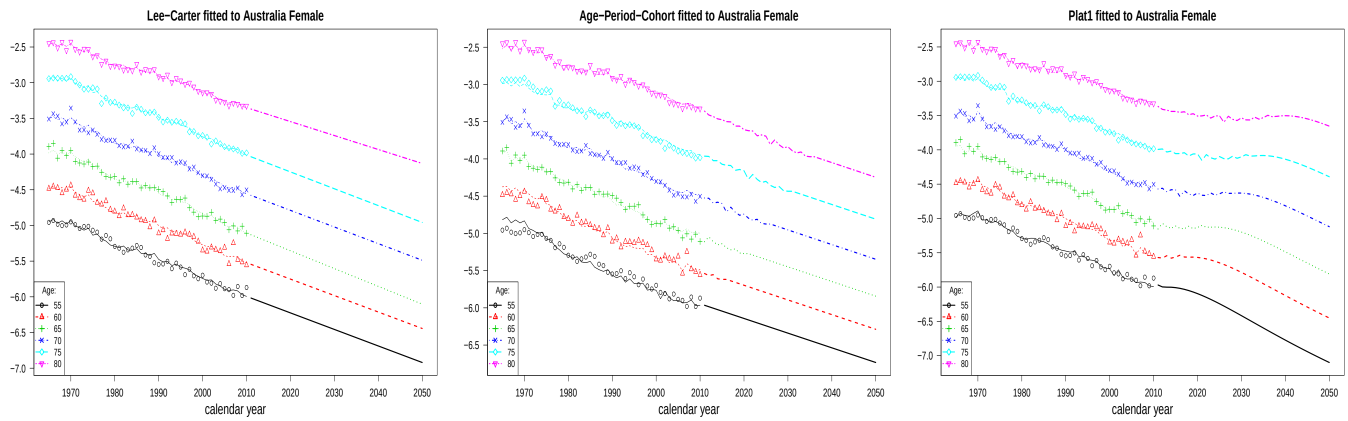

Figure A26: Force of mortality (log scale) from selected models fitted to Australia females.

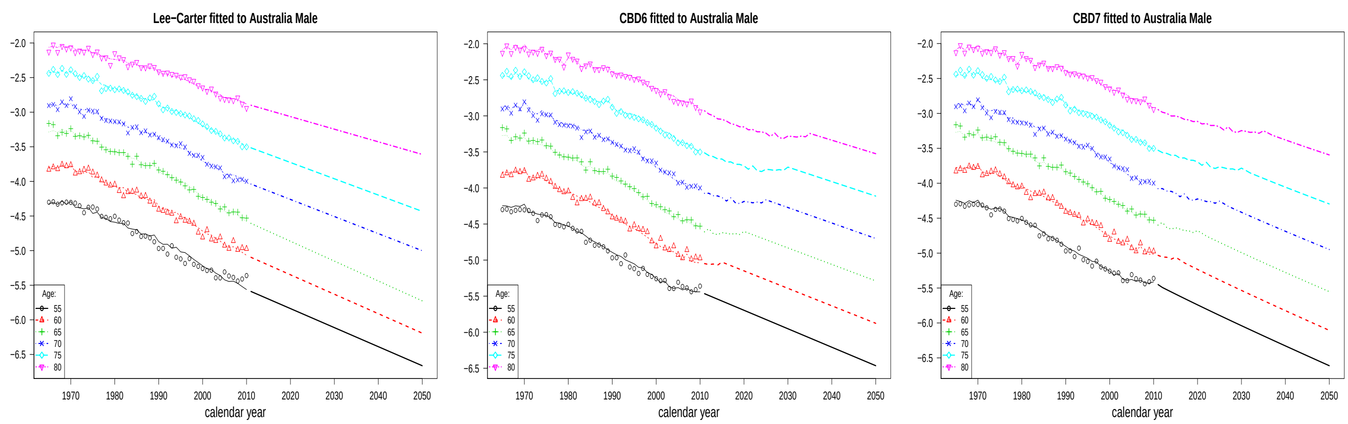

Figure A27: Force of mortality (log scale) from selected models fitted to Australia males.

B.2 Mortality projection models applied to Austria.

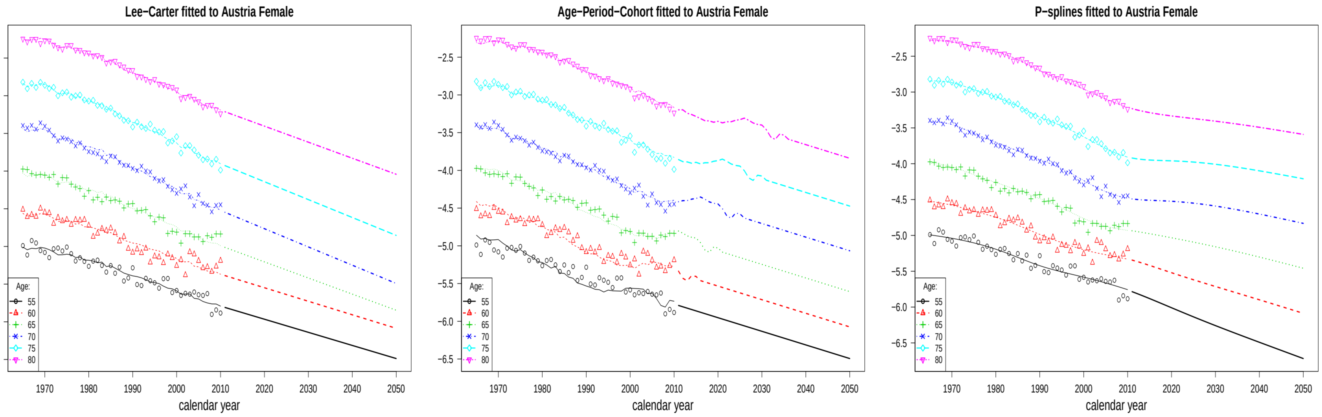

Figure A28: Force of mortality (log scale) from selected models fitted to Austria females.

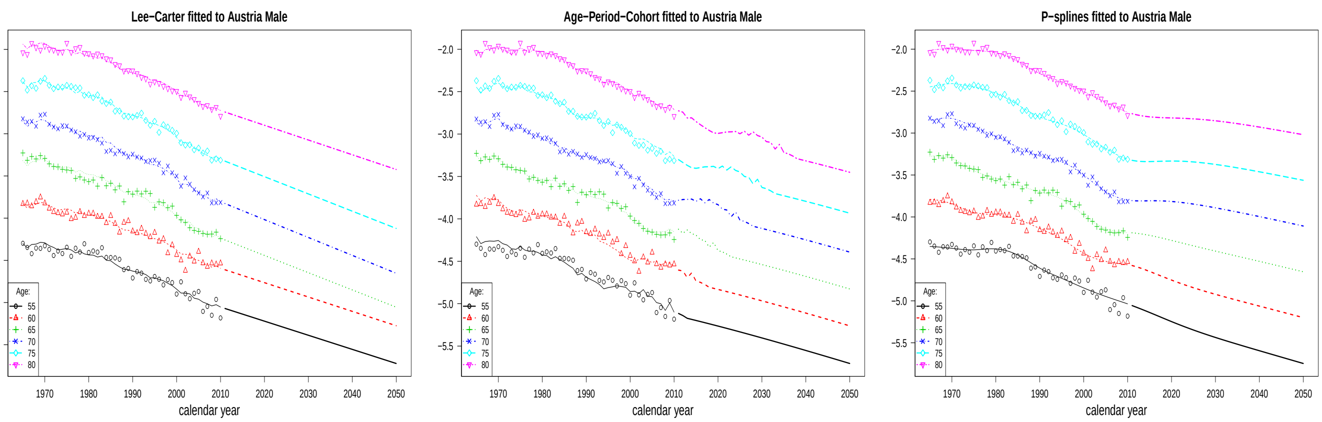

Figure A29: Force of mortality (log scale) from selected models fitted to Austria males.

B.3 Mortality projection models applied to Belgium.

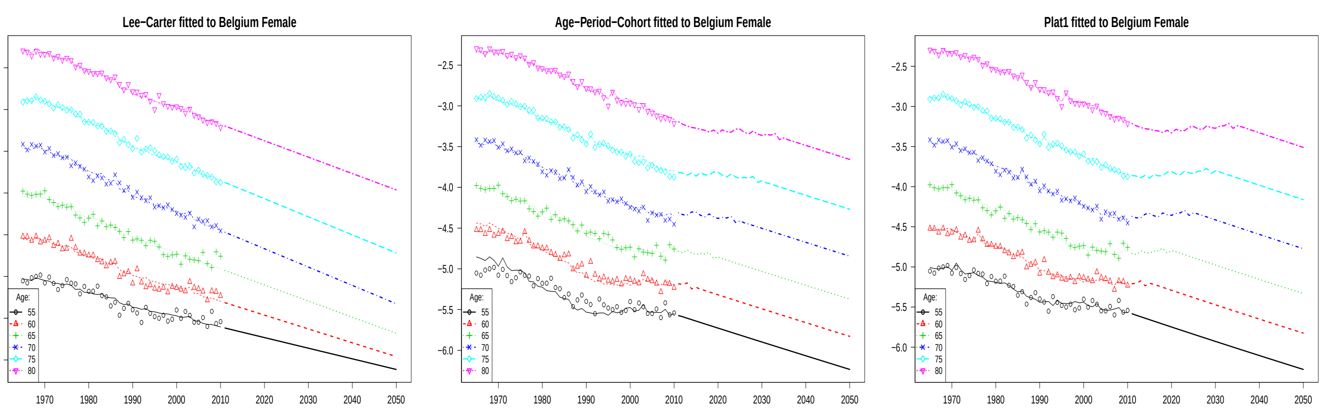

Figure A30: Force of mortality (log scale) from selected models fitted to Belgium females.

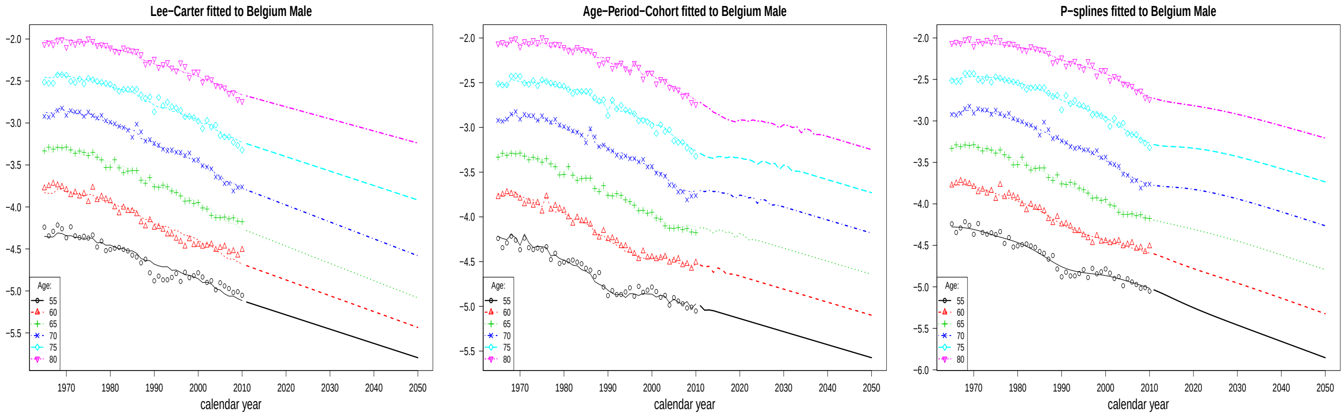

Figure A31: Force of mortality (log scale) from selected models fitted to Belgium males.

B.4 Mortality projection models applied to Canada.

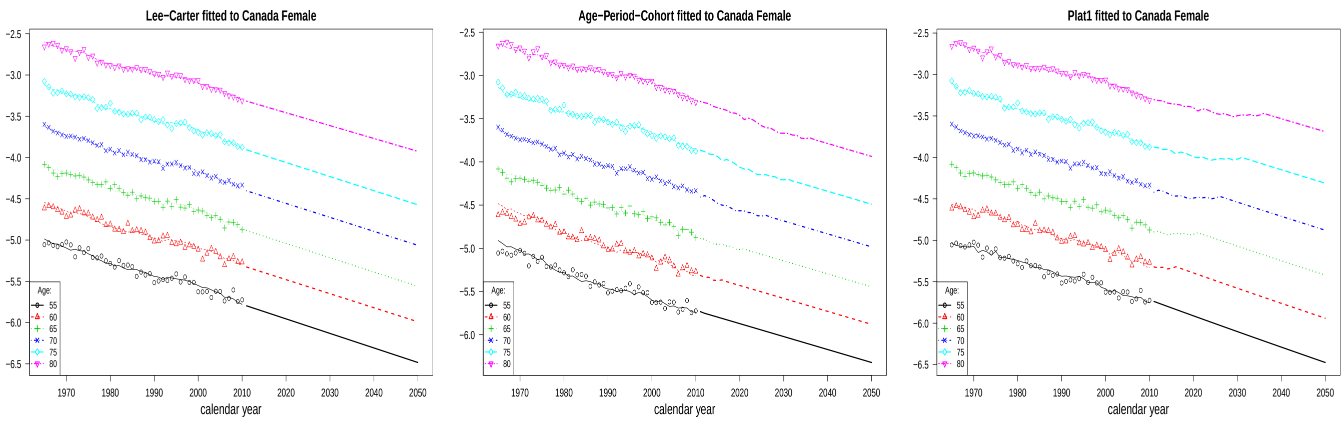

Figure A32: Force of mortality (log scale) from selected models fitted to Canada females.

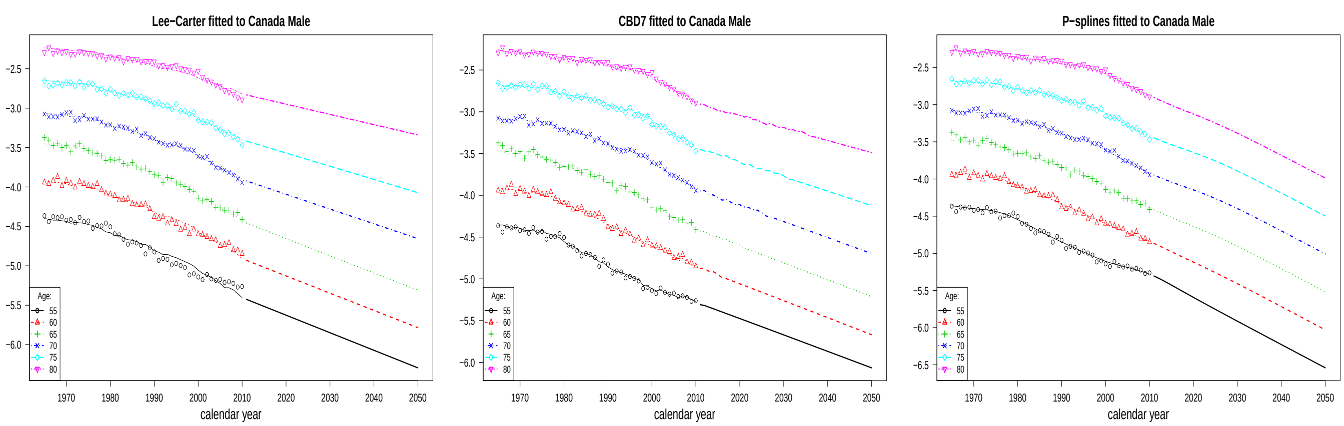

Figure A33: Force of mortality (log scale) from selected models fitted to Canada males.

B.5 Mortality projection models applied to Denmark.

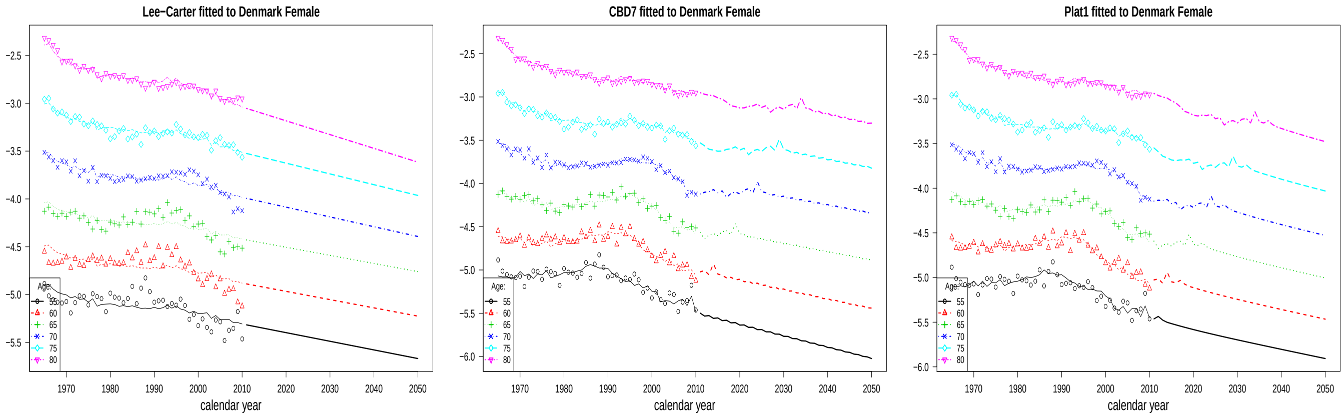

Figure A34: Force of mortality (log scale) from selected models fitted to Denmark females.

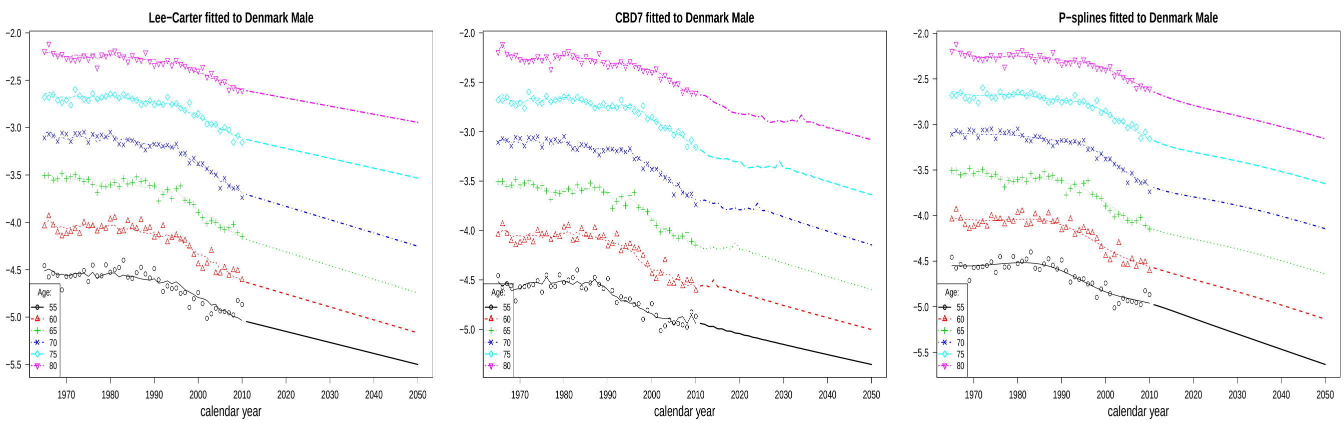

Figure A35: Force of mortality (log scale) from selected models fitted to Denmark males.

B.6 Mortality projection models applied to Finland.

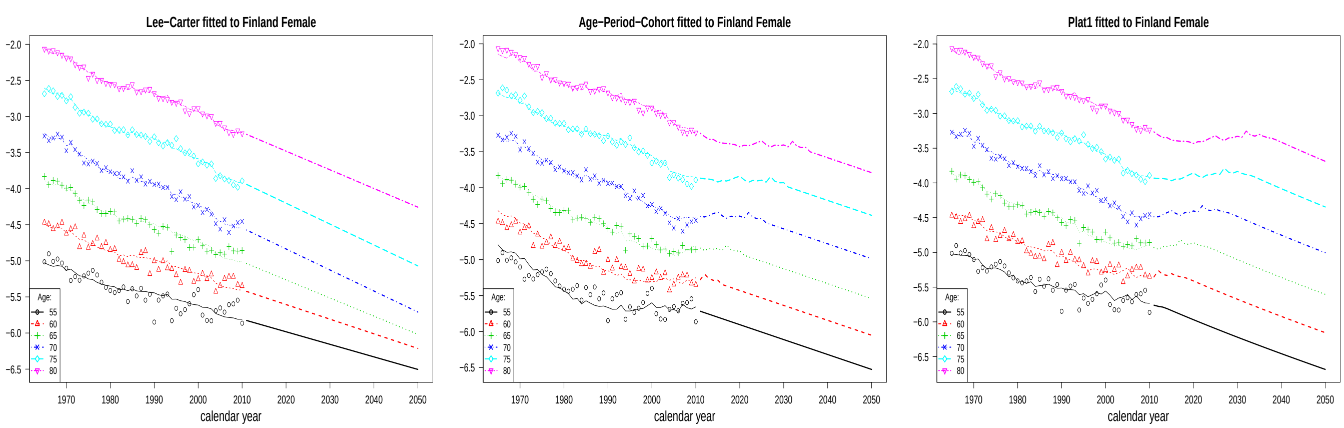

Figure A36: Force of mortality (log scale) from selected models fitted to Finland females.

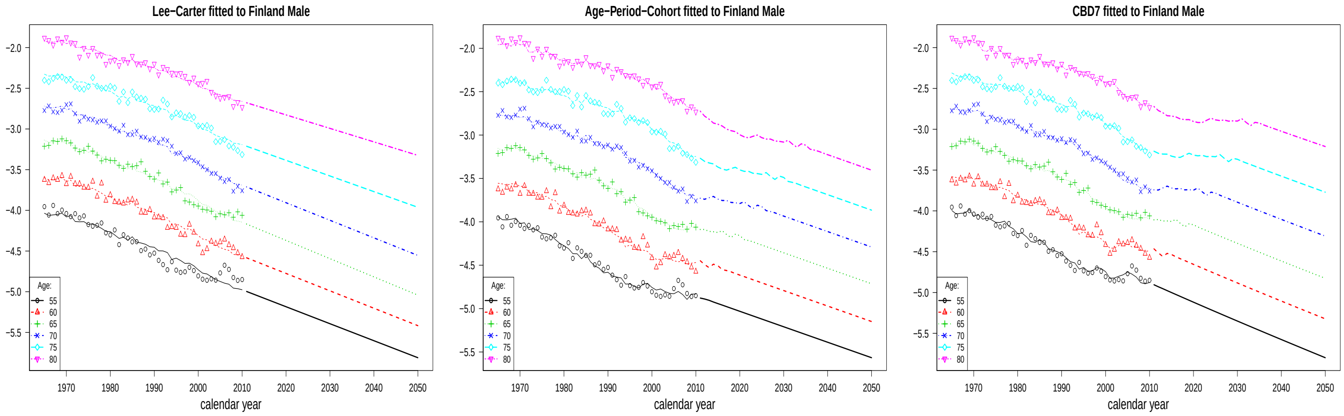

Figure A37: Force of mortality (log scale) from selected models fitted to Finland males.

B.7 Mortality projection models applied to France.

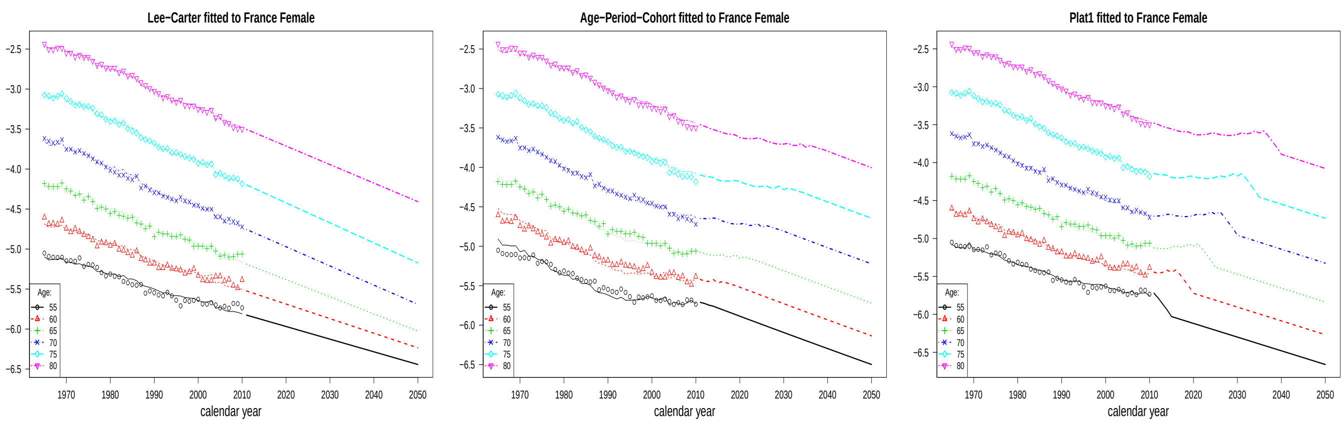

Figure A38: Force of mortality (log scale) from selected models fitted to France females.

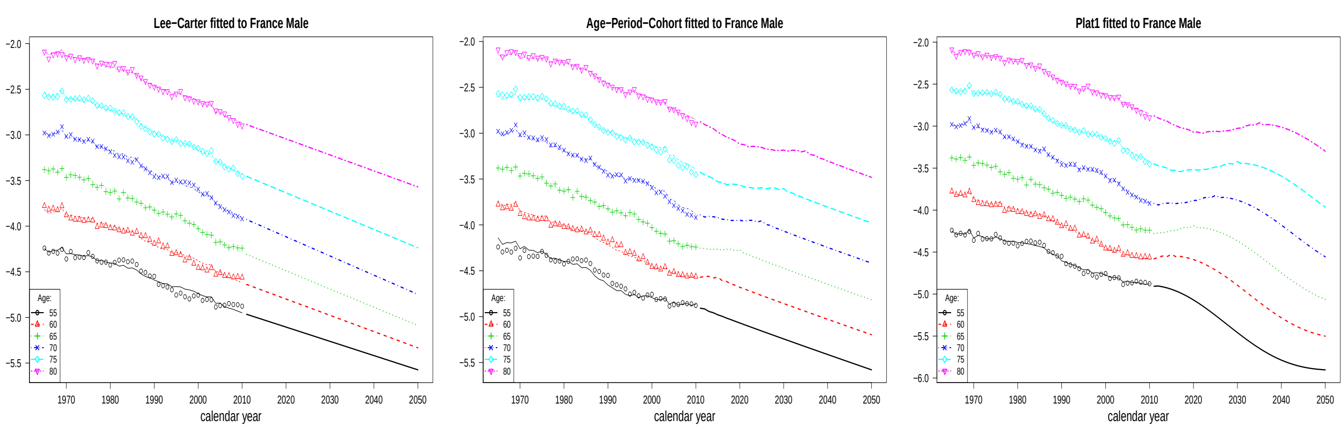

Figure A39: Force of mortality (log scale) from selected models fitted to France males.

B.8 Mortality projection models applied to Germany.

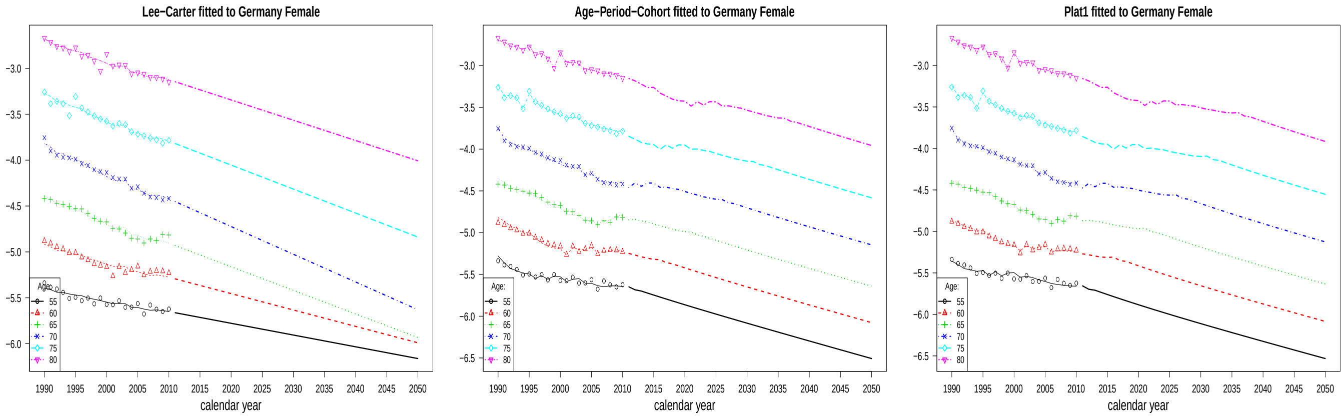

Figure A40: Force of mortality (log scale) from selected models fitted to Germany females.

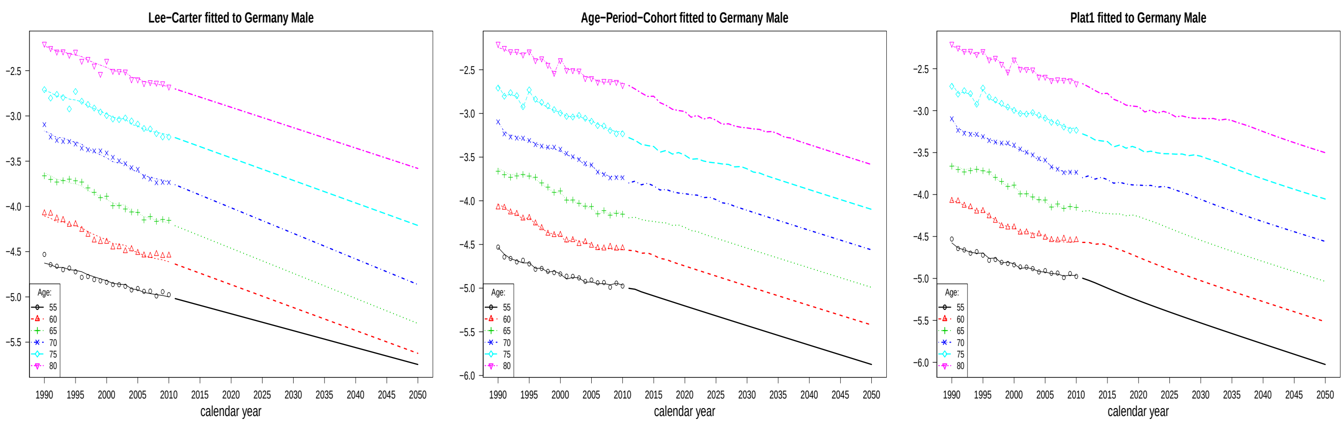

Figure A41: Force of mortality (log scale) from selected models fitted to Germany males.

B.9 Mortality projection models applied to Greece.

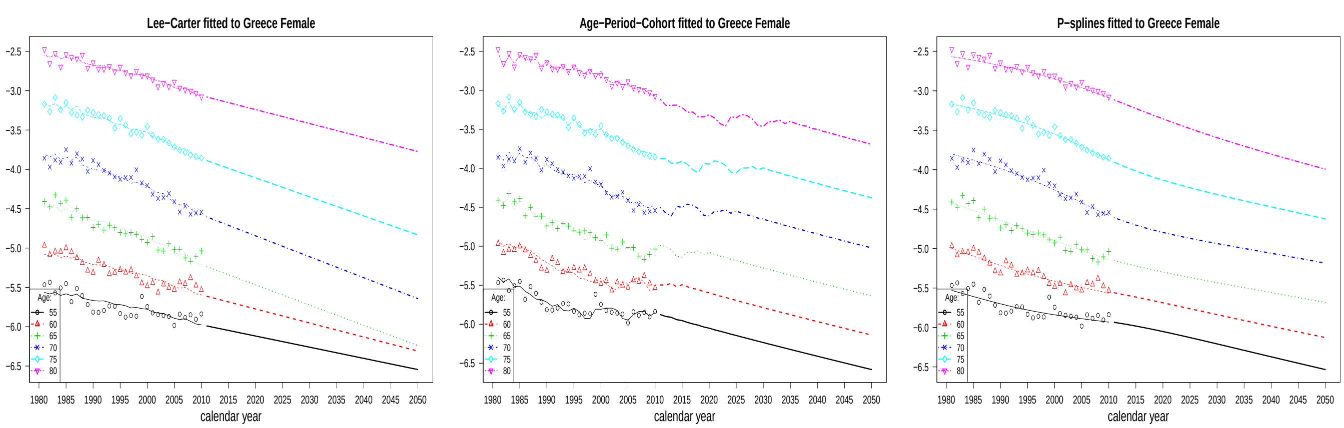

Figure A42: Force of mortality (log scale) from selected models fitted to Greece females.

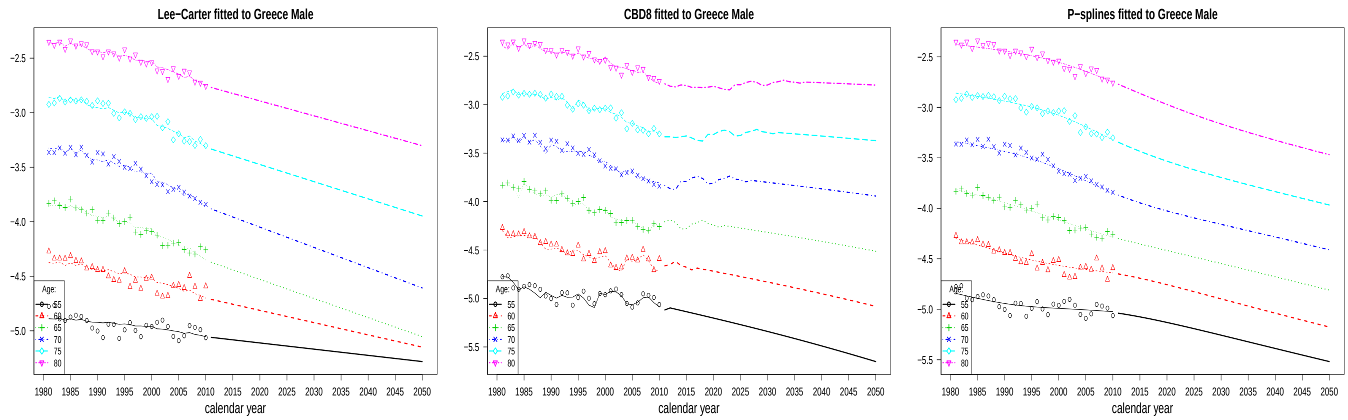

Figure A43: Force of mortality (log scale) from selected models fitted to Greece males.

B.10 Mortality projection models applied to Ireland.

Figure A44: Force of mortality (log scale) from selected models fitted to Ireland females.

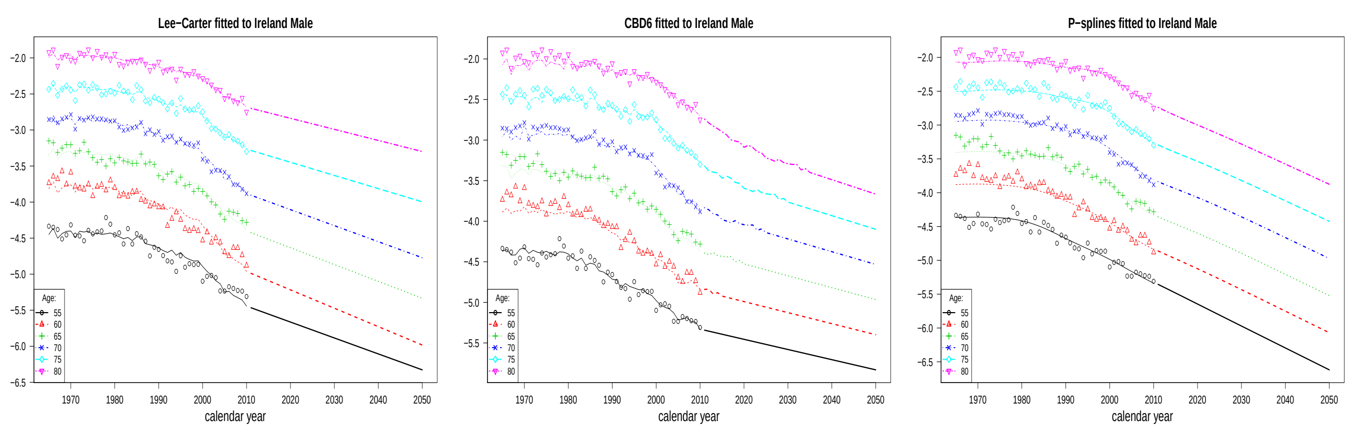

Figure A45: Force of mortality (log scale) from selected models fitted to Ireland males.

B.11 Mortality projection models applied to Italy.

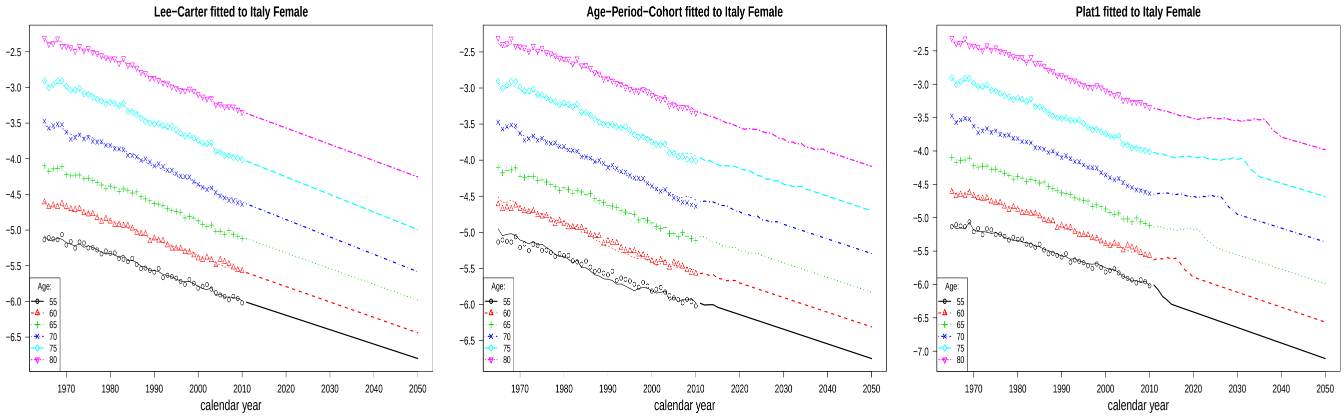

Figure A46: Force of mortality (log scale) from selected models fitted to Italy females.

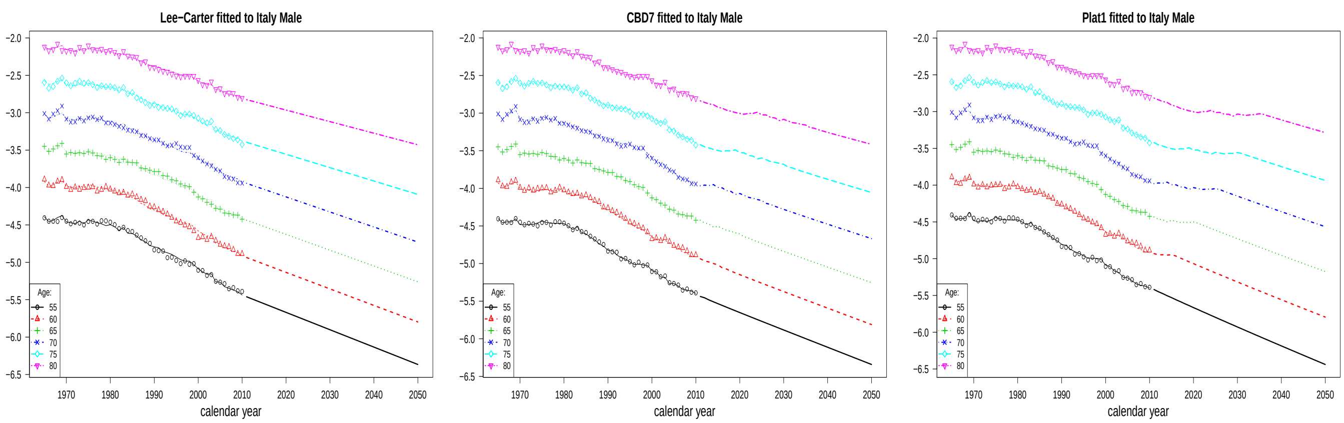

Figure A47: Force of mortality (log scale) from selected models fitted to Italy males.

B.12 Mortality projection models applied to Japan.

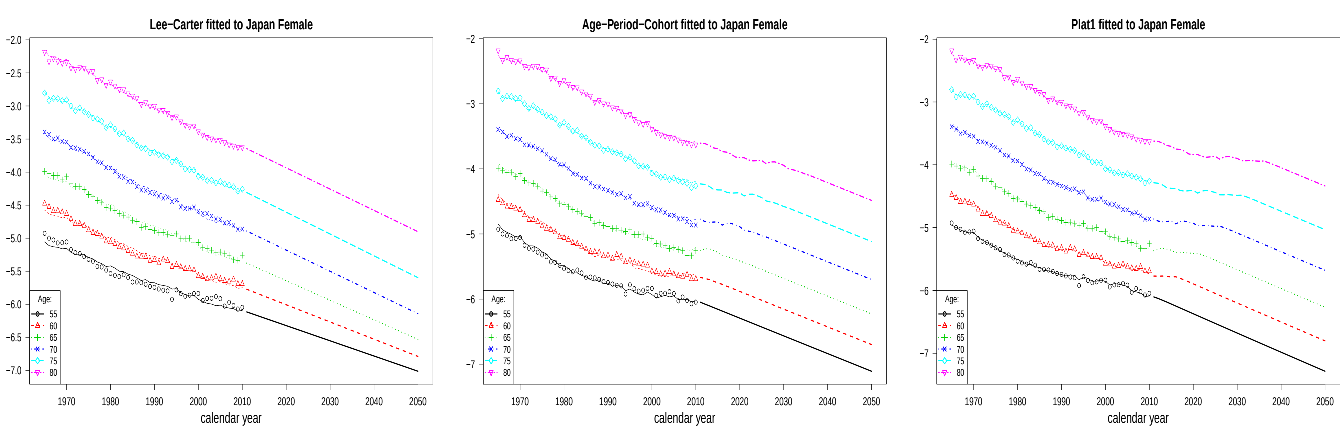

Figure A48: Force of mortality (log scale) from selected models fitted to Japan females.

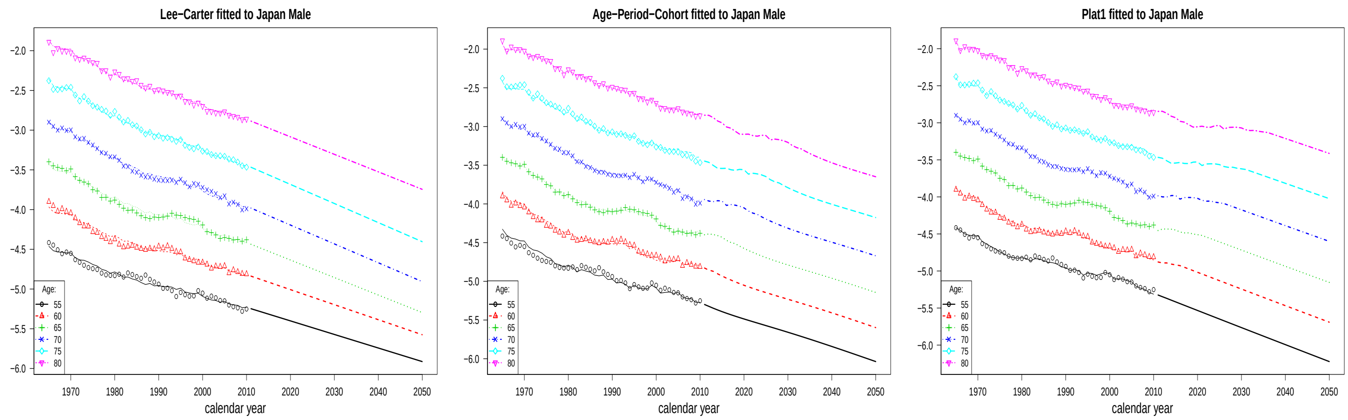

Figure A49: Force of mortality (log scale) from selected models fitted to Japan males.

B.13 Mortality projection models applied to Netherlands.

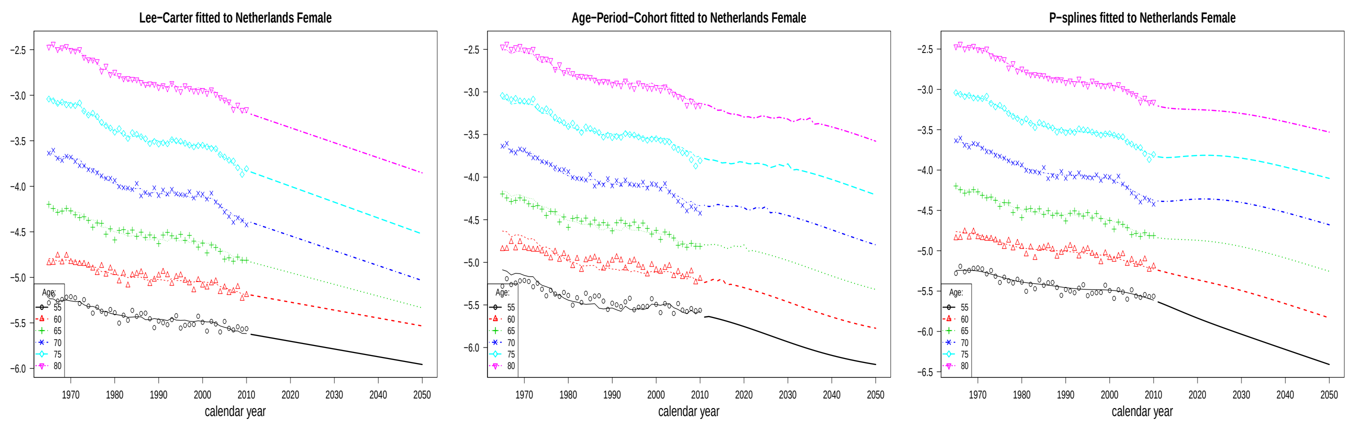

Figure A50: Force of mortality (log scale) from selected models fitted to Netherlands females.

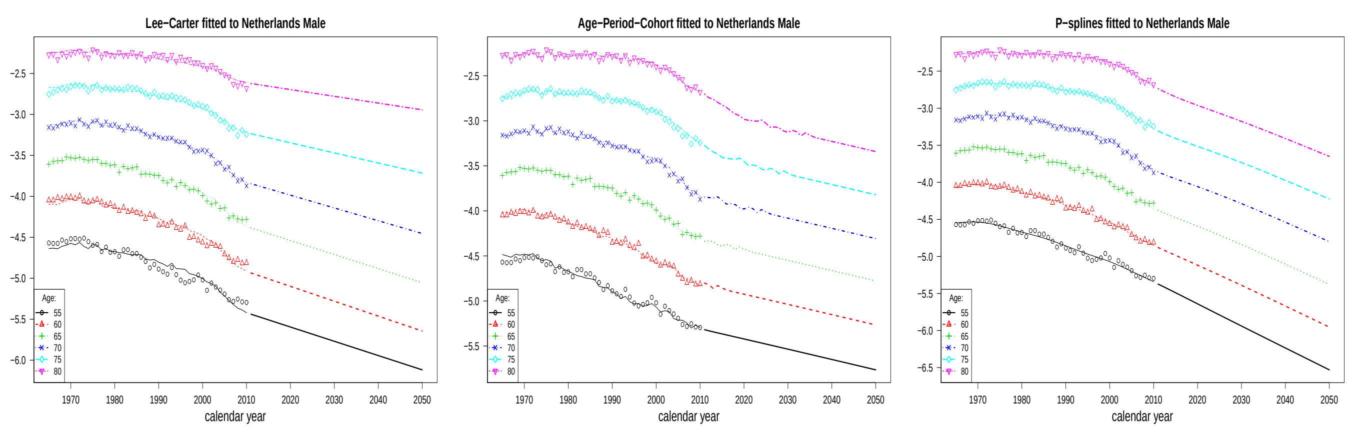

Figure A51: Force of mortality (log scale) from selected models fitted to Netherlands males.

B.14 Mortality projection models applied to NewZealand.

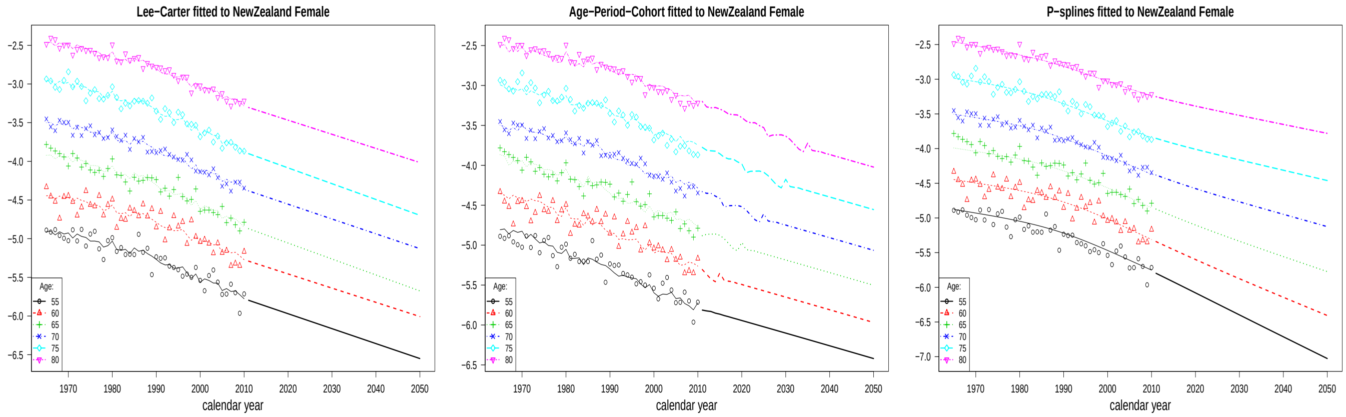

Figure A52: Force of mortality (log scale) from selected models fitted to NewZealand females.

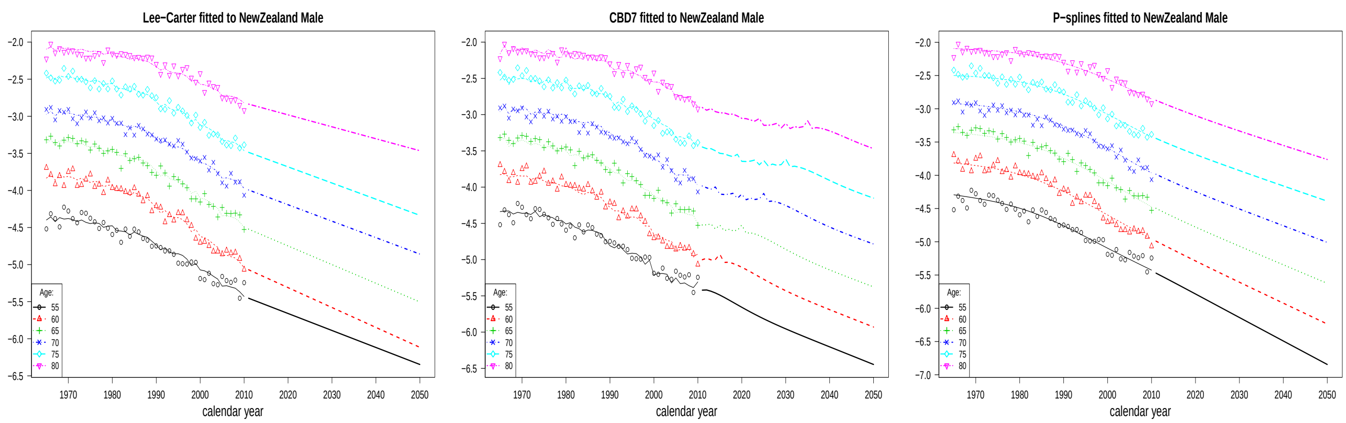

Figure A53: Force of mortality (log scale) from selected models fitted to NewZealand males.

B.15 Mortality projection models applied to Norway.

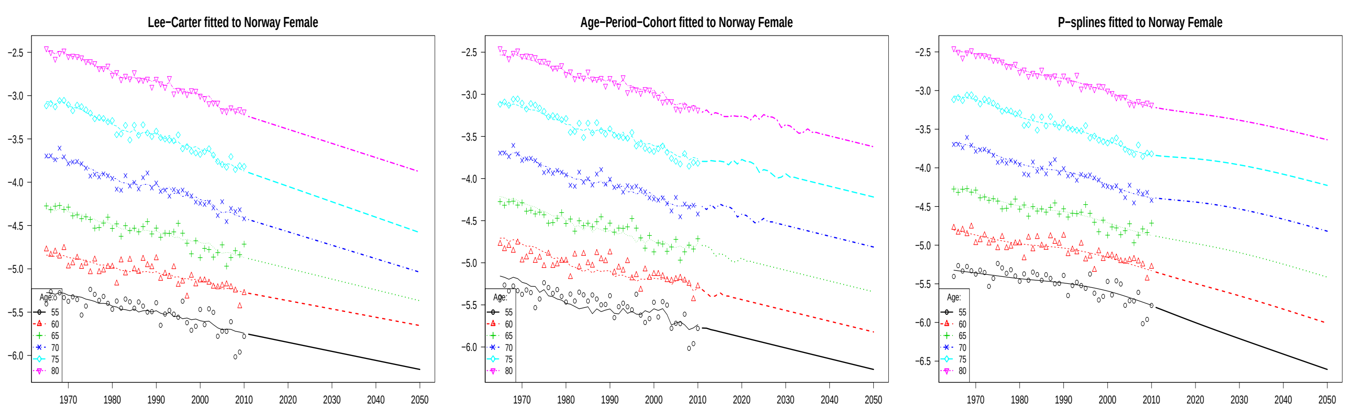

Figure A54: Force of mortality (log scale) from selected models fitted to Norway females.

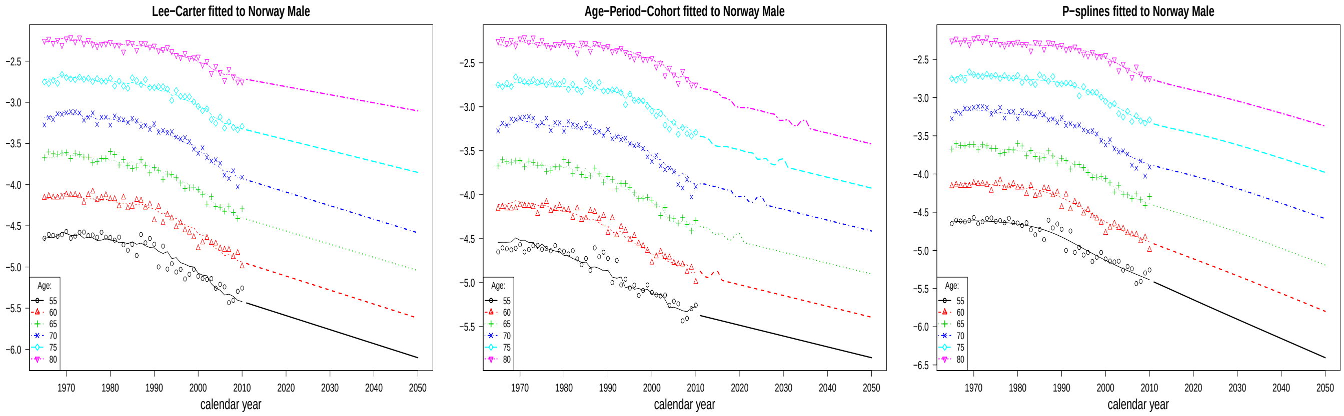

Figure A55: Force of mortality (log scale) from selected models fitted to Norway males.

B.16 Mortality projection models applied to Portugal.

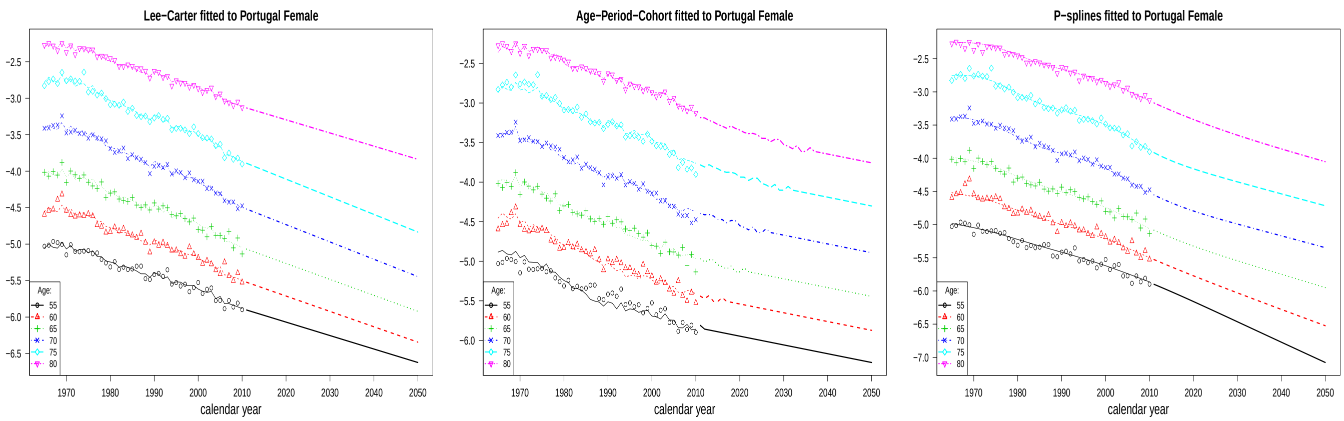

Figure A56: Force of mortality (log scale) from selected models fitted to Portugal females.

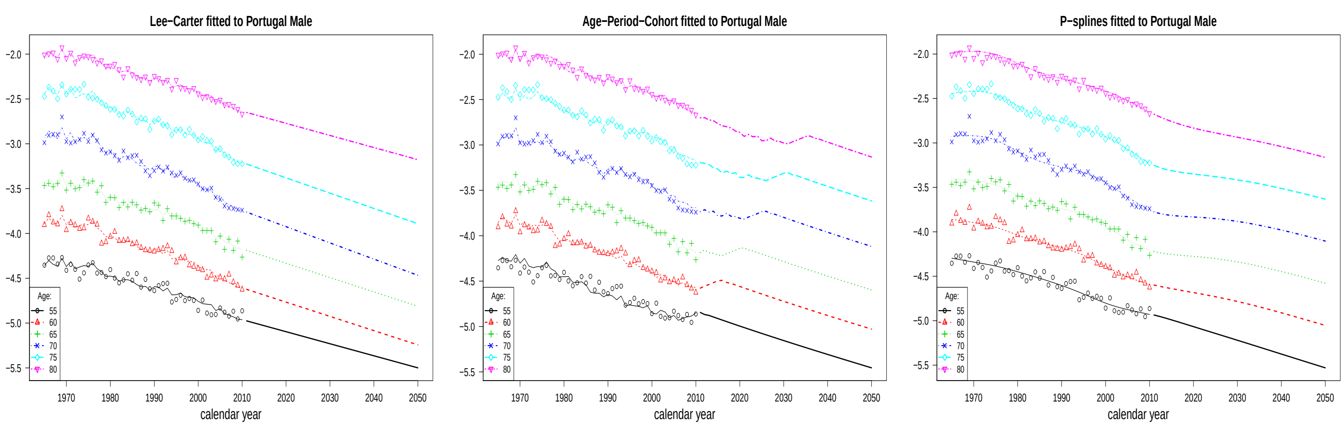

Figure A57: Force of mortality (log scale) from selected models fitted to Portugal males.

B.17 Mortality projection models applied to Spain.

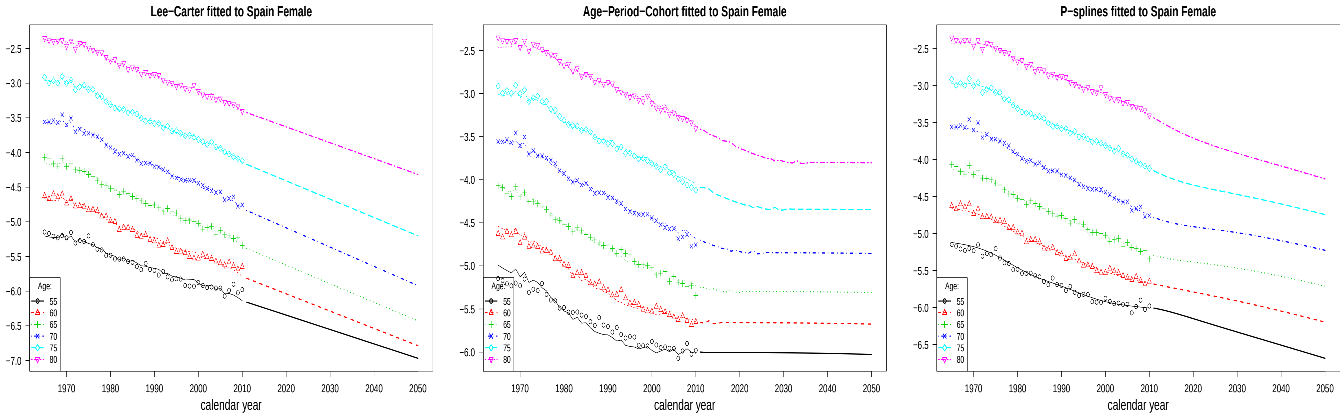

Figure A58: Force of mortality (log scale) from selected models fitted to Spain females.

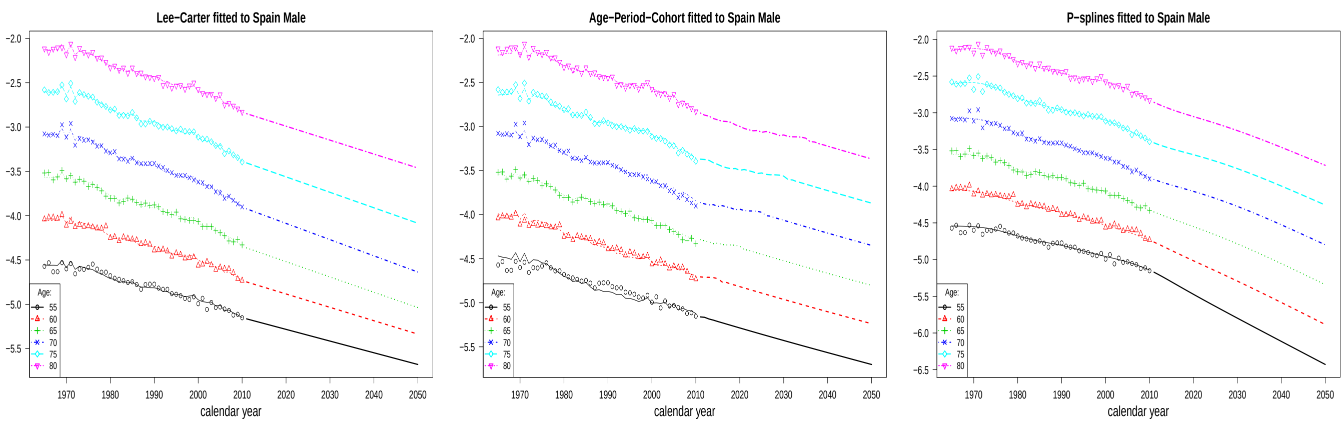

Figure A59: Force of mortality (log scale) from selected models fitted to Spain males.

B.18 Mortality projection models applied to Sweden.

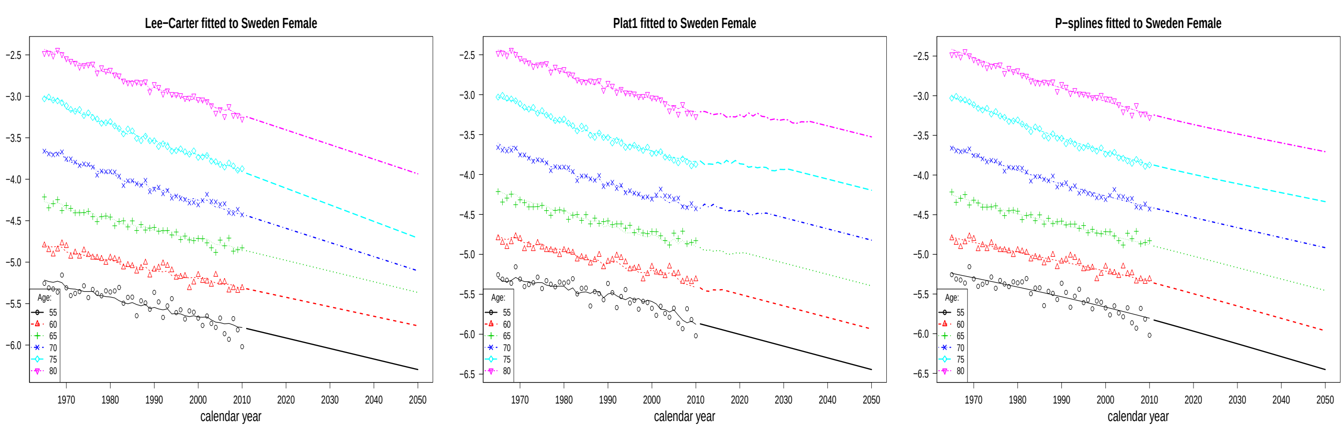

Figure A60: Force of mortality (log scale) from selected models fitted to Sweden females.

Figure A61: Force of mortality (log scale) from selected models fitted to Sweden males.

B.19 Mortality projection models applied to Switzerland.

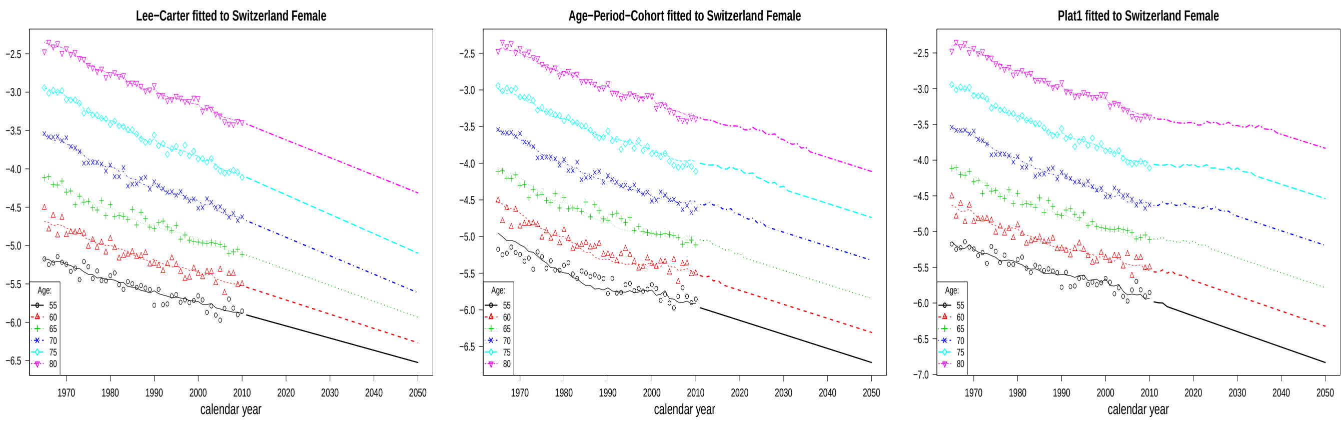

Figure A62: Force of mortality (log scale) from selected models fitted to Switzerland females.

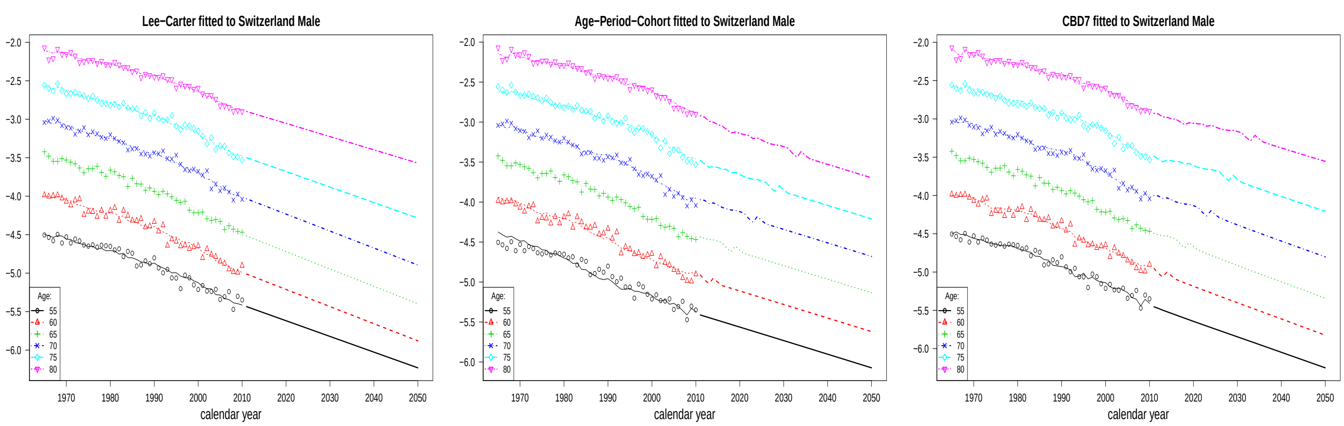

Figure A63: Force of mortality (log scale) from selected models fitted to Switzerland males.

B.20 Mortality projection models applied to Taiwan.

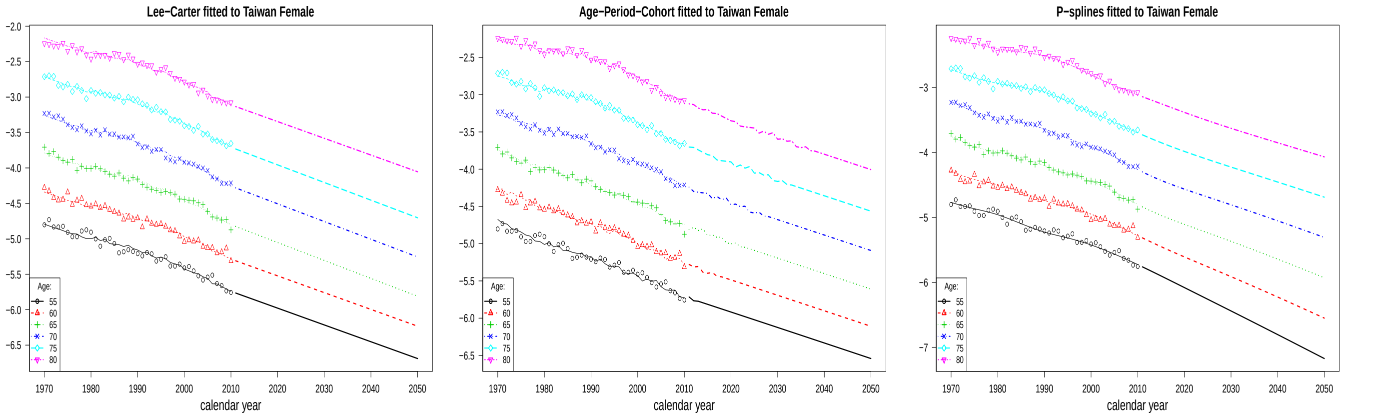

Figure A64: Force of mortality (log scale) from selected models fitted to Taiwan females.

Figure A65: Force of mortality (log scale) from selected models fitted to Taiwan males.

B.21 Mortality projection models applied to UK.

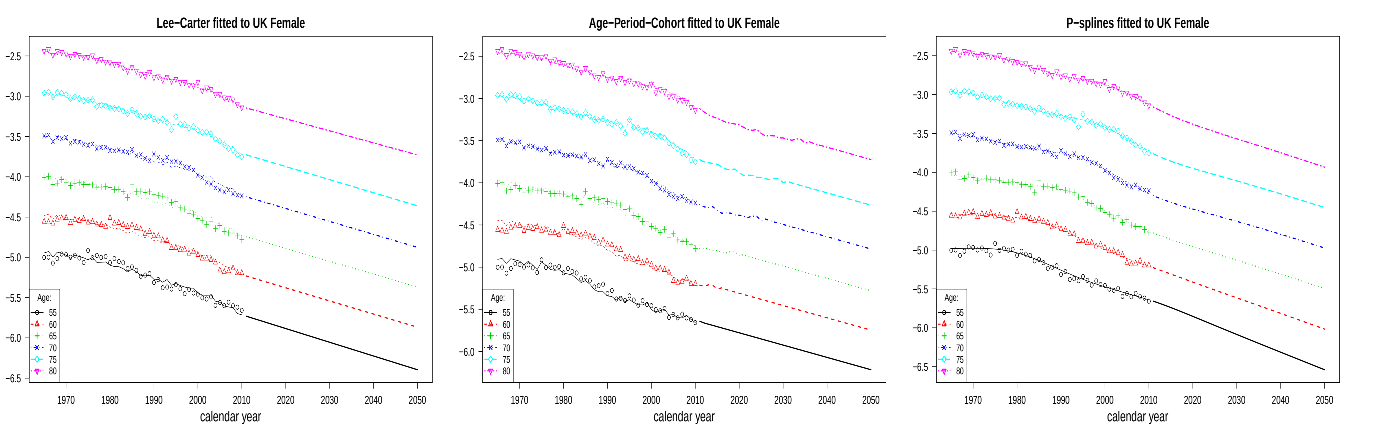

Figure A66: Force of mortality (log scale) from selected models fitted to UK females.

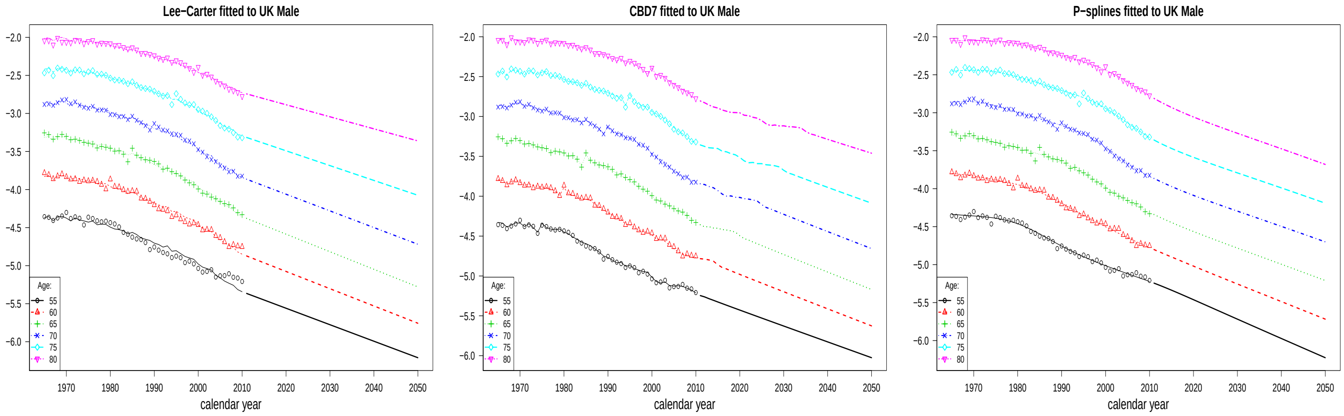

Figure A67: Force of mortality (log scale) from selected models fitted to UK males.

B.22 Mortality projection models applied to USA.

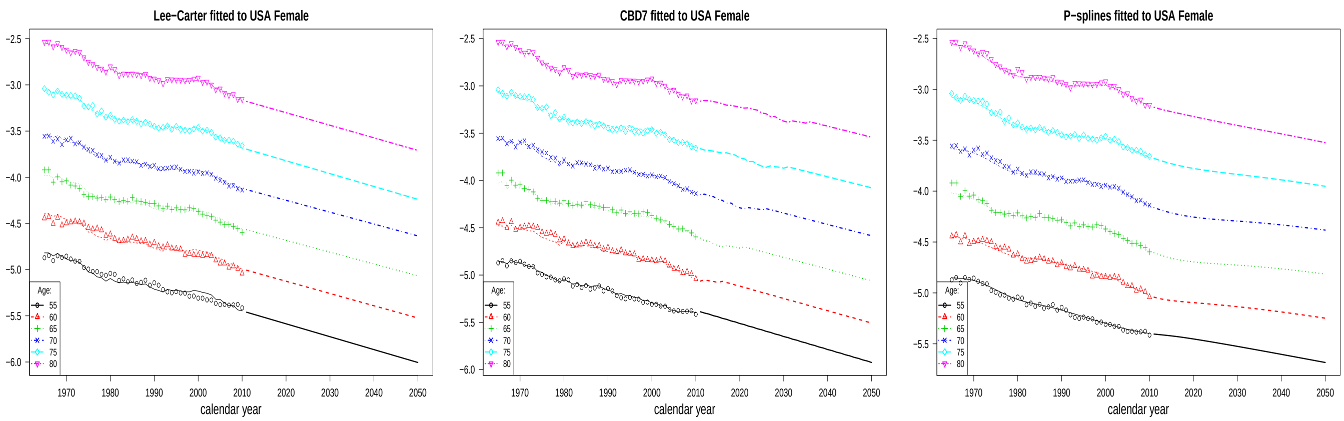

Figure A68: Force of mortality (log scale) from selected models fitted to USA females.

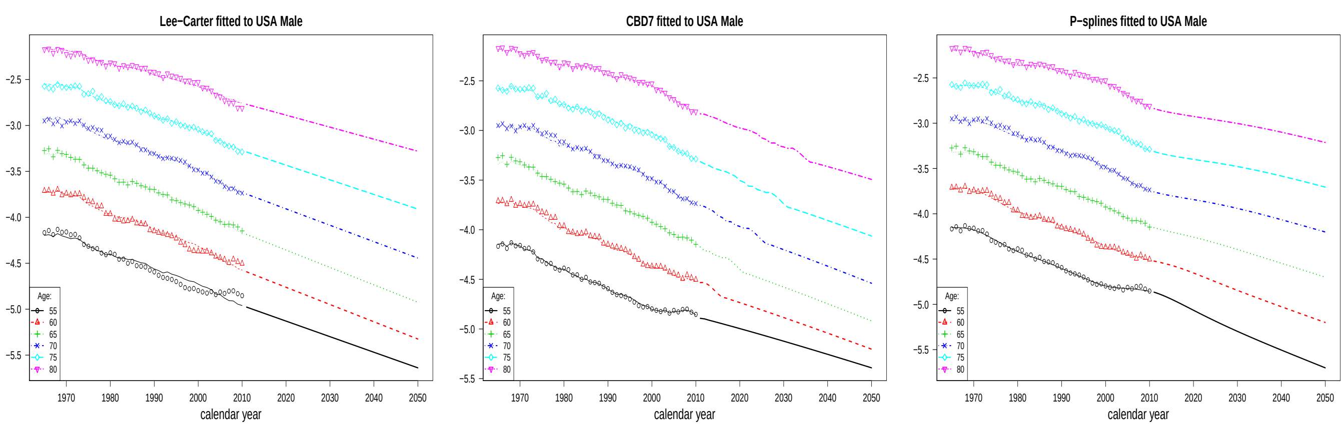

Figure A69: Force of mortality (log scale) from selected models fitted to USA males.