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Continuous Mortality Investigation

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WORKING PAPER 166

Fitting UK and US mortality projection models to each other's data

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Summary

This paper compares two mortality projection models – the latest version of the CMI Mortality Projections Model, CMI_2021, and the latest version of MIM-2021 (MIM-2021-v3), produced by the Society of Actuaries (SoA) and based on concepts developed by the Retirement Plans Experience Committee (RPEC). We applied both models to data for England & Wales and the US and compared results.

Note that the SoA distinguishes between the MIM-2021 model and the MP-2021 mortality improvements scale produced by MIM-2021.

The two models have similar principles – both project mortality improvements by interpolating between recent mortality improvements, estimated based on historical data, and assumed long-term rates of mortality improvement. However, the details of the models differ, including:

- How they estimate current mortality improvements. The CMI model imposes a more rigid structure on historical mortality improvements, considering them as the combination of age, period and cohort terms. In contrast, the RPEC model has a more flexible structure, which enables it to fit historical improvements more closely.
- The period over which mortality improvements converge to the long-term rate. The convergence periods for MIM-2021 do not vary by age, but those for CMI_2021 do, and can be longer or shorter than the MP-2021 convergence periods at different ages.

Our analysis focusses on comparing how results for a given country vary between the two models, rather than how results vary between the countries. We find that:

- For younger ages, CMI_2021 tends to give lower projected mortality rates than MP-2021.
- For older ages, MIM-2021 tends to give lower projected mortality rates than CMI_2021.
- For most ages and datasets, MIM-2021 leads to higher cohort life expectancies[1] than CMI_2021, as life expectancies are more strongly affected by mortality rates at older ages, when most deaths occur.

Life expectancy is more sensitive to the long-term rate for the RPEC model than for the CMI model, for both genders and both datasets. This is likely due to the differences in the start years (2017 for the RPEC model and 2021 for the CMI model) and convergence periods between the models, meaning that the long-term rates apply in full for longer in the RPEC model.

[1] We say “cohort life expectancies” to distinguish from “period life expectancies”. Period life expectancy takes no account of future mortality improvements. Cohort life expectancy does take account of expected future changes in mortality.

Contents

Reliances and limitations

The purpose of this paper and the accompanying spreadsheets is to compare mortality in England & Wales and the USA, and to compare the CMI_2021 and MIM-2021 mortality projection models.

We aim to produce high-quality outputs and take considerable care to ensure that the analysis in this paper is accurate. However:

- We cannot guarantee its accuracy (see the Disclaimer on the last page of this document).
- There is a reliance on underlying data, although we have exercised judgement in the choice of dataset, the age range and the period used.
- We have also applied judgement and assumptions in the choice of Model parameters and in how we have shown results.

Anyone using either model, for any population, should ensure that it is appropriate for their particular use and that suitable values are used for the parameters.

- The models (including but not limited to their default parameter values) do not provide any form of guidance and should not be relied upon as such.
- The analysis only considers data up to 2019, and results for later periods may be materially different, particularly in light of the COVID-19 pandemic.
- Results from future versions of the CMI Model may be affected by revisions to historical data following the 2021 census in England & Wales.

The opinions expressed and conclusions reached by the authors are their own and do not represent any official position or opinion of the Society of Actuaries Research Institute, Society of Actuaries, or its members. The Society of Actuaries Research Institute makes no representation or warranty to the accuracy of the information.

1. Introduction

This paper compares mortality projection models produced by the UK and US actuarial professions and widely used in those countries.

1.1 Background

The UK and US actuarial professions each publish models to project future mortality:

- The CMI Mortality Projections Committee (MPC) publishes the CMI Mortality Projections Model (the "CMI model"), with the latest version being CMI_2021, published in March 2022.
- The Society of Actuaries (SoA) Research Institute's Retirement Plans Experience Committee (RPEC) has published mortality improvement scales annually from 2014 through 2021, with the most recent scale being MP-2021. The scales are primarily intended for use in pension plan valuations and are produced using the MIM-2021 model (also referred to as the "RPEC model" in this paper), with the most recent version, MIM-2021-v3, released in October 2022.

The CMI and RPEC models have similar principles, despite differences in the details of their implementation and being calibrated to different datasets.

For some time, MPC and RPEC have had informal discussions on mortality projections, recognising the benefit of comparing approaches and learning from each other. This paper contains a more detailed comparison of the two models, including fitting each model to the other country's data. It has been prepared jointly by a subset of the members of MPC and RPEC.

Although the paper looks at mortality in England & Wales and the USA, the methods and principles may be of interest when considering how to adapt the models for other populations.

1.2 COVID-19

In this paper, we have compared the CMI_2021 and MIM-2021-v3 versions of the CMI and RPEC models. These both exclude the impact of the pandemic – the Core version of CMI_2021 places no weight on data for 2020 or 2021 and MIM-2021-v3 does not use any data beyond 2019.

1.3 Contents

This paper is organised as follows:

- Section 2 describes the methods and datasets used by the CMI and RPEC and compares them.
- Section 3 analyses and contrasts data for England & Wales and the USA, using simpler methods than the CMI and RPEC models.
- Section 4 contains results from fitting the CMI and RPEC models to mortality experience from England & Wales and the USA.
- The appendix includes detailed results, including life expectancies by individual age and larger versions of heatmap charts from Section 4.

1.4 Compliance

This paper compares the CMI_2021 and MIM-2021-v3 models and shows illustrative results from applying them to data for England & Wales and the USA.

This paper complies with the principles in the Financial Reporting Council's Technical Actuarial Standard "TAS 100: Principles for Technical Actuarial Work". Any person using this paper should exercise judgement over its suitability and relevance for their purpose.

1.5 Feedback

Comments on this paper are welcome and can be sent to projections@cmilimited.co.uk or research@soa.org for our consideration.

1.6 Acknowledgements

The committee members involved in the production of this paper are:

- SoA RPEC: Jim Berberian, Mei Du, Martin Hill and Patrick Nolan
- CMI MPC: Cobus Daneel and Steven Rimmer

We are grateful to Steve Bale, Susan Hanlon, Brian Sewell and Mark Spong for reviewing an earlier draft of this paper.

2. Methods and data

This section describes and compares the methods and data used by the CMI and RPEC models. Section 2.1 has a high-level overview, and later sections provide more detail.

2.1 Overview

The CMI and RPEC models have similar principles, although there are differences in the detailed methods and calibration data.

- The models are primarily models of mortality improvements rather than mortality rates. Users can apply mortality improvements from the models to their own choice of base mortality table to obtain projected mortality rates.
- The principle of each model is to project rates of mortality improvement by interpolating between:
  - current improvement rates, which are estimated from historical data; and
  - assumed long-term improvement rates.
- The projection of mortality improvements is carried out diagonally for cohort (birth year) and horizontally for age-period components and then combined.
- MIM-2021 includes a standard projection based on assumptions specified by RPEC, but the CMI requires users to make an assumption for the long-term rate of mortality improvements – its intention being to encourage user engagement in determining future longevity improvement assumptions.
- Both models allow users to vary parameters to reflect their views on projections and the specific populations that the models are being used for. The CMI model has three layers of parameters – Core, Extended, and Advanced. The CMI particularly encourages users to consider the appropriateness of the values of the Core and Extended parameters.

2.2 Calibration data

CMI

The calibration data for CMI_2021 is based on data from the Office for National Statistics (ONS) for the general population. The CMI makes some estimates to enable prompt updates to the CMI Model:

- Deaths and exposure data for 1981-2020 are taken directly from an annual ONS publication.
- Deaths for 2021 are estimated by the CMI from weekly ONS publications.
- Exposures for 2021 are estimated by the CMI.

The CMI makes two types of adjustment to the data:

- It uses a variant of the Kannisto-Thatcher method, described in CMI Working Paper 106, to estimate the exposure distribution at ages 85 and above.
- It adjusts exposures for selected combinations of age and calendar year where the values appear implausible compared to neighbouring ages.

RPEC

The calibration data used for the MIM-2021-v3 model were published by the Social Security Administration (SSA) in conjunction with the 2021 Old-Age and Survivors Insurance and Federal Disability Insurance Trustees' Report. These rates are smoothed across ages for each individual year through calendar year 2018 (SSA 2021). The data for calendar years 1950 through 2016 used in MIM-2021-v3 were taken directly from these SSA-published mortality rates.

Data for 2017 through 2019 were developed by RPEC using the same graduation methodology used by the SSA and the most recent versions of the underlying data sources for the SSA mortality rates. The graduation methodology is outlined in the SSA's Actuarial Study No. 120 (Bell and Miller 2005). The deaths for ages below

65 were taken from the Centers for Disease Control and Prevention (CDC) Wide-ranging Online Data for Epidemiologic Research WONDER database (CDC 2021), and the exposures for ages below 65 were taken from the most recent population estimates published by the U.S. Census Bureau (USC 2020). Deaths and exposures for ages 65 and above were made available to RPEC by the Centers for Medicare and Medicaid Services (CMS).

2.3 Initial improvements

CMI

The CMI fits its age-period-component improvement (APCI) model to historical data. This assumes a specific parametric structure for historical mortality which views the logarithm of mortality as the sum of smooth age, period (calendar year) and cohort (birth year) terms.

The model is fitted to data for ages 20-100 and calendar years 1981-2021 using an objective function that combines goodness of fit with smoothness penalties. Users can vary model parameters that control the smoothness of the fit. In particular, users are encouraged to consider the "period smoothing parameter" which controls to what extent initial improvements are based on the most recent or longer-term data.

The model has other parameters which users can vary. They are particularly encouraged to consider:

- The "initial addition", which enables users to make an adjustment to reflect socio-economic differences.
- Weights for data for individual years. The standard version of the model puts no weight on data for 2020 or 2021, as this is thought likely to be unrepresentative of future mortality improvements.

After fitting the APCI model, its structure allows age-period and cohort components of mortality improvements to be determined.

RPEC

The historical U.S. population mortality improvement rates were obtained by graduating separate male and female datasets as follows:

1. Calculating the natural logarithm of each mortality rate, covering all calendar years 1950 through 2019 and all ages 15 through 97.
2. Using Whittaker-Henderson weights based on U.S. population data obtained from the Human Mortality Database. Normalized weights for each age and calendar year were developed by dividing the individual weights by the sum of weights.
3. Defining Whittaker-Henderson smoothness as the sum of the squares of the third finite differences. The SoA has also considered an order-2 graduation, but we have not analysed that in this paper.
4. Selecting two-dimensional smoothness parameters of 100 in the calendar year direction and 400 in the age direction.

The resulting graduated values, denoted *s(x, y)* for each age, *x*, from 15 through 97, and each calendar year, *y*, from 1951 through 2019, were transformed into smooth mortality improvement rates, *f(x, y)*, using the following formula:

$$f(x,y) = 1 - e^{s(x,y)-s(x,y-1)}$$

So-called "edge effects" are instabilities that arise from the absence of data beyond the edges of the dataset being graduated. To mitigate these edge effects, RPEC steps back two years from the most recent calendar year of actual experience. Hence, even though the two-dimensional Whittaker-Henderson graduation was applied to the SSA mortality rates through 2019, the most recent calendar year of historic mortality improvement rates included in MIM-2021-v3 is 2017. Similarly, to avoid potential edge effects with respect to ages, RPEC limited the historical mortality improvement rates to ages 20 through 95.

Comparison

The key difference between the two approaches is the CMI Model imposes a more rigid structure on historical mortality improvements, considering them as the combination of age, period and cohort terms. In contrast the RPEC model has a more flexible structure, which enables it to fit historical improvements more closely.

2.4 Projected improvements

CMI

The calibration process produces age-period and cohort components of initial improvements. These are projected separately and then summed.

- The age-period components are projected to converge to the assumed long-term rate over a specified convergence period. The age-period convergence period varies by age, with a maximum of 20 years. Under the standard form of the model, the long-term rate is specified as a single rate that applies to age 85, then falls linearly to nil at age 110. However, users can specify other age structures if they wish.
- The cohort components are projected to converge to nil over a specified convergence period. The cohort convergence period varies by age, with a maximum of 40 years.

For each component, convergence uses a cubic polynomial. Under the standard approach, this is symmetrical, with 50% convergence being reached half-way through the convergence period, and with nil gradient at the start and end of the convergence period. However, users can vary the shape of the convergence function and the length of the convergence period.

The calibration and projection use what the CMI terms “m-style” improvements, which are related to central mortality rates. At the very end of the process, these are converted to “q-style” improvements, which are related to initial mortality rates, and are more convenient for users of the model.

RPEC

RPEC's method also utilizes a family of cubic polynomials to transition from the historical data to the assumed long-term rates of improvement over a user-specified convergence period. These cubic polynomials are constructed to reproduce the improvement rates in the last year of the historical data and at the end of the convergence period, along with selected slopes at those years. The initial slope at the final year of historical data is determined by the change in mortality improvement values between the last two years of graduated historical data (i.e. 2016 and 2017 for MP-2021) and the slope at the end of the convergence period is defined to be zero.

For each age 20 through 95, these cubic polynomials are used to interpolate mortality improvement rates over the assumed convergence period in two separate directions: one set of “horizontal” interpolations performed across fixed age paths, and a second set of “diagonal” interpolations performed along fixed year-of-birth paths. The horizontal and diagonal polynomials are then blended using user-specified linear weights, with MP-2021 giving 50% weight to each direction.

Comparison

Once the initial improvements have been determined, the approaches to projections are similar. The key difference is the period over which improvements converge to the long-term rate:

- In the RPEC model, under the settings used to produce MP-2021, convergence is over 10 years horizontally (similar to CMI’s age-period) and 20 years diagonally (similar to CMI’s cohort).
- In the Core version of the CMI model, convergence varies by age in the starting year and is between 5 and 20 years for age-period and between 5 and 40 years by cohort.
- Users can vary the convergence parameters in either model if desired.

3. Historical mortality

This section compares historical mortality experience in England & Wales and the USA using methods which are not specific to the CMI or RPEC models. The analysis uses the datasets underlying CMI_2021 and MP-2021 respectively.

We have only shown the period to 2019 here, as later years do not affect the results shown in this paper.

3.1 Deaths and exposures

Charts 3A and 3B compare exposures and deaths respectively for England & Wales and the USA. In each case, the figures are for the age range 20-100, corresponding to the data used to calibrate the CMI Model.

Chart 3A: Exposures

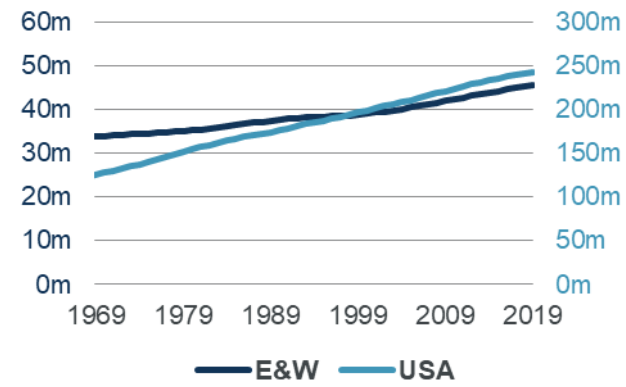
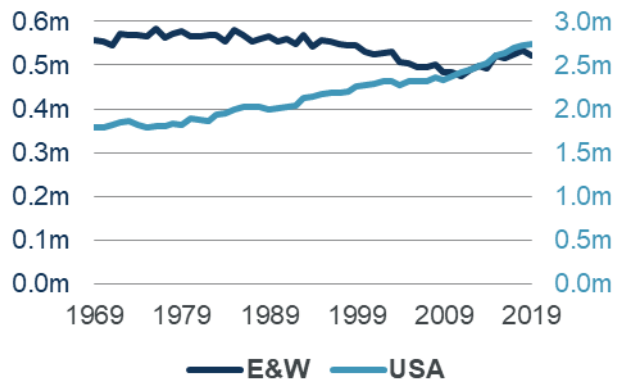


Chart 3B: Deaths



In recent years, the US dataset has been roughly five times the size of the E&W dataset.

3.2 Mortality by age

Charts 3C and 3D compare crude mortality rates, by age and gender, between England & Wales and the USA in 2019. Charts 3E and 3F show the ratios of these rates: USA divided by England & Wales.

For both genders, mortality rates at the younger ages shown were considerably higher in the USA than in England & Wales in 2019. The relative difference reduces as age increases, and mortality rates at the oldest ages shown are similar in each country. The dips at age 99 in Charts 3E and 3F are due to England & Wales data, which has an artefact for that age due to birth patterns following World War I.

Chart 3C: Mortality by age in 2019 – males

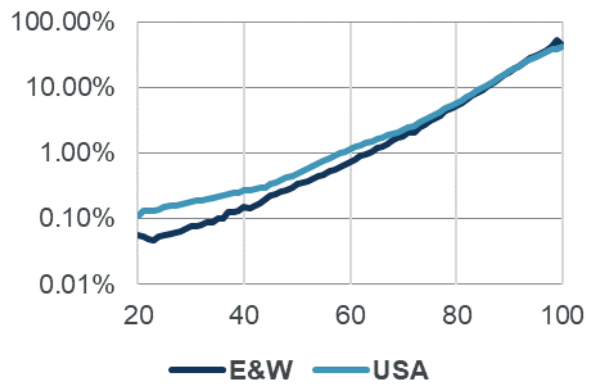


Chart 3D: Mortality by age in 2019 – females

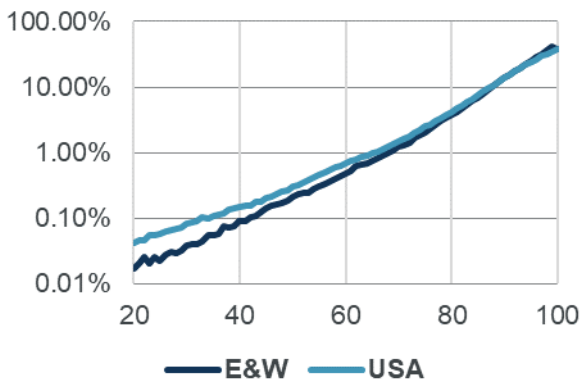


Chart 3E: Mortality ratio by age in 2019 – males

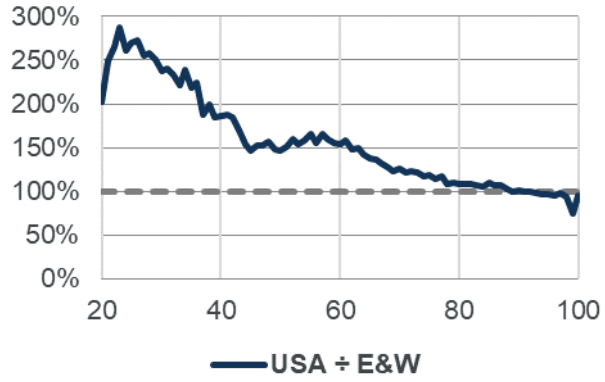
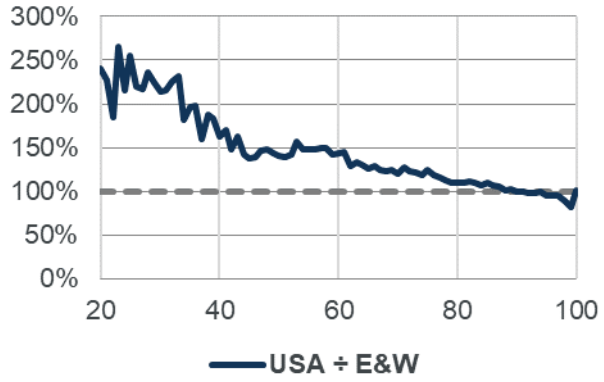


Chart 3F: Mortality ratio by age in 2019 – females



3.3 Progression of mortality

In this section we compare mortality rates between England & Wales and the USA over time. To make a fair comparison, and to remove the impact of differences and changes in population structure, we use age-standardised mortality rates (ASMRs) over time. The ASMR is the rate that would have been seen if the observed age-specific rates had applied in a given standard population.

These are calculated as:

$$ASMR_t = \sum_x S_x (D_{x,t} \div E_{x,t}) \div \sum_x S_x$$

where $D_{x,t}$ are deaths, $E_{x,t}$ are exposures, and S_x is a standard population.

We have used the European Standard Population 2013, consistent with other recent CMI analyses. While its shape is not as close to the US population as to the England & Wales population, we consider it acceptable for the comparisons in this section.

Charts 3G and 3H show the progression of male and female ASMRs for ages 20-100. In both cases, mortality was lower in the US than in England & Wales at the start of the period shown, but lower in England & Wales by the end of the period.

Chart 3G: ASMRs over time – males 20-100

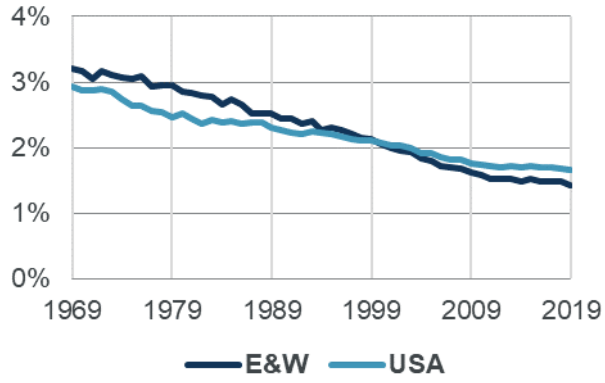
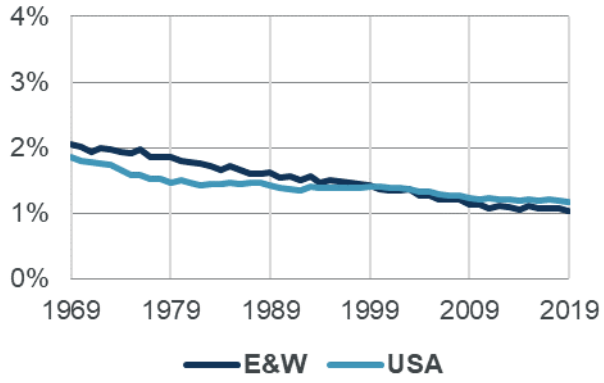


Chart 3H: ASMRs over time – females 20-100



Charts 3I and 3J show five-year average mortality improvements derived from the ASMRs for ages 20-100 and Charts 3K to 3R do the same by age band. Mortality improvements were higher for England & Wales than for the US for most age groups for most of the period shown. The main exception is for US males ages 20-44, who had very high improvements around the year 2000.

Chart 3I: Five-year average mortality improvements – males 20-100

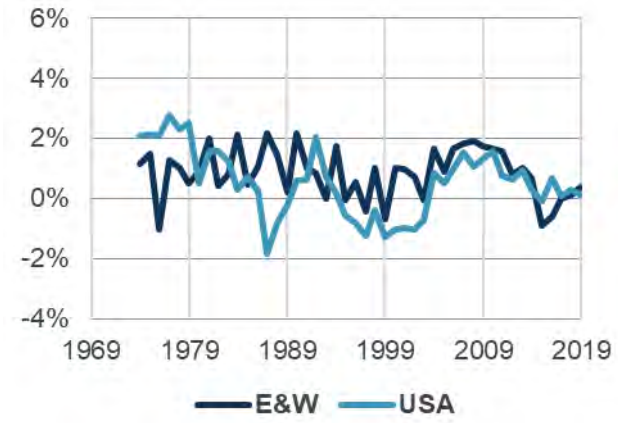


Chart 3J: Five-year average mortality improvements – females 20-100

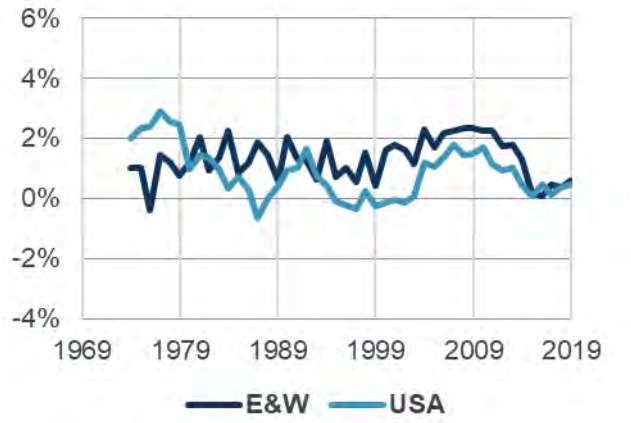


Chart 3K: Five-year average mortality improvements – males 20-44

Chart 3L: Five-year average mortality improvements – females 20-44

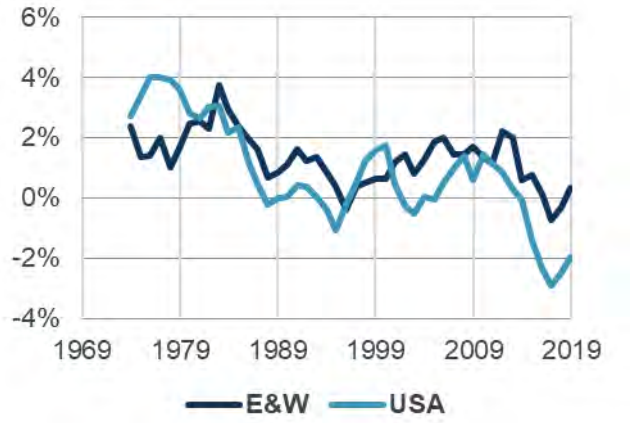


Chart 3M: Five-year average mortality improvements – males 45-64

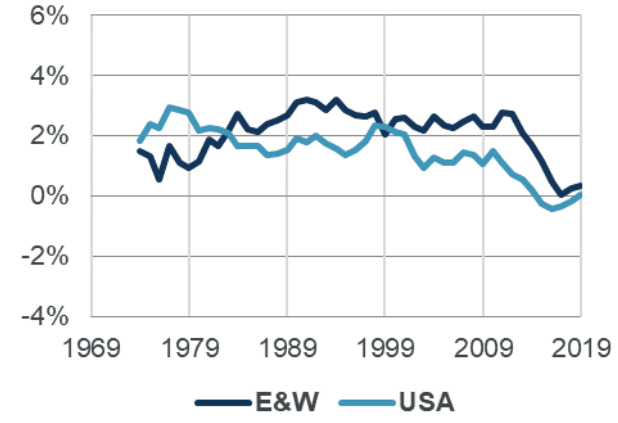


Chart 3N: Five-year average mortality improvements – females 45-64

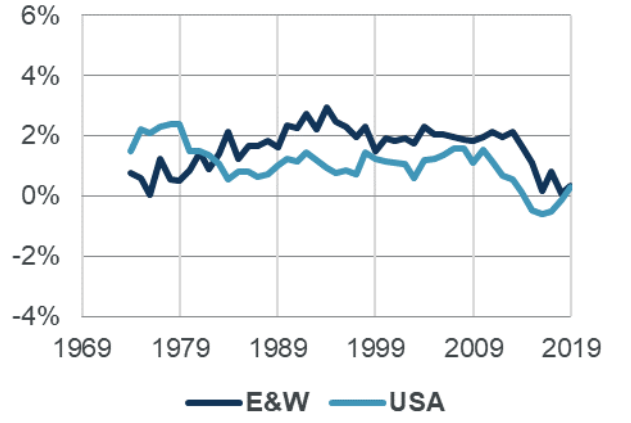


Chart 3O: Five-year average mortality improvements – males 65-84

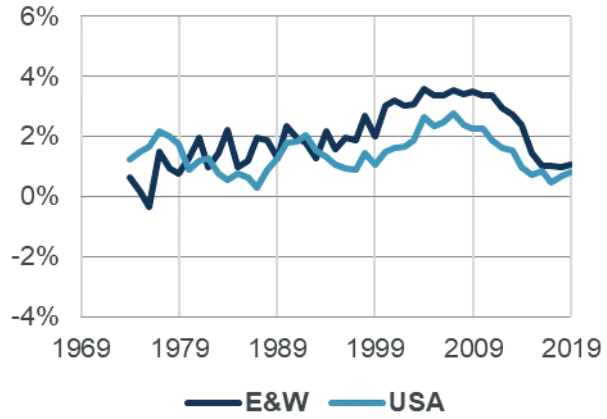


Chart 3P: Five-year average mortality improvements – females 65-84

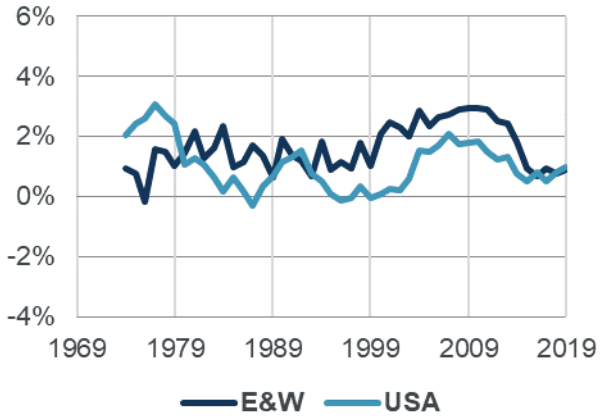


Chart 3Q: Five-year average mortality improvements – males 85-100

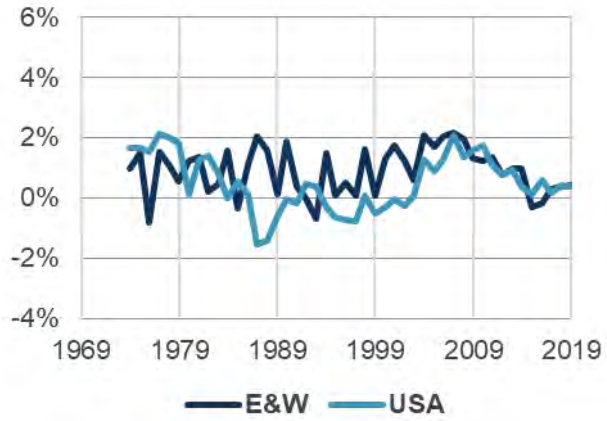
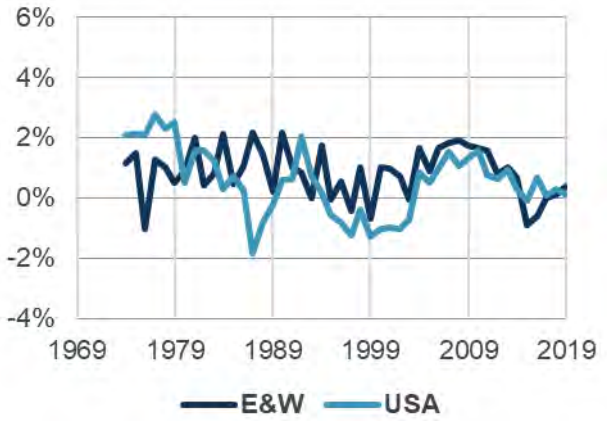


Chart 3R: Five-year average mortality improvements – females 85-100



3.4 Progression of mortality by age

The previous section compared ASMRs for ages 20-100. However, mortality improvements vary materially by age.

In this section we show "heatmaps" of mortality improvements, by age and time. In order to make a like-for-like comparison between the datasets that is not influenced by the structure of either model, we use a "structure-free" approach, previously used by the CMI in Working Paper 159.

Under this approach:

- We specify a simple model of mortality, that allows mortality to vary by age and calendar year:

  $$\log m_{x,t} = A + Bx + Ct$$

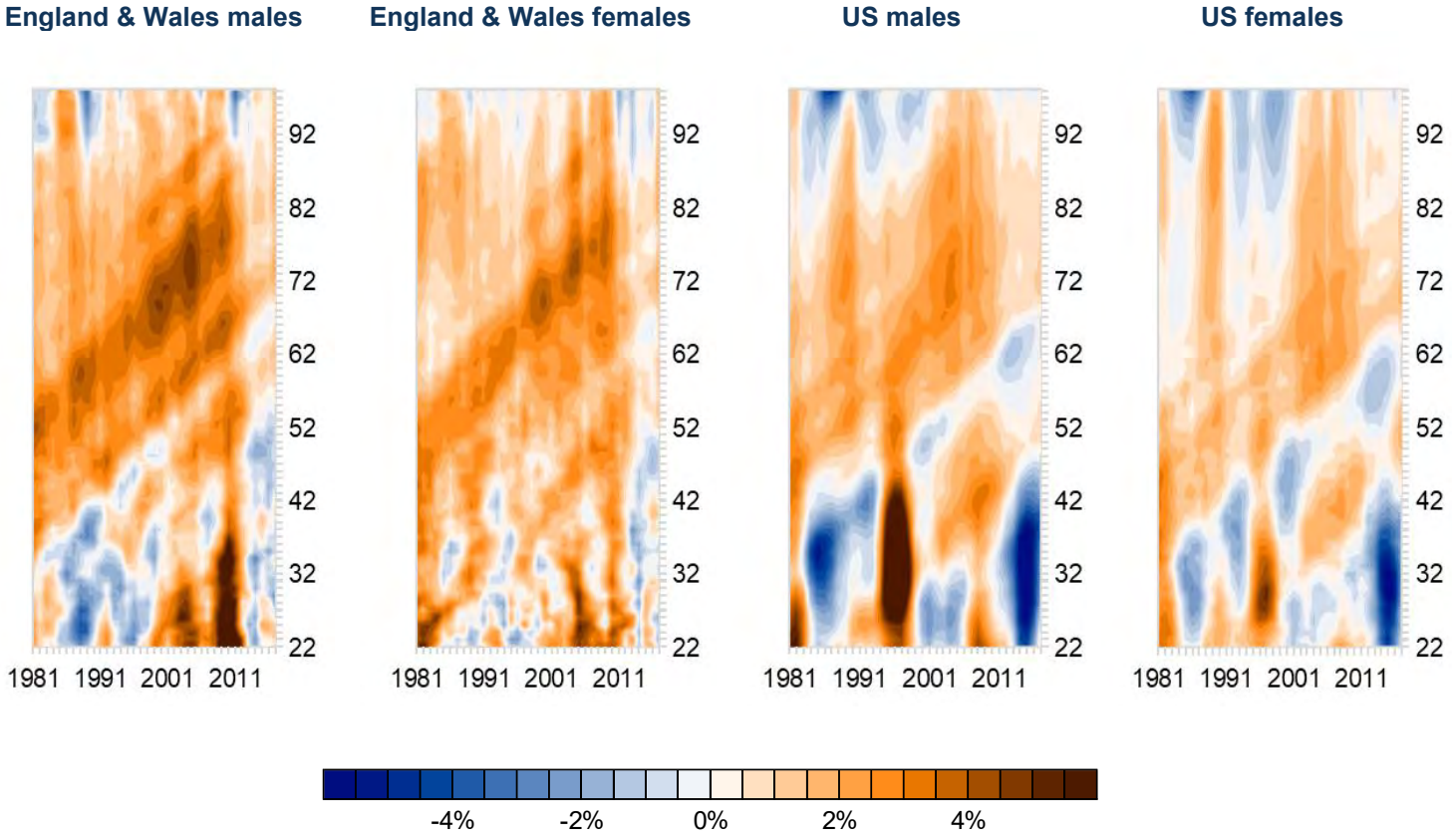
- We fit this to historical deaths and exposure data for ages $x - 2$ to $x + 2$ and years $t - 2$ to $t + 2$, using maximum likelihood estimation under the usual Poisson assumption for deaths.
- The structure-free mortality improvement for age x and year t is then given by $-C$, since:

  $$MI_{x,t} = \log m_{x,t-1} - \log m_{x,t} = \big(A + Bx + C(t-1)\big) - (A + Bx + Ct) = -C$$

Chart 3S shows the improvements for ages 22 to 98 and calendar years 1981 to 2017.

- For England & Wales males, there are clear signs of cohort (birth year) effects at older ages, particularly centred on birth years around 1930. The strongest improvements are for younger ages around 2010.
- England & Wales females show a broadly similar pattern to males, but with less strong improvements.
- For US males, there are signs of cohort effects at older ages, but these are less strong than for England & Wales. Younger ages have very high improvements in the mid-1990s and strong negative improvements in recent years.
- US females show a broadly similar pattern to males, but with less strong improvements.

Chart 3S: Heatmaps of structure-free mortality improvements



4. Model results

We have calibrated versions of the CMI_2021 and MIM-2021 models to data for England & Wales and the US and used these to project mortality improvements and calibrate illustrative life expectancies.

This means we have four model versions in total:

- Calibrating CMI_2021 to US data;
- Calibrating MIM-2021 to US data;
- Calibrating CMI_2021 to England & Wales data; and
- Calibrating MIM-2021 to England & Wales data;

4.1 Methods and data

Section 2 describes the broad methods used for the CMI and RPEC models. This section describes the specific choices we have made for the results in this paper.

Long-term rate

As a matter of policy, the CMI does not provide any value for the long-term rate of mortality improvements and requires users of the CMI model to choose a suitable value. In contrast, RPEC makes its own assumption for the long-term rate in MP-2021 (although users can input their own long-term improvement rate in the RPEC model).

In order to compare results from the two models in this paper, we have used long-term rate assumptions made by RPEC. For both the CMI and RPEC models:

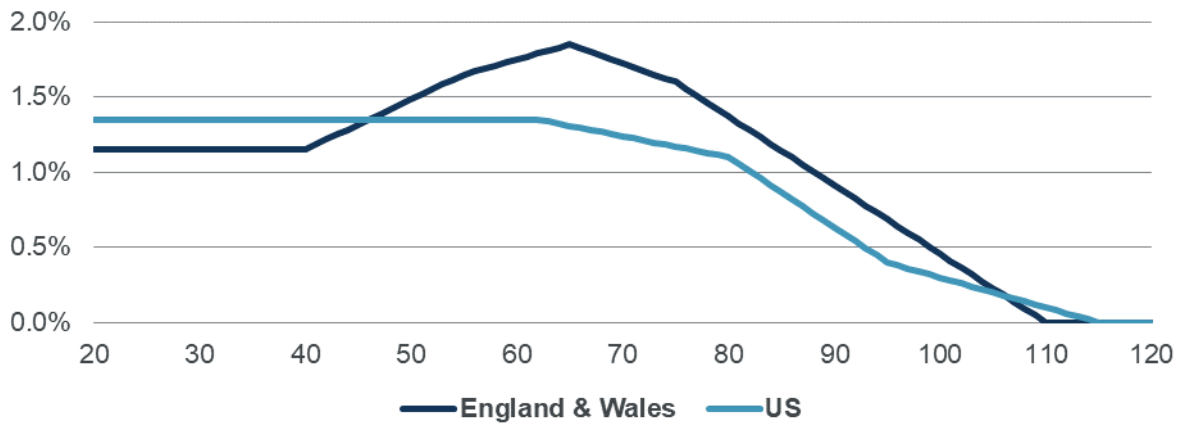
- For the US, the long-term rates are taken from Scale MP-2021. These were developed using an analysis of historical probabilities of death published by the Social Security Administration.
- For England & Wales, long-term rates have been calculated by RPEC based on historical data for England & Wales and applying a method consistent with its analysis of the US long-term rate. This method determines historical long-term rates by fitting an exponential curve to historical age-adjusted death rates from 1950-2019 for five-year age groups. The long-term rate assumption is chosen by selecting a piecewise linear curve that approximates these historical long-term rates by age.

We stress that the long-term rates used for England & Wales in this paper do not reflect a view or recommendation from the CMI or SoA.

Chart 4A shows the long-term rate assumptions used for the analysis in this paper. Within each country the same long-term rates apply for males and females. In the Core version of the CMI model, the user specifies a single value for the long-term rate that applies at all ages up to 85 before tapering to nil at age 110. The assumption used here is more complex and would be an Advanced parameter.

There is an argument that mortality improvements for the countries should be the same in the very long term, so that mortality does not diverge. However, in this paper our analysis focusses on comparisons between models for each country, rather than comparisons between the countries, so the differences in the long-term rates are not as important.

Chart 4A: Long-term mortality improvement rates by age used in this paper



CMI Model with England & Wales data

When using the CMI Model with England & Wales data:

- We use the Core CMI_2021 Model.
- The long-term rate is the RPEC assumption for England & Wales described above.

CMI Model with US data

When using the CMI Model with US data:

- We use the CMI_2021 Model and vary the Advanced parameters.
- The dataset uses US data to 2019, taken from the MP-2021 dataset.
- As no weight is placed on data for 2020 and 2021, any values can be used in the CMI_2021 software for those years. For convenience, we leave those values blank.
- We increase the smoothing parameters to reflect the larger size of the US dataset compared to England & Wales. This is done using the automatic adjustment feature of the CMI_2021 software.
- We note that the pattern of residuals over time when fitting the CMI Model to US data shows a poor fit for some years. Residuals should appear random, but they tend to be negative for most of 1981 to 1991 and positive for much of 1995 to 2005, suggesting that there may be too much smoothing during these periods. However, the fit does look more reasonable for the past decade. We considered alternative smoothing parameters to improve the historical fit but doing so worsened the fit in more recent years, which is more important as they determine initial improvements.
- The long-term rate is the RPEC assumption from MP-2021.

RPEC Model with England & Wales data

When using the RPEC model with England & Wales data:

- We use a version of the MIM-2021 model that is calibrated to the CMI_2021 dataset.
- For calendar years 2010-2019, the CMI_2021 mortality rates are smoothed within calendar years using the process outlined in Social Security Administration Actuarial Study #120
- The long-term rate is the RPEC assumption for England & Wales described above.

RPEC Model with US data

When using the RPEC model with US data:

- We use the standard MP-2021 scale.

4.2 Mortality improvements

This section shows "heatmaps" of mortality improvements, where the colour represents the level of mortality improvements:

- For each dataset we show heatmaps of results from the RPEC model, the CMI model, and the difference between them.
- The heatmaps include smoothed historical mortality improvements as well as projected improvements.

We have included larger versions of these charts in Appendix 1.

We note that it is not straightforward to deduce the impact on life expectancy of differences between the models based on the heatmaps in this section. This and the following sections show:

- heatmaps of mortality improvements (this section);
- differences in projected mortality (Section 4.3) arising from the accumulated differences in mortality improvements; and
- differences in life expectancy (Section 4.4) arising from the differences in projected mortality improvements over multiple years.

USA

Charts 4B and 4C show heatmaps of mortality improvements for US males and females respectively:

For males:

- Cohort effects differ between the two models, with the CMI model having a strong cohort effect centred on the 1965 birth year. Also, cohort effects persist for longer in the CMI model.
- At younger ages, the RPEC model has stronger period effects in recent years, which leads to it having lower projected improvements.

There is a similar pattern of differences for females, although the differences tend to be smaller for females than males.

Chart 4B: Mortality improvements – US data, males

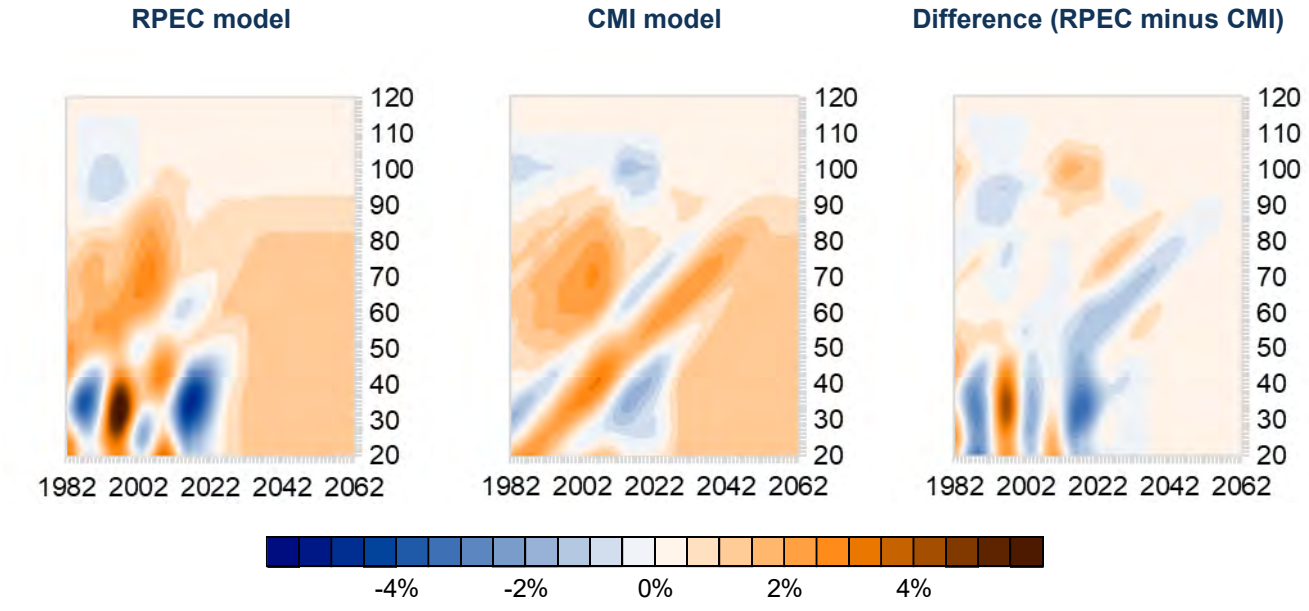
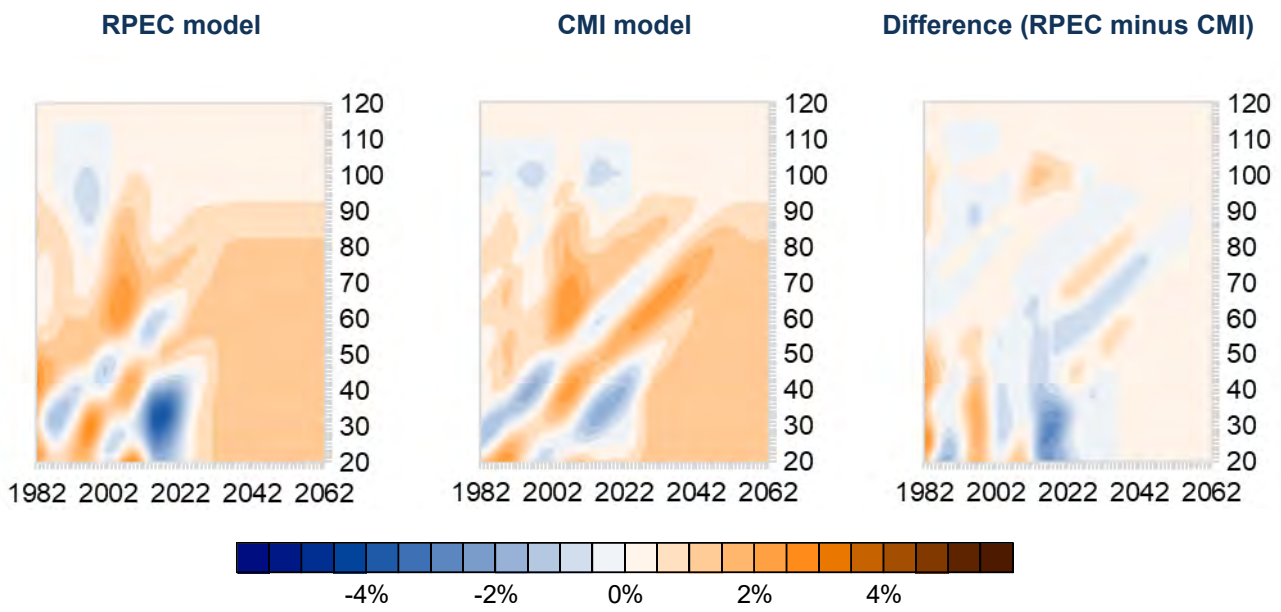


Chart 4C: Mortality improvements – US data, females



England & Wales

Charts 4D and 4E show heatmaps of mortality improvements for England & Wales males and females respectively:

For males:

- As with the US, there are differences in cohort effects between the two models, with the CMI model having a strong cohort effect centred on the 1965 birth year and cohort effects persisting for longer in the CMI model.
- At younger ages, the RPEC model has stronger negative period effects in recent years.

Differences for females are similar, though more modest.

Chart 4D: Mortality improvements – England & Wales data, males

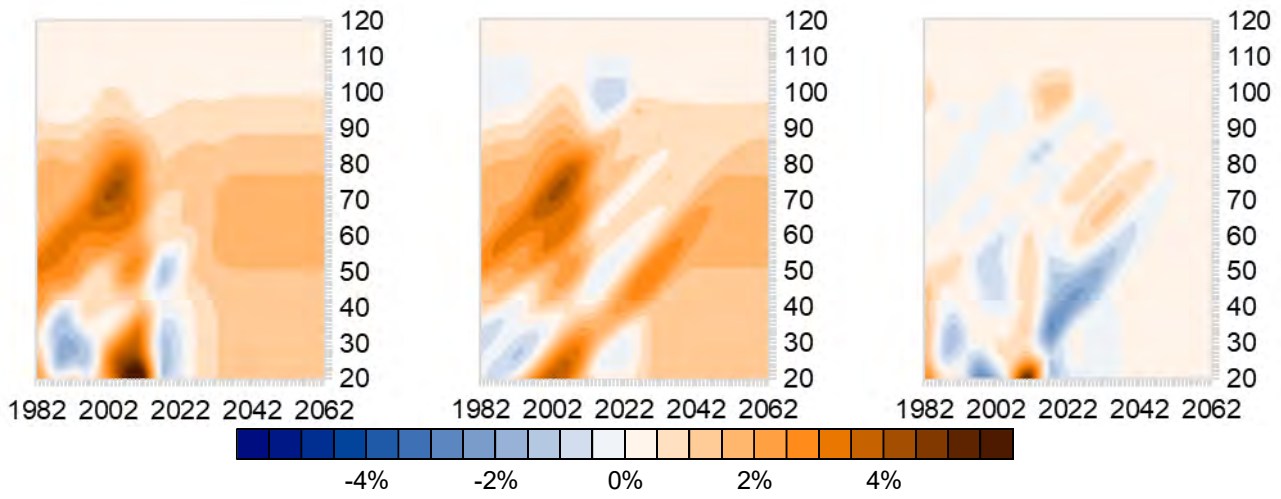
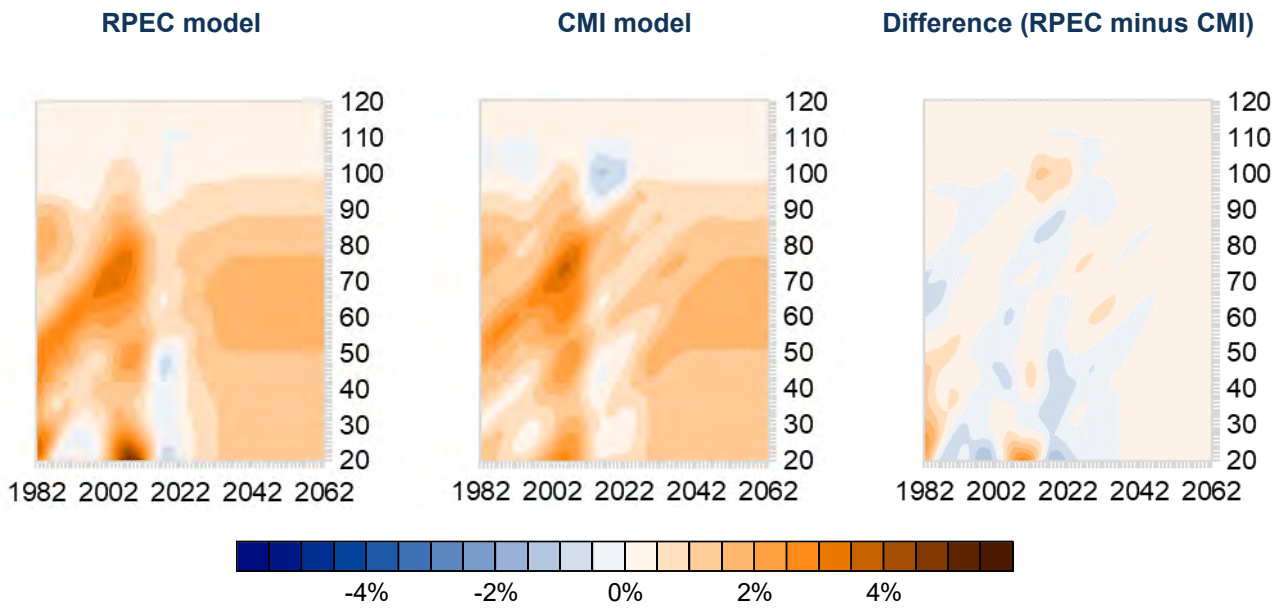


Chart 4E: Mortality improvements – England & Wales data, females



USA – initial improvements

Charts 4F and 4G show initial mortality improvements when fitting CMI_2021 and MIM-2021 to US data for males and females respectively. The initial improvements are not directly comparable as they are in different years – 2021 for CMI_2021 and 2017 for MP-2021 – so we have also shown the mortality improvements from the CMI_2021 model in 2017.

There are material differences between the initial improvements. For both males and females:

- At younger ages the initial improvements are lower in MIM-2021 than CMI_2021. The difference is particularly notable around age 35, where for males the MIM-2021 improvements reach a low of -4.8% compared to -0.8% in CMI_2021.
- At the highest ages the initial improvements are lower in CMI_2021 than MIM-2021. For males at age 100, the CMI_2021 improvement is -1.4% compared to +0.4% in MIM-2021.

Chart 4F: Initial mortality improvements with US data, male

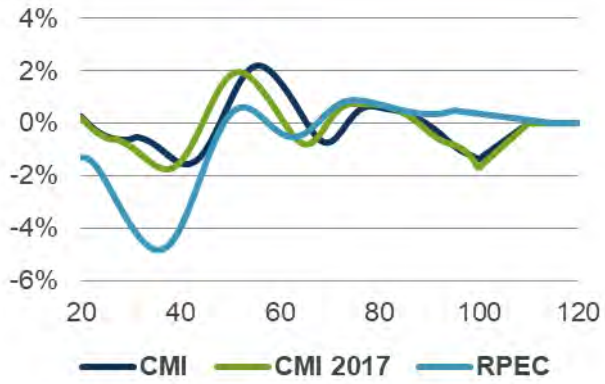
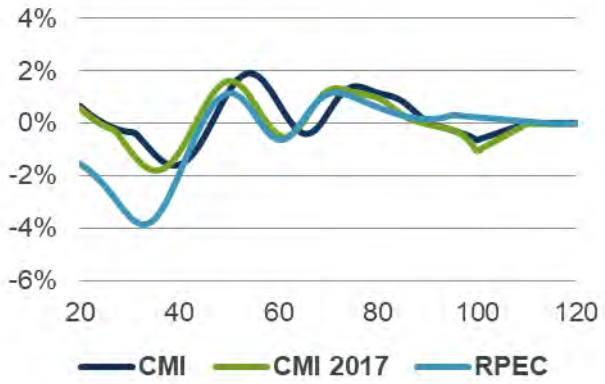


Chart 4G: Initial mortality improvements with US data, female



Charts 4H and 4I show the split of initial improvements into age-period and cohort components for the US dataset. The structure of the APCI model that the CMI uses to fit to historical data explicitly splits improvements between age, period and cohort effects. In contrast RPEC uses a Whittaker-Henderson graduation to determine overall improvements and the projection method implicitly treats these improvements as being half age-period effects and half cohort effects. Consequently, the RPEC age-period and cohort effects are identical, shown as "both" on Charts 4H and 4I.

Chart 4H: Components of initial mortality improvements with US data, male

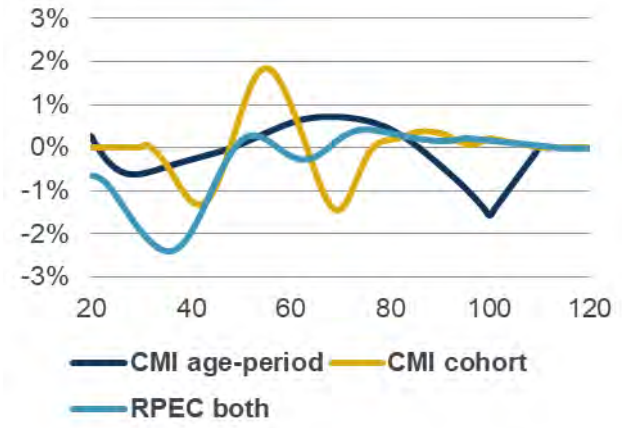
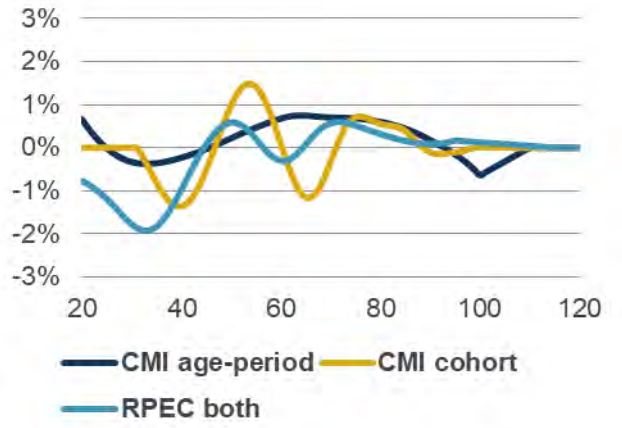


Chart 4I: Components of initial mortality improvements with US data, female



England & Wales – initial improvements

Charts 4J and 4K show initial mortality improvements when fitting CMI_2021 and MIM-2021 to England & Wales data for males and females respectively. As for Charts 4F and 4G, the initial improvements are not directly comparable as they are in different years, so we have also shown the mortality improvements from the CMI_2021 model in 2017.

For both males and females:

- At younger ages the initial improvements are lower in MIM-2021 than CMI_2021, as for the US dataset, although the differences are not as large as for the US dataset.
- At the highest ages the initial improvements are lower in CMI_2021 than MIM-2021, as for the US dataset.

Chart 4J: Initial mortality improvements with England & Wales data, male

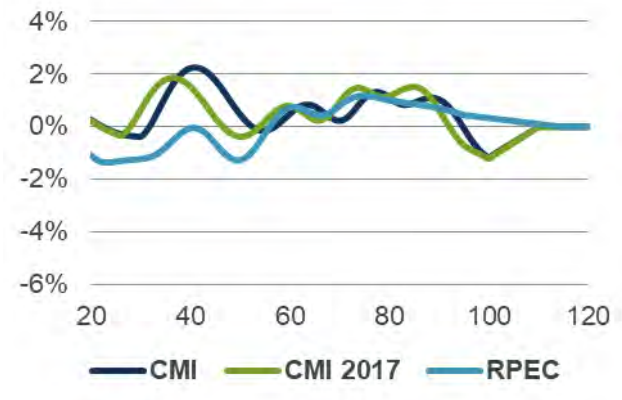
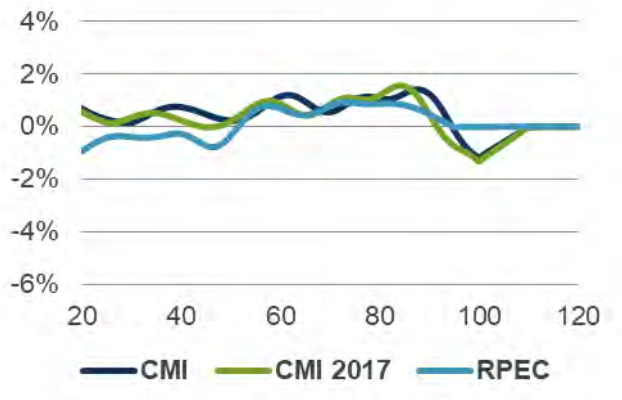


Chart 4K: Initial mortality improvements with England & Wales data, female



Charts 4L and 4M show the split of initial improvements into age-period and cohort components for the US dataset. As can be seen in the chart, there are substantial differences between the two approaches.

Chart 4L: Components of initial mortality improvements with US data, male

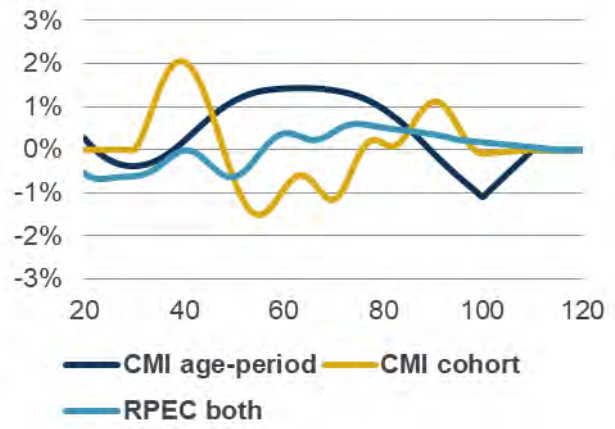
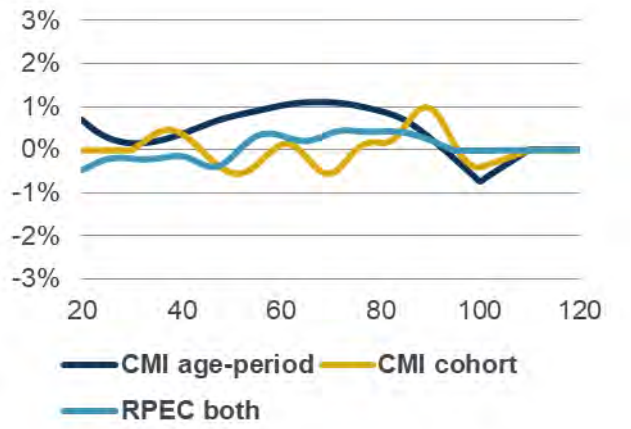


Chart 4M: Components of initial mortality improvements with US data, female



4.3 Relative mortality

Before considering the impact on the different models in life expectancy, we first compare projected mortality rates between the CMI and RPEC models. This is helpful in understanding the differences in life expectancies in the next section.

When comparing life expectancies for each dataset:

- For the England & Wales dataset we use the S3PMA and S3PFA tables for males and females respectively. These are part of the CMI's "S3" Series of mortality tables, which are based on data for self-administered pension schemes.
- For the US dataset we use the Pri-2012 amount-weighted mortality rates for the total dataset. We use employee rates for ages below 62 and retiree rates for ages 62 and above.

Because the charts in this section show ratios of mortality rates, the values shown depend only on the projected mortality improvements, not the rates in the base mortality tables. However, the charts are affected by the effective dates of the base mortality tables, which differ: 1 January 2013 for the "S3" Series and 1 January 2012 for the Pri-2012 tables.

The charts plot the ratios between the projected rates and show the RPEC rate divided by the CMI rate:

- For Chart 4N, the differences in projected mortality rates reflect the differences in mortality improvements between the effective date of the table and 1 January 2022 as well as differences in future improvements.
  - The ratios in Chart 4N are, by definition, 100% for the base year of the mortality tables – 2012 for US data and 2013 for England & Wales data.
- For Chart 4O, we use the same model to project the base mortality tables to 1 January 2022, so that mortality improvements only differ after that date. Specifically:
  - For England & Wales, we use CMI_2021 to project the "S3" Series tables to 1 January 2022.
  - For the US, we use MP-2021 to project the Pri-2021 tables to 1 January 2022.
  - The ratios in Chart 4O are 100% in 2022.
- For later years, the ratio between the models reflects the accumulation of the mortality improvements shown in the section above. For example, the ratio of mortality rates for US males ages 80 in 2030 in Chart 4N reflects differences between the models in mortality improvements at age 80 between 2012 and 2030.
- Note that the colour scale for this chart is different to other heatmaps in this paper.

For Chart 4N, using the base mortality tables, for all four combinations of country and gender, projected mortality rates tend to be higher for the RPEC model at younger ages and higher for the CMI Model at older ages. The nature of the projections means that the ratios are stable in the longer term, as the same long-term rates are used for both models.

For Chart 4O, which only reflects differences after 2022, the differences are much smaller. There is again a tendency for projected mortality rates to be higher for the RPEC model at younger ages and higher for the CMI Model at older ages.

The ratios of mortality rates in Chart 4O (reflecting differences from 2022 onwards) are affected by a combination of differences in initial mortality improvements and differences in the periods for convergence to the long-term rate. For example, for US males, the initial mortality improvements shown in Chart 4F are higher under the RPEC model than the CMI model, and the long-term rate is reached sooner under the RPEC model.

Chart 4N: Ratio of mortality rates (RPEC model ÷ CMI model) using base mortality tables

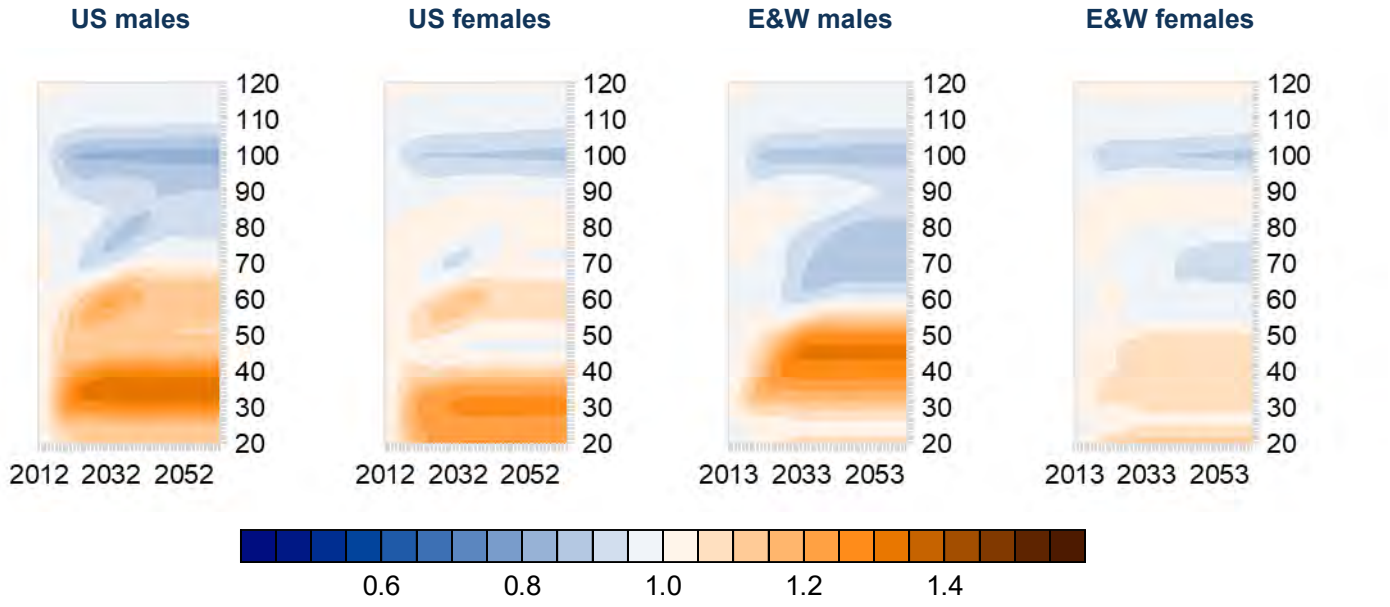
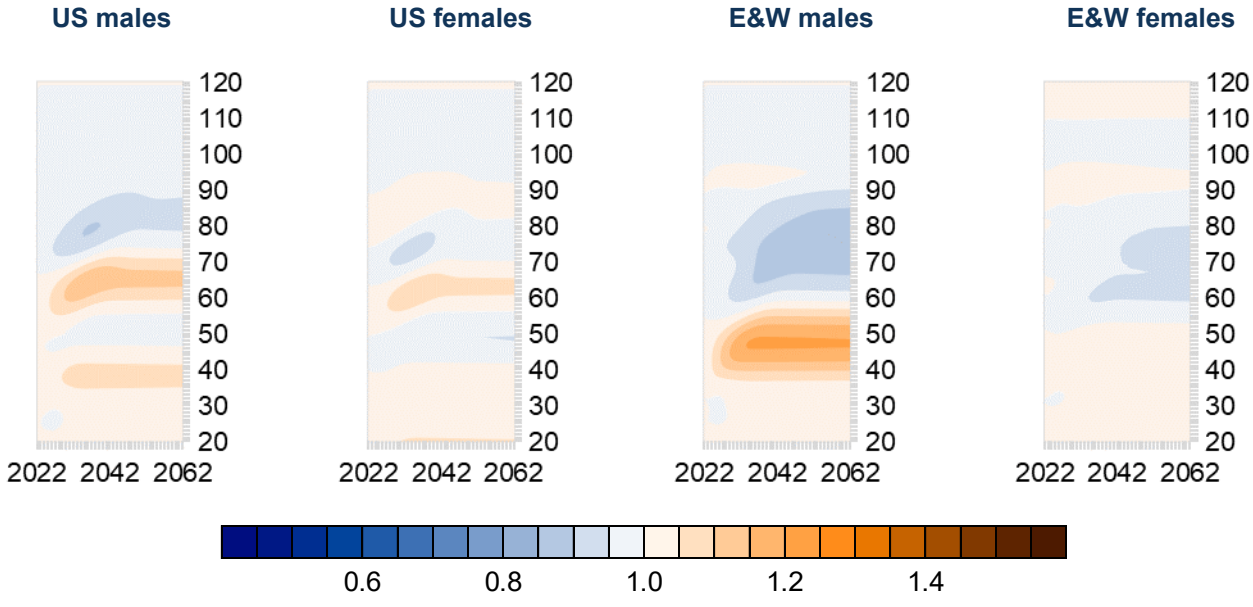


Chart 4O: Ratio of mortality rates (RPEC model ÷ CMI model) using tables projected to 2022



4.4 Life expectancies

Tables in this section compare illustrative life expectancies, at 1 January 2022, produced by the CMI and RPEC models, showing how the differences in projected mortality rates shown above lead to different life expectancies.

As in the previous section, we show two sets of results:

- where the projections vary for every year since the base mortality tables, corresponding to Chart 4N; and
- where the projections only vary from 2022 onwards, corresponding to Chart 4O.

4.4.1 Projections varying since the base tables

Tables 4.1 to 4.4 show life expectancies for the RPEC and CMI models and differences between them, for different populations. Chart 4P plots the differences by age. We note that within each table we use the same long-term rates for each model, so the differences in life expectancy shown arise from a combination of differences in initial improvements and differences in convergence assumptions rather than differences in the long-term rate.

- For US males, the RPEC model produces higher life expectancies than the CMI model. The greatest absolute difference is around 0.8 years at age 65, but the greatest relative difference is for age 95.
- For US females, the RPEC model tends to produce higher life expectancies than the CMI model, but this is not the case at all ages. The greatest differences, both absolute and relative, are for age 95.
- For England & Wales males, the RPEC model produces higher life expectancies than the CMI model. The greatest absolute difference is around 0.7 years at ages 45 and 55, but the greatest relative difference is for age 95.
- For England & Wales females, the RPEC model tends to produce higher life expectancies than the CMI model, but this is not the case at all ages. The greatest absolute differences are at the youngest and oldest ages, and the greatest relative difference is for age 95.

Table 4.1: Comparison of life expectancies for US males

Age	25	35	45	55	65	75	85	95
RPEC model	61.325	50.850	40.451	30.105	20.552	12.664	6.519	3.156
CMI model	61.104	50.613	40.223	29.784	19.758	12.303	6.195	2.754
Difference (RPEC – CMI)	+0.220	+0.237	+0.228	+0.321	+0.794	+0.362	+0.324	+0.402
Difference %	+0.4%	+0.5%	+0.6%	+1.1%	+4.0%	+2.9%	+5.2%	+14.6%

Table 4.2: Comparison of life expectancies for US females

Age	25	35	45	55	65	75	85	95
RPEC model	64.010	53.383	42.833	32.365	22.536	14.101	7.531	3.732
CMI model	63.954	53.341	42.851	32.306	22.363	14.177	7.388	3.471
Difference (RPEC – CMI)	+0.057	+0.043	-0.018	+0.059	+0.173	-0.076	+0.143	+0.261
Difference %	+0.1%	+0.1%	-0.0%	+0.2%	+0.8%	-0.5%	+1.9%	+7.5%

Table 4.3: Comparison of life expectancies for England & Wales males

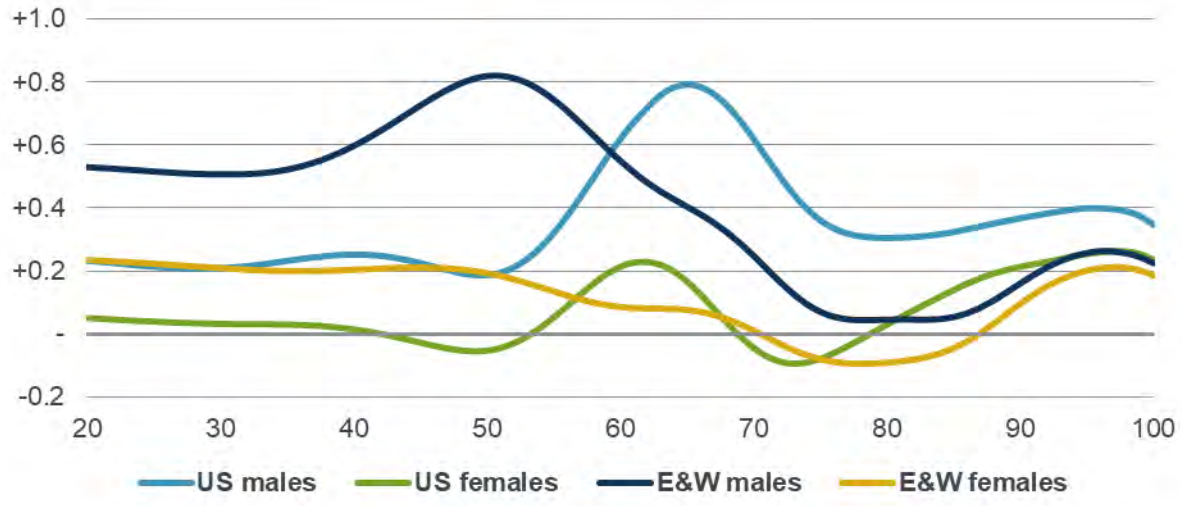
Age	25	35	45	55	65	75	85	95
RPEC model	63.491	52.814	42.257	32.058	22.304	13.530	6.752	2.929
CMI model	62.948	52.274	41.518	31.304	21.895	13.458	6.698	2.669
Difference (RPEC – CMI)	+0.543	+0.540	+0.738	+0.754	+0.409	+0.072	+0.054	+0.260
Difference %	+0.9%	+1.0%	+1.8%	+2.4%	+1.9%	+0.5%	+0.8%	+9.7%

Table 4.4: Comparison of life expectancies for England & Wales females

Age	25	35	45	55	65	75	85	95
RPEC model	65.949	55.221	44.619	34.300	24.336	15.095	7.574	3.233
CMI model	65.687	54.994	44.389	34.153	24.252	15.172	7.619	3.028
Difference (RPEC – CMI)	+0.262	+0.227	+0.229	+0.147	+0.083	-0.078	-0.044	+0.205
Difference %	+0.4%	+0.4%	+0.5%	+0.4%	+0.3%	-0.5%	-0.6%	+6.8%

Chart 4P: Differences in life expectancy: RPEC model minus CMI model

A positive value here indicates that the RPEC model projects higher life expectancy than the CMI model.



4.4.2 Projections varying since 2022 only

Tables 4.5 to 4.8 shows life expectancies for the RPEC and CMI models and differences between them, for different populations. Chart 4Q plots the differences by age.

Compared to Tables 4.1 to 4.4 and Chart 4P, where the projections vary since 2012 or 2013:

- The differences in life expectancy between the RPEC and CMI models at older ages are much smaller when considering differences in mortality improvements only after 2022.

- The differences in life expectancy between the RPEC and CMI models at younger ages are similar when considering differences in mortality improvements only after 2022.

Table 4.5: Comparison of life expectancies for US males

Age	25	35	45	55	65	75	85	95
RPEC model	61.325	50.850	40.451	30.105	20.552	12.664	6.519	3.156
CMI model	61.176	50.730	40.402	30.003	20.039	12.531	6.476	3.126
Difference (RPEC – CMI)	+0.149	+0.120	+0.049	+0.102	+0.513	+0.133	+0.043	+0.030
Difference %	+0.2%	+0.2%	+0.1%	+0.3%	+2.6%	+1.1%	+0.7%	+1.0%

Table 4.6: Comparison of life expectancies for US females

Age	25	35	45	55	65	75	85	95
RPEC model	64.010	53.383	42.833	32.365	22.536	14.101	7.531	3.732
CMI model	63.955	53.351	42.864	32.319	22.390	14.204	7.528	3.715
Difference (RPEC – CMI)	+0.055	+0.033	-0.032	+0.046	+0.146	-0.104	+0.003	+0.018
Difference %	+0.1%	+0.1%	-0.1%	+0.1%	+0.7%	-0.7%	+0.0%	+0.5%

Table 4.7: Comparison of life expectancies for England & Wales males

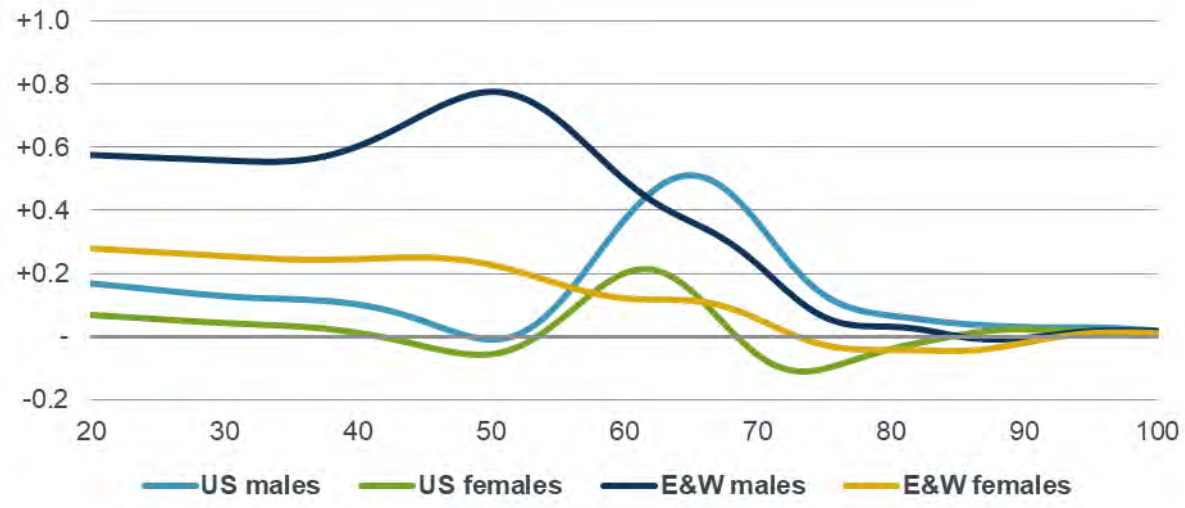
Age	25	35	45	55	65	75	85	95
RPEC model	63.515	52.830	42.224	31.994	22.259	13.519	6.698	2.685
CMI model	62.948	52.274	41.518	31.304	21.895	13.458	6.698	2.669
Difference (RPEC – CMI)	+0.567	+0.557	+0.706	+0.690	+0.364	+0.061	-0.000	+0.016
Difference %	+0.9%	+1.1%	+1.7%	+2.2%	+1.7%	+0.5%	-0.0%	+0.6%

Table 4.8: Comparison of life expectancies for England & Wales females

Age	25	35	45	55	65	75	85	95
RPEC model	65.955	55.240	44.641	34.322	24.368	15.147	7.575	3.040
CMI model	65.687	54.994	44.389	34.153	24.252	15.172	7.619	3.028
Difference (RPEC – CMI)	+0.268	+0.246	+0.252	+0.169	+0.116	-0.025	-0.044	+0.012
Difference %	+0.4%	+0.4%	+0.6%	+0.5%	+0.5%	-0.2%	-0.6%	+0.4%

Chart 4Q: Differences in life expectancy: RPEC model minus CMI model

A positive value here indicates that the RPEC model projects higher life expectancy than the CMI model.



4.5 Sensitivities to parameters

This section considers "sensitivities" of model results to the long-term rate of mortality improvements – i.e. how life expectancies from the models are affected by different choices of that parameter. We have not shown sensitivities to other parameters, as these are not directly comparable between the two models.

To assess sensitivity to the long-term rate we have produced versions of the CMI and RPEC with modified long-term rates and calculated the resulting percentage change in life expectancy compared to the results in Section 4.4.1. The modifications to the long-term rates are done by specifying a multiplier (50%, 75%, 125% or 150%) and then multiplying the long-term rates shown in Chart 4A by this value at each age.

The sensitivities are shown in Tables 4.9 to 4.12. In all cases a greater long-term rate leads to higher life expectancy and the relationship between the LTR multiplier and life expectancy is broadly linear.

Life expectancy is more sensitive to the long-term rate for the RPEC model than for the CMI model, for both genders and both datasets. This is likely due to the differences in the start years and convergence periods between the models, meaning that the long-term rates apply in full for longer in the RPEC model:

- For the RPEC model, the long-term rates apply in full from 2027 (10 years after the start year of 2017) when projected horizontally and apply in full from 2037 (20 years after the start date) when projected diagonally.
- For the CMI Model, the period when the long-term rate applies in full varies by age from 2026 (for ages 95 and above) to 2041 (for ages 60 to 80) – 5 to 20 years after the start year of 2021.

Table 4.9: Sensitivities to the long-term rate – US data, RPEC model

LTR multiplier	Male 45	Male 65	Male 85	Female 45	Female 65	Female 85
50%	-2.9%	-2.0%	-0.6%	-2.7%	-1.9%	-0.7%
75%	-1.5%	-1.0%	-0.3%	-1.3%	-0.9%	-0.3%
125%	+1.5%	-1.0%	+0.3%	+1.4%	+1.0%	+0.3%
150%	+2.9%	-2.0%	+0.7%	+2.7%	+1.9%	+0.7%

Table 4.10: Sensitivities to the long-term rate – US data, CMI model

LTR multiplier	Male 45	Male 65	Male 85	Female 45	Female 65	Female 85
50%	-2.2%	-1.2%	-0.4%	-2.2%	-1.3%	-0.5%
75%	-1.1%	-0.6%	-0.2%	-1.1%	-0.7%	-0.2%
125%	+1.1%	+0.6%	+0.2%	+1.1%	+0.7%	+0.2%
150%	+2.3%	+1.3%	+0.4%	+2.2%	+1.3%	+0.5%

Table 4.11: Sensitivities to the long-term rate – England & Wales data, RPEC model

LTR multiplier	Male 45	Male 65	Male 85	Female 45	Female 65	Female 85
50%	-3.6%	-2.5%	-0.9%	-3.2%	-2.3%	-0.9%
75%	-1.8%	-1.3%	-0.5%	-1.6%	-1.2%	-0.5%
125%	+1.8%	+1.3%	+0.5%	+1.6%	+1.2%	+0.5%
150%	+3.6%	+2.6%	+0.9%	+3.1%	+2.4%	+0.9%

Table 4.12: Sensitivities to the long-term rate – England & Wales data, CMI model

LTR multiplier	Male 45	Male 65	Male 85	Female 45	Female 65	Female 85
50%	-2.9%	-1.7%	-0.6%	-2.6%	-1.7%	-0.7%
75%	-1.5%	-0.9%	-0.3%	-1.3%	-0.8%	-0.3%
125%	+1.5%	+0.9%	+0.3%	+1.3%	+0.9%	+0.3%
150%	+2.9%	+1.8%	+0.6%	+2.6%	+1.7%	+0.7%

References

MP-2021

The Mortality Improvement Scale MP-2021 is available from the SoA website together with documentation and a video and podcast.

Access to these materials is unrestricted.

MIM-2021-v3

The Mortality Improvement Model, MIM-2021-v3 is available from the SoA website together with documentation and a data analysis tool

Access to these materials is unrestricted.

Social Security Administration Historical Probabilities of Death

The historical probabilities of death used to develop the assumption for the long-term rates of improvement for Scale MP-2021 are available from the Social Security Administration website.

Access to these materials is unrestricted.

Social Security Administration Actuarial Study #120

The process used to smooth historical mortality rates within individual calendar years is described in Actuarial Study #120.

Access to these materials is unrestricted.

CMI_2021

The CMI_2021 version of the CMI Mortality Projections Model is available alongside Working Paper 160 together with various supporting documentation and data.

Access to these materials is restricted to CMI's Authorised Users, apart from the Frequently Asked Questions.

CMI Working Paper 106

CMI Working Paper 106 considers mortality at high ages and describes the CMI's implementation of the Kannisto-Thatcher method.

Access to this paper is unrestricted.

Appendix 1: Large version of mortality improvement heatmaps

This appendix includes larger versions of the mortality improvement heatmaps from Section 4.2, so that detail can be seen more clearly.

Chart A1A: Mortality improvements – US data, males

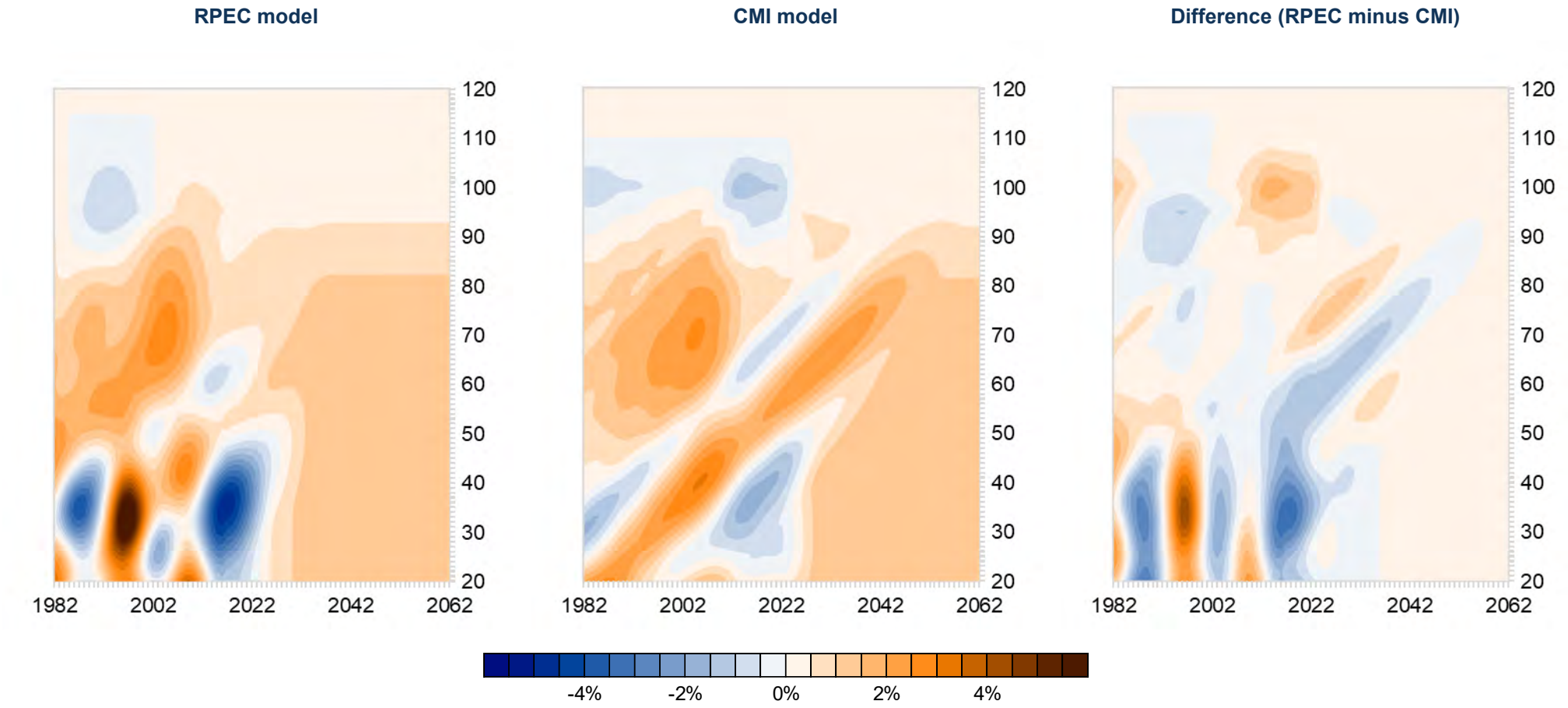


Chart A1B: Mortality improvements – US data, females

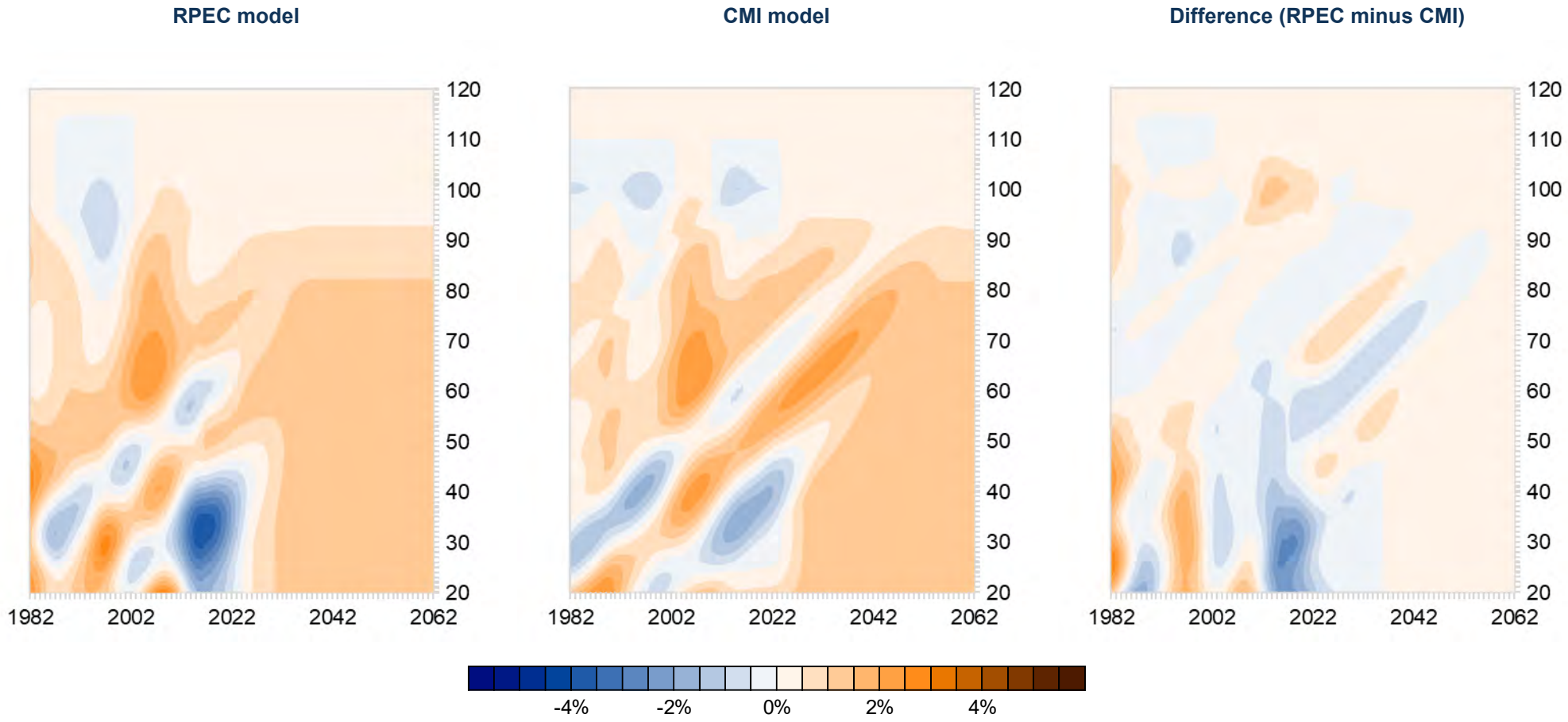


Chart A1C: Mortality improvements – England & Wales data, males

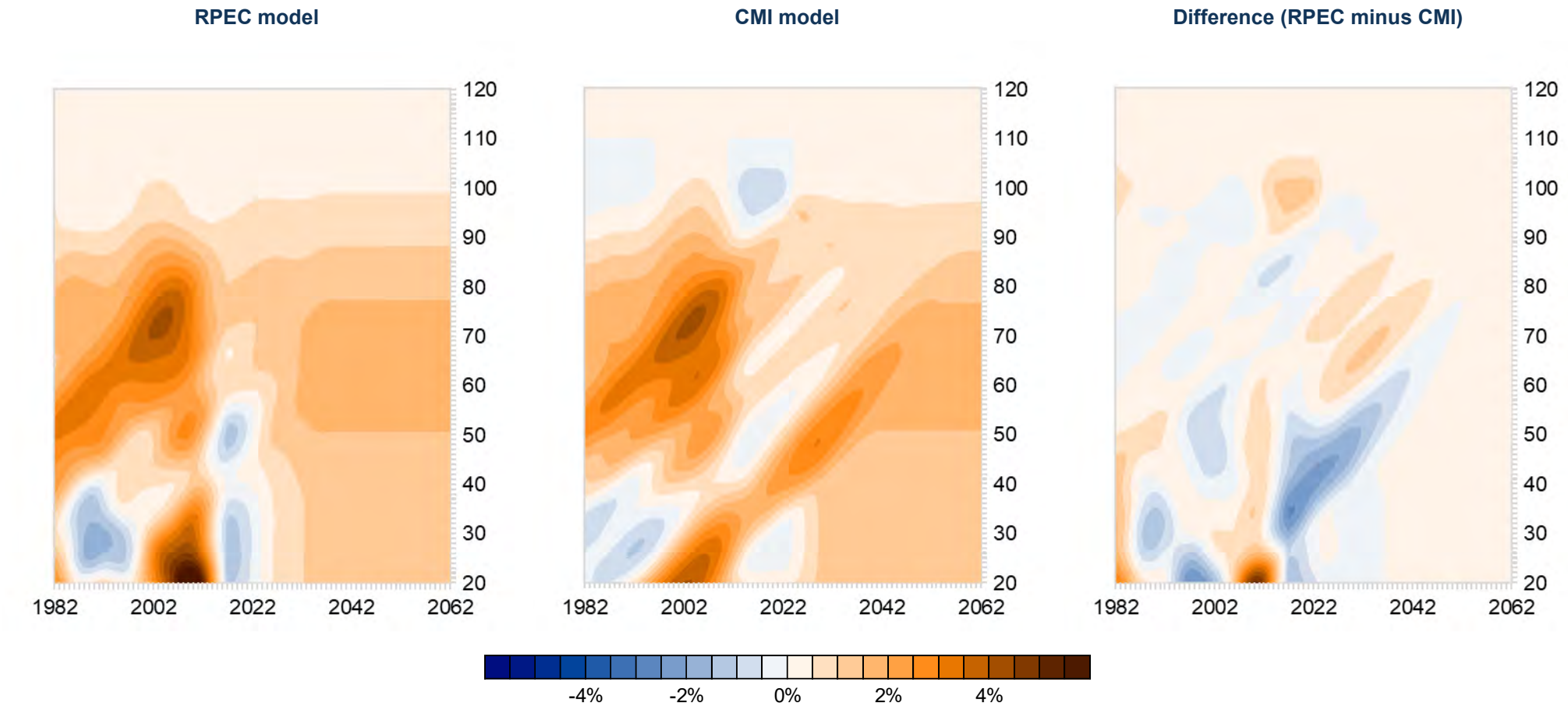
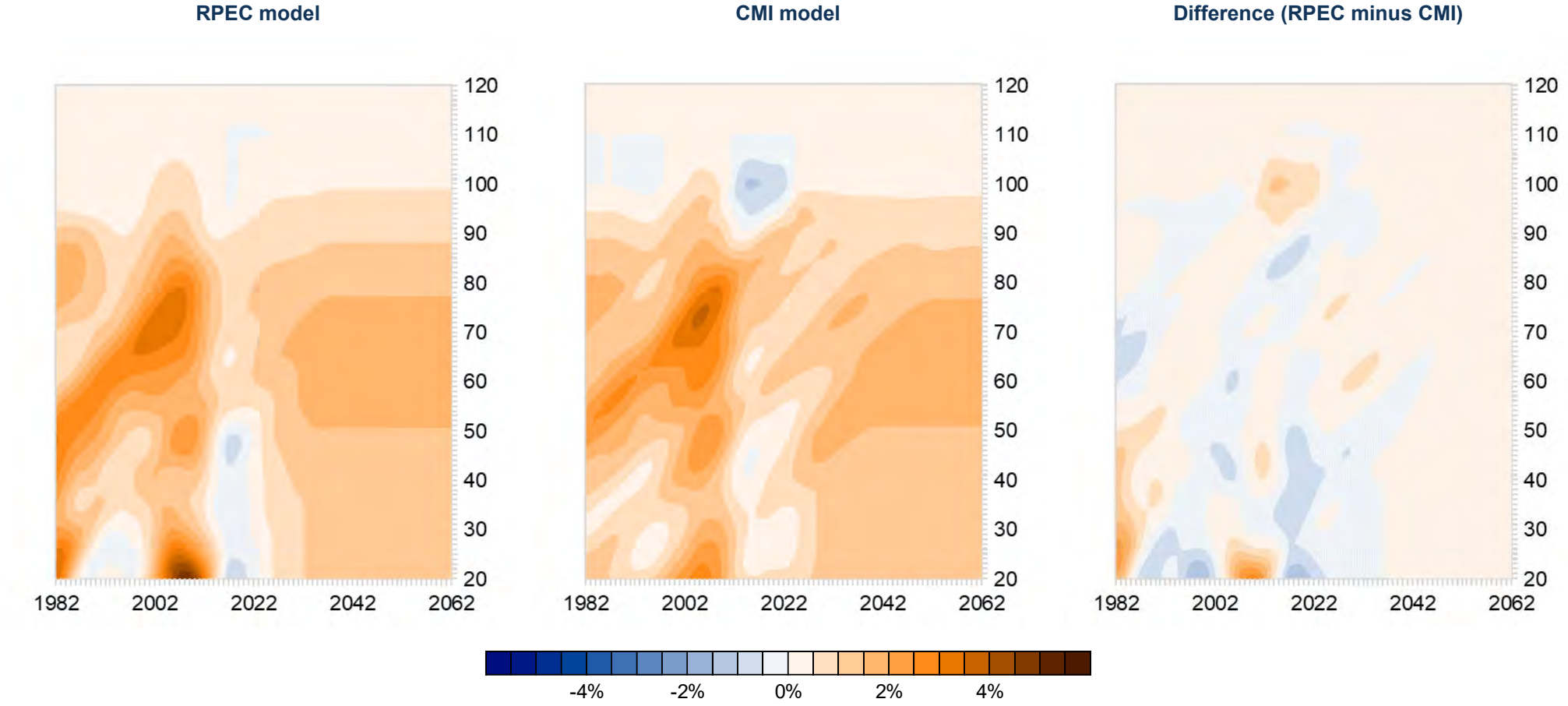


Chart A1D: Mortality improvements – England & Wales data, females



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