Continuous
Mortality Investigation
Institute and Faculty of Actuaries

The CMI Model and High Age Mortality

Presentation to the Highlights of Life Conference 2016

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Chair, CMI Mortality Projections Committee

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14 and 28 March 2017

CMI

CMI

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Mission

To produce high-quality impartial analysis, standard tables and models of mortality and morbidity for long-term insurance products and pension scheme liabilities on behalf of subscribers and, in doing so, to further actuarial understanding.

Our vision is to be regarded across the world as setting the benchmark for the quality, depth and breadth of analysis of industry-wide insurance company and pension scheme experience studies

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High Age Mortality

Steve Bale
Chair, CMI High Age Mortality Working Party

Phase 1: Initial findings

- Working Paper 85 released October 2015
- Key areas of analysis:
  - Summary of recent research
  - Functional forms for closing mortality rate tables
  - Modelled impacts of late reporting and age mis-statement
  - Closed cohort mortality
- https://www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation/cmi-working-papers/mortality-projections/cmi-wp-85

Phase 2: Continued analysis

Focus today:

- Does mortality decelerate at high ages?
- Principles for closing off mortality tables
- Population exposure modelling

Also in development:

- Analysing high quality annuitant portfolio data for analysis

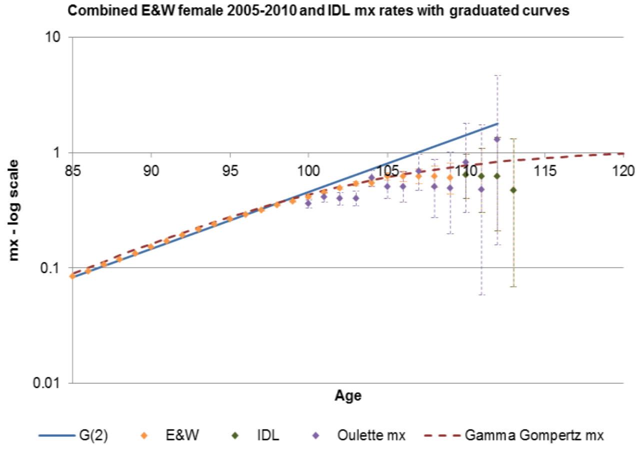
- Work in progress, provisional findings presented

Does mortality decelerate at high ages?

Recent studies

Column title	Gavrilov & Gavrilova (2015)	Ouellette and Bourbeau (2014)	Rau et al (2016)
Data	International Database on Longevity 668 supercentenarians across 15 countries 1980-2007	Canadian church parish registers 2,198 French-Canadian Catholics born in Quebec between 1870 and 1896, dying between 1970 and 2009	HMD Data from seven large countries (France, West Germany, Italy, Japan, Spain, UK, USA) over 1980 - 2010
Age range focus	110-115	100-115	80-109
Conclusion	Gompertz good fit	Observe deceleration	Deceleration models fit μ_x plateau 0.8 for females and 1.2 for males
Features	Concerns with incomplete data Pre 1885 cohorts excluded No context from younger ages	Relatively clean data - match birth dates with baptismal certificate Low number of deaths No context from younger ages	Test model fit: Gompertz vs Gompertz Makeham (plus makehum variant)

Implications for mortality at the oldest old

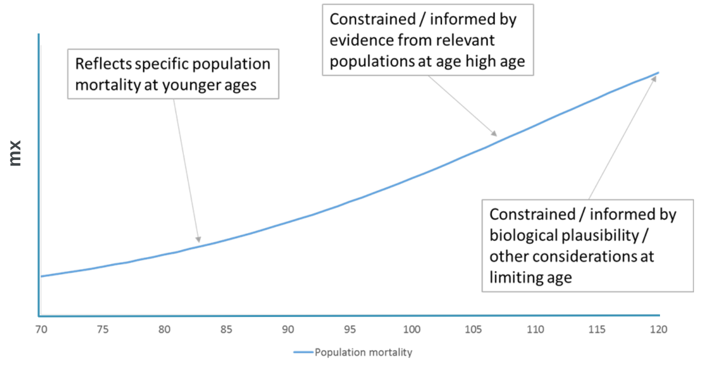


Implied m_x = 1 at age 120

Analysis supports a mortality curve with deceleration at highest ages

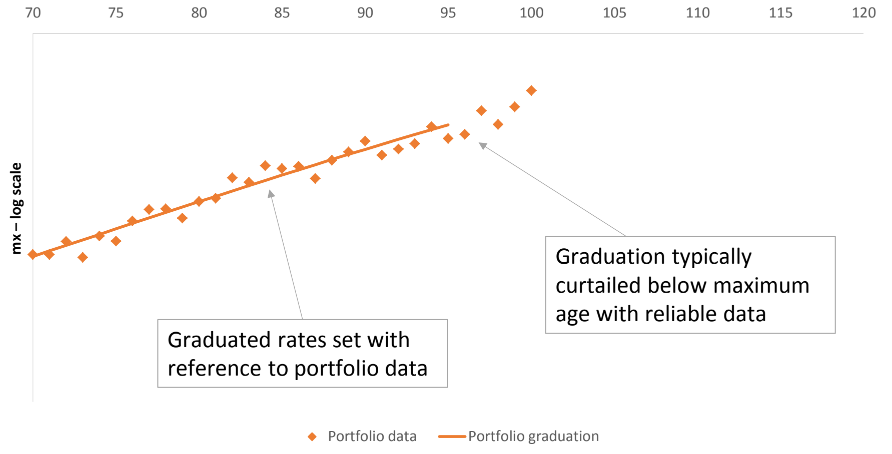
Closing mortality rate tables

Closing mortality tables: Desirable features

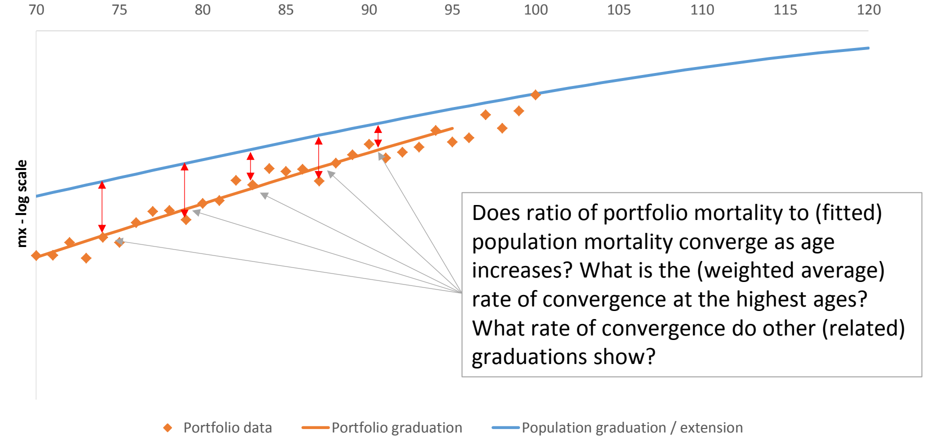


- Plausibility
- Data compatibility
- Cohort features
- Robustness of fit
- Uncertainty assessment
- Trend allowance
- Smooth progression

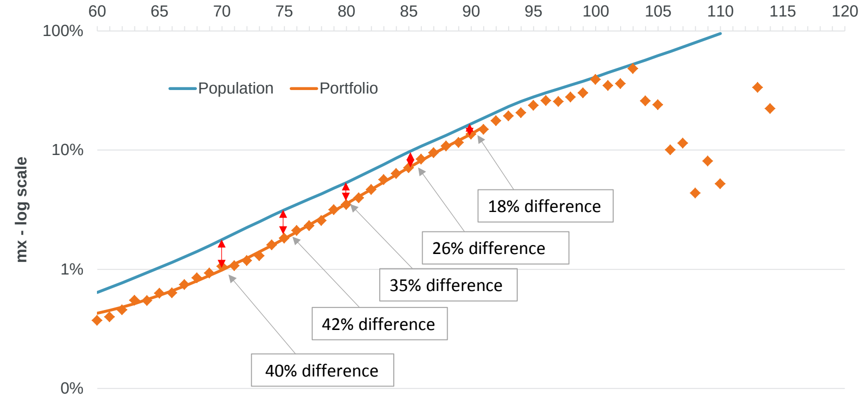
Proposed framework: 1- Graduate portfolio data



Proposed framework: 2- Analyse convergence

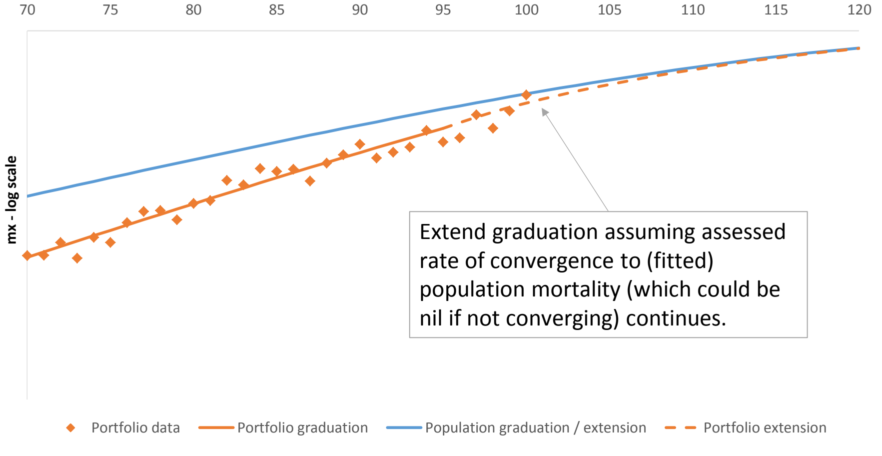


Example: Analyse convergence

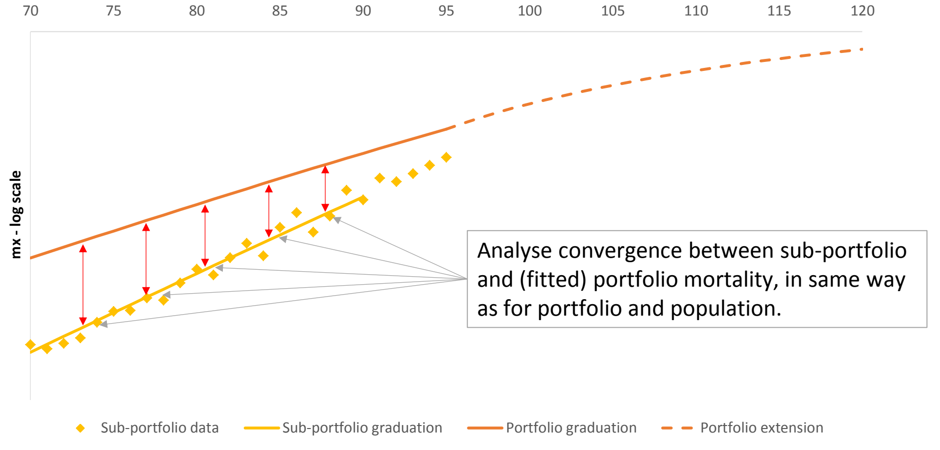


- Evidence of convergence, % difference reducing by around x0.75 each 5 years

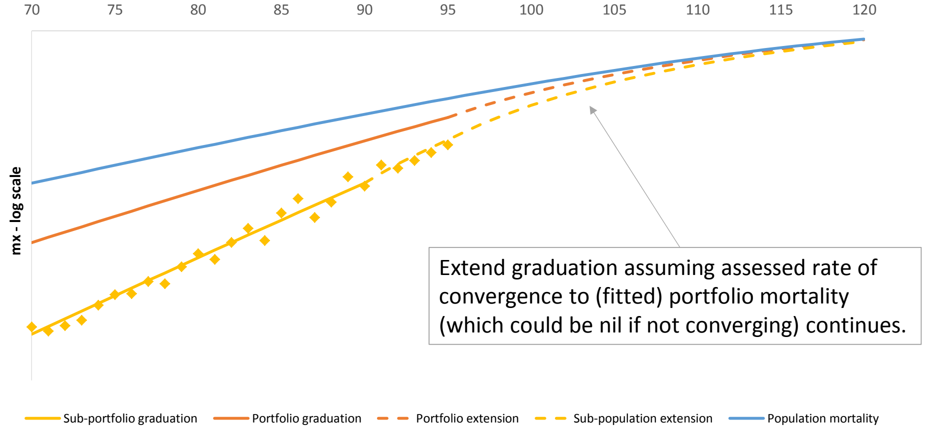
Proposed framework: 3- Extend graduation



Sub-portfolios: 1- Analyse convergence



Sub-portfolios: 2- Extend graduation



Population exposure modelling

Accuracy of official high age population estimates in England & Wales – ONS (2016)

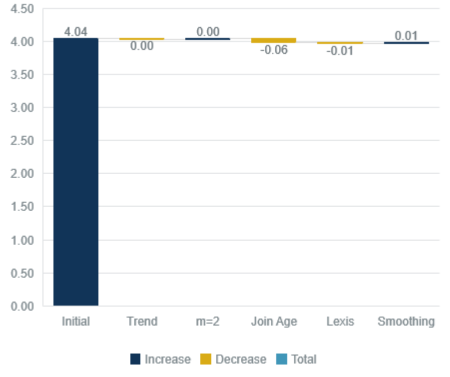
Theme	Analysis	Findings	Implication
Death reporting	Validation of birth date information for lives 105-109 for 2000-2014 (excludes c10% born outside UK) Analysis of high age death counts by occurrence vs registration	96% birth date match plus 1-2% close match Number and distribution of deaths very similar	Reported age at death assumed to be accurate Choice of definition has minimal impact on mid-year population estimates
Impact of migration	Analysis of intra UK and international migration	Low intra UK migration (~0.03% of 90+ population) Low international migration (~0.07% of 90+ population)	Migration has a negligible impact on mid-year population estimates at high ages
Kannisto-Thatcher modelling	Fit of KT estimates to 2002-2014 registers from Sweden and Finland Testing against synthetic populations under alternative mortality scenarios	KT estimates fit well up to age 94, but deviate thereafter Correction factor close to 1 when mortality doesn't vary, but deviates under mortality trend scenarios	Consider impact of mortality trend on KT methodology
Comparison against administrative data	Comparison of KT estimates against NHS Patient Register, DWP and Higher Education databases	Administrative dataset 2011 population estimates close to unconstrained KT estimates	Target minimal population estimate constraint

Variants considered

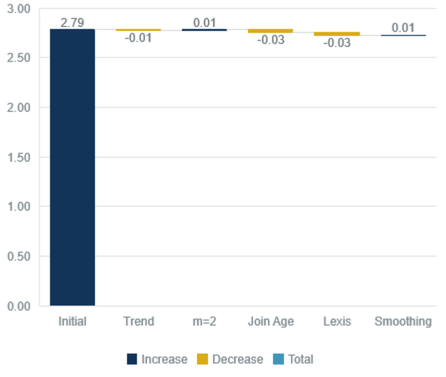
Variant	Description and Motivation
Mortality trend	Allow explicitly for the average recent trend in survivor ratios to continue into the next year in order to better capture local pattern of mortality improvements.
Parameters k and m	ONS implementation of KT model currently uses (k,m) = (5,5) where m = number of birth cohorts; and k = number of past ages in each cohort over which deaths are summed. Decreasing these parameters means averaging over less data in the survivor ratio.
Join age	Test the impact of reducing join age below 90 to seek more robust outcome. If join age is N this means that the K-T method is extended down to age N (and constrained to the N+ population total).
Lexis adjustments to death data	More sophisticated approach to determine 'age at 1 January' death counts from the 'age at death' input data. May lead to greater accuracy and improve internal smoothness of population estimates.
Exposure adjustments	Adjust modelled population exposures for convexity and birth distribution (or apply pragmatic smoothing to similar effect). Aims to correct anomalies identified by Cairns et al arising from distributional effects.

Life expectancy impact – ONS male data

Period life expectancy from 2011-2015 mortality rates (age 90, males, ONS data)

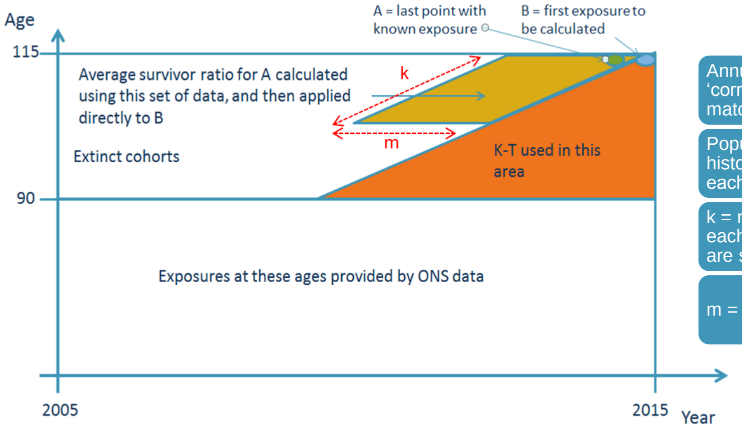


Period life expectancy from 2011-2015 mortality rates (age 95, males, ONS data)



Note: Impact on period life expectancy below age 85 is less than 0.5%

Current Kannisto-Thatcher methodology

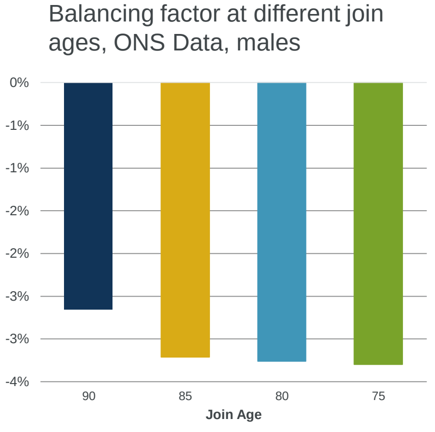


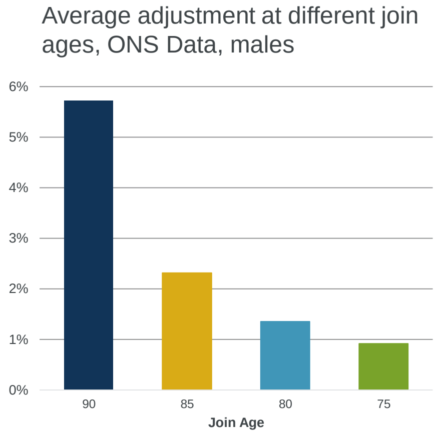
- Annual survivor ratio 'correction factor' applied to match final year 90+ population
- Population estimates for historical years scaled to match each year's 90+ population
- k = number of past ages in each cohort over which deaths are summed
- m = number of birth cohorts

Join age

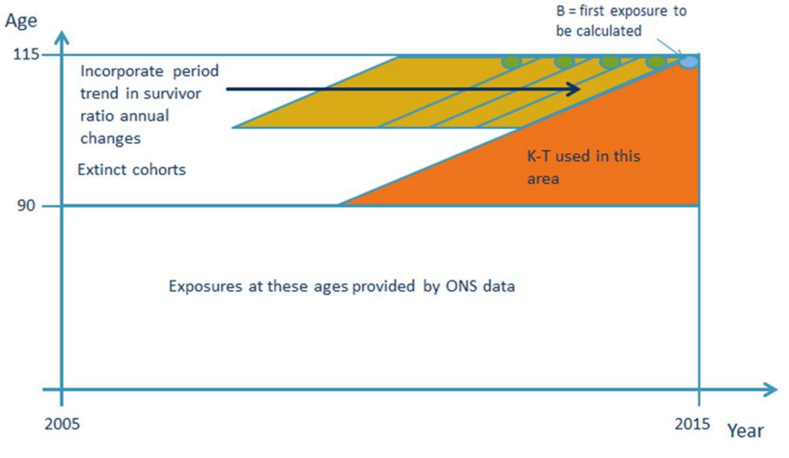
- KT method applied by ONS for ages 90+, with constraint applied to match official 90+ population total
- Unadjusted published figures adopted below this age
- Concerns with current join age of 90:
  - Several data consistency/accuracy issues noted in ONS December 2016 paper
  - Discontinuities at age 89/90 boundary also noted by ONS
  - Working Paper 85 indicated 90+ population overstated
- Expect reliability of census-based figures to improve at younger ages
  - Population counts larger and less susceptible to recording issues
- Tested range of lower join ages against current ONS value of 90

Join age – Results (ONS male data)



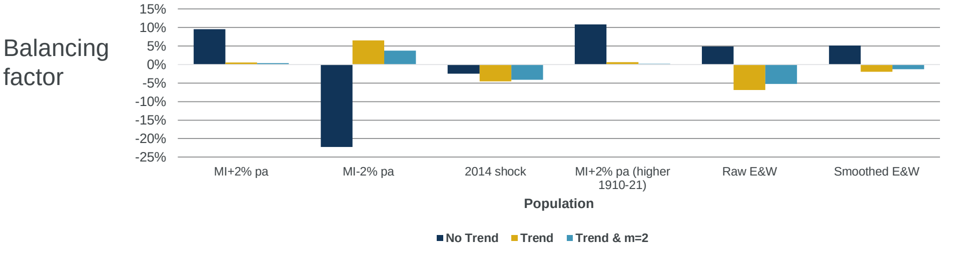


Current Kannisto-Thatcher methodology



Trend variants – Results (synthetic data)

- Testing on synthetic populations – population figures known to be "correct"
- Simple improvement / complex features / real experience regimes
- Overall improvement in balancing factors and average adjustments



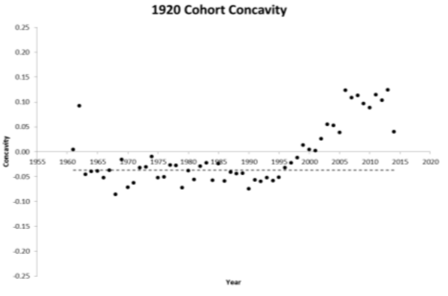
Lexis adjustments

- K-T method requires death counts based on 'age at 1 January' from 'age at death' input data
- Current ONS Lexis triangle approach assumes 50/50 split of deaths into ages
- Proposed refinements:
  - Rundown of exposure within a calendar year
  - Unequal cohort sizes
  - Mortality differential between adjacent ages
  - Uneven patterns of birth distribution
  - Seasonality of deaths
- Produces improved balancing factors and average adjustments

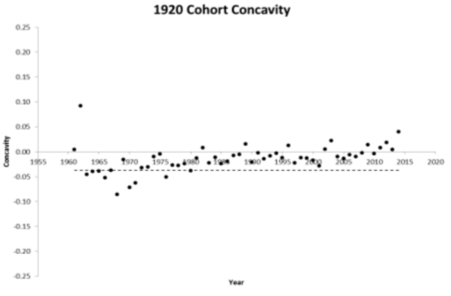
Exposure adjustments

- Simplified method to smooth abnormal population exposures
- Measure log-linearity of death rates
  $C(x,t) = \log m_{x,t} - \frac{1}{2}\left(\log m_{x-1,t} + \log m_{x+1,t}\right)$

Without CMI exposure smoothing



With CMI exposure smoothing



Next Steps

- Working Paper scheduled for release in Q217 covering
  - Methodology for closing mortality rate tables
  - Population exposure modelling
- Large pension annuity dataset
  - Data collection underway for 2017 analysis

Questions

Comments

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The CMI Model

Tim Gordon
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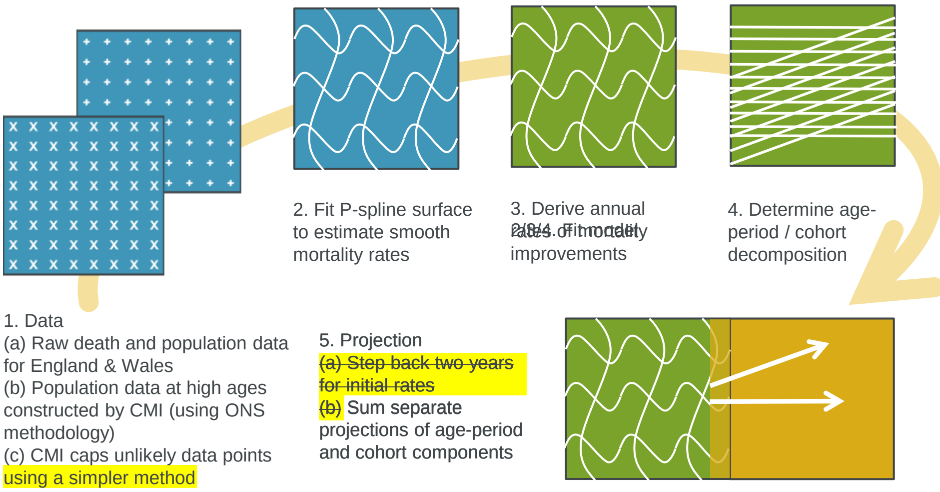
What's changed – big picture



Model log m_{xt}

- Definition of the model: $\log m_{xt} = \alpha_x + \beta_x(t - \bar{t}) + \kappa_t + \gamma_{t-x}$
- Mortality improvement (reduction in $\log m_{xt}$) is:

$$MI_{xt} = \boxed{-\beta_x} + \boxed{(\kappa_{t-1} - \kappa_t)} + \boxed{(\gamma_{t-x-1} - \gamma_{t-x})}$$

Age Period Cohort

- Fit by maximising log likelihood (or −½ deviance) *less* smoothness penalty:

$$\boxed{\sum_{xt}(D_{xt}\log m_{xt} - n_{xt}m_{xt})} \quad \text{Log likelihood}$$

$$\boxed{-\frac{1}{2}10^{S_\alpha}\sum_x(\Delta^3\alpha_x)^2 - \frac{1}{2}10^{S_\beta}\sum_x(\Delta^3\beta_x)^2 - \frac{1}{2}10^{S_\gamma}\sum_{b=t-x}(\Delta^3\gamma_b)^2 - \frac{1}{2}10^{S_\kappa}\sum_t(\Delta^2\kappa_t)^2}$$

Smoothness prior

where n_{xt} is exposure and D_{xt} is deaths

- *Plus 'identifiability' – sometimes seen as a detail, but this is material*

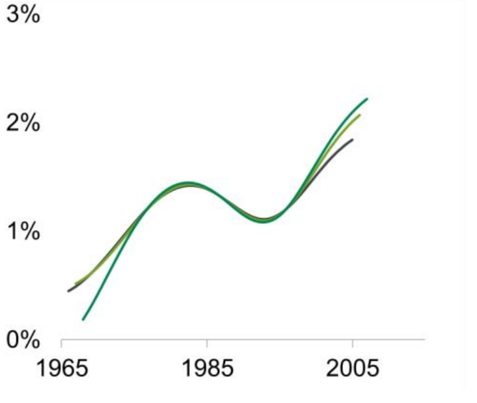
Projection – features for discussion

1. Direction of travel
2. High age shape of long-term rate (LTR)

Apparent direction of travel

Chart shows period components of mortality improvements from the (old) p-spline model fitted to male data for various 41-year periods

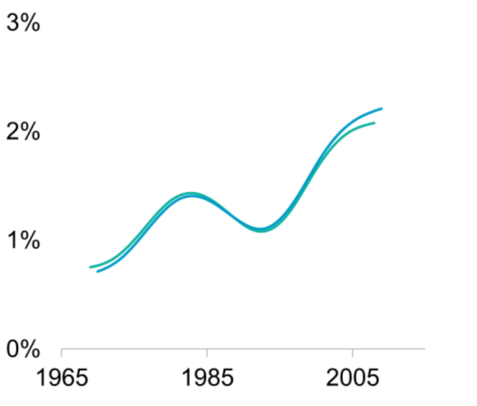
Periods ending in 2005, 2006, 2007



Apparent direction of travel

Chart shows period components of mortality improvements from the (old) p-spline model fitted to male data for various 41-year periods

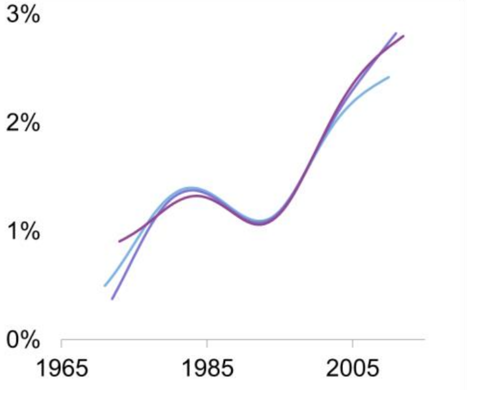
Periods ending in 2008, 2009



Apparent direction of travel

Chart shows period components of mortality improvements from the (old) p-spline model fitted to male data for various 41-year periods

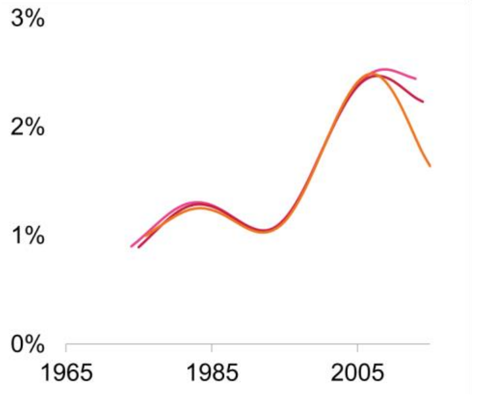
Periods ending in 2010, 2011, 2012



Apparent direction of travel

Chart shows period components of mortality improvements from the (old) p-spline model fitted to male data for various 41-year periods

Periods ending in 2013, 2014, 2015



Apparent direction of travel

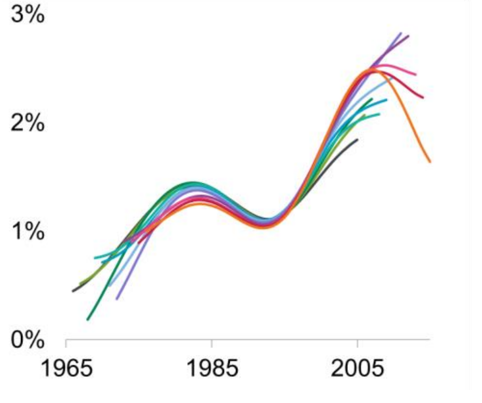
Lesson:

Apparent direction of travel from period component is uncertain

CMI proposed approach

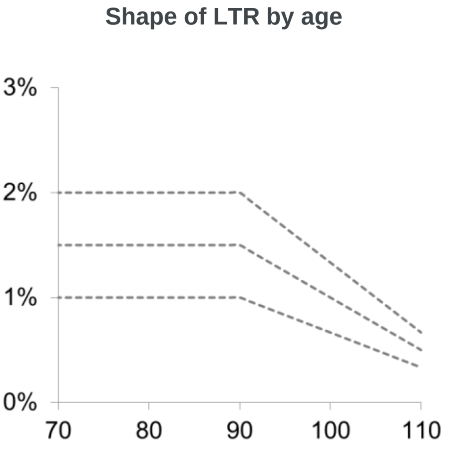
- Core assumption to remain as nil allowance for direction of travel
- Give users option to specify direction of travel
- Model to output direction of travel

Periods ending in 2005 to 2015



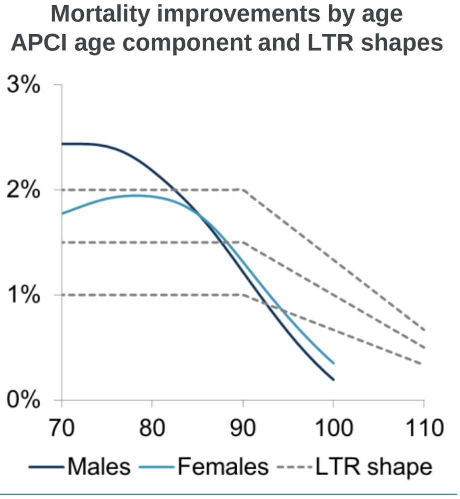
Current shape of long-term rate (LTR)

- Under the current Core assumption, the LTR applies up to age 90, and tapers to zero at 120



Current shape of long-term rate (LTR)

- Under the current Core assumption, the LTR applies up to age 90, and tapers to zero at 120
- This implies a sharp rise in improvements for centenarians in future, which is out of line with past experience



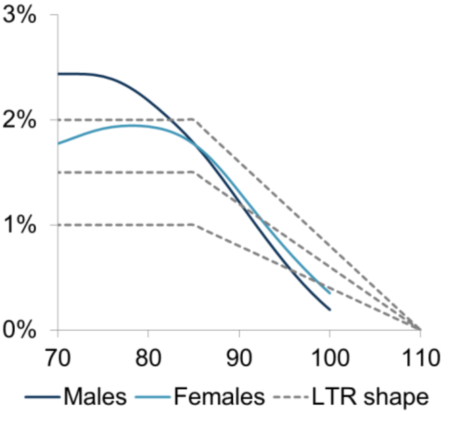
Proposed shape of long-term rate (LTR)

- We propose that the LTR applies up to age **85**, and tapers to zero at age **110**
- This implies a more modest rise in improvements for centenarians

Note

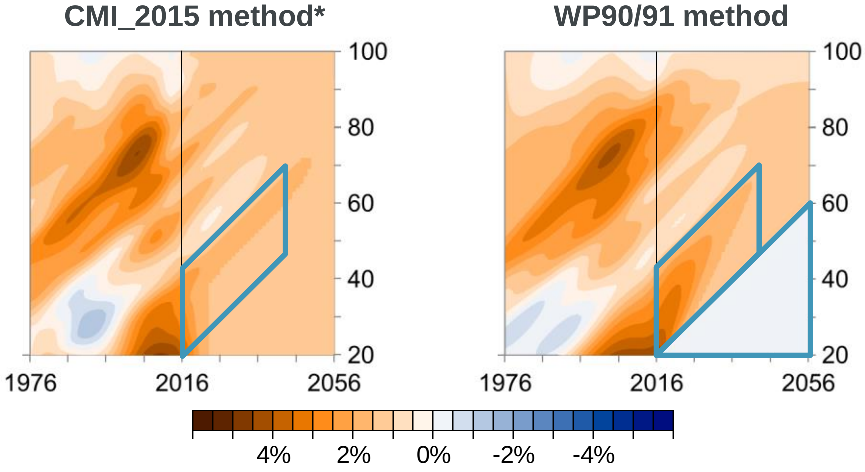
- **The objective is best estimate**
- **This still allows for higher improvements at later ages**

Mortality improvements by age
APCI age component and LTR shapes



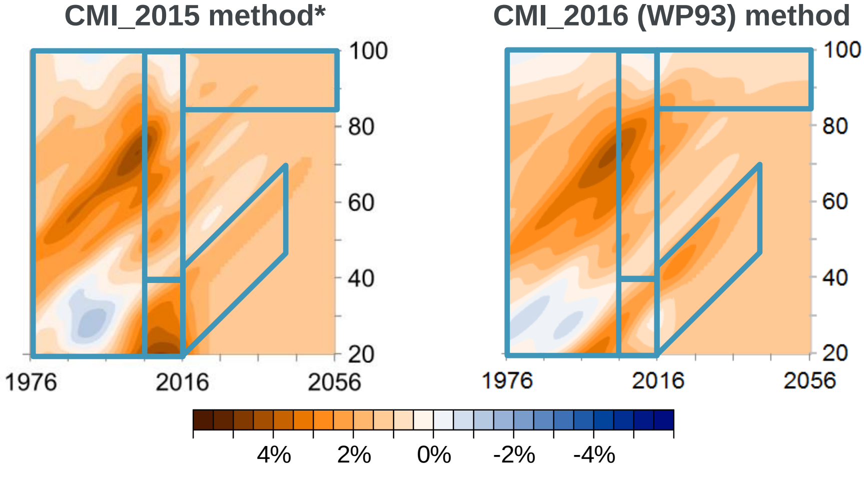
Projection – impact

Male improvements (using data to end 2015)



* Same method as CMI_2015, but based on actual data to end 2015

Male improvements (using data to end 2015)



* Same method as CMI_2015, but based on actual data to end 2015

CMI_2016 impact on life expectancies

Sex	Method	Age 35	Age 45	Age 55	Age 65	Age 75	Age 85	Age 95
Male	CMI_2013	−2.02%	−2.34%	−2.87%	−2.35%	−2.15%	−4.32%	−10.10%
	CMI_2014	−2.25%	−2.52%	−2.72%	−2.54%	−2.33%	−4.38%	−8.43%
	CMI_2015	−1.73%	−1.86%	−1.88%	−1.31%	−0.49%	−2.46%	−6.84%
Female	CMI_2013	−1.98%	−2.53%	−3.62%	−4.06%	−4.81%	−9.03%	−14.43%
	CMI_2014	−2.98%	−3.12%	−3.19%	−3.35%	−3.39%	−5.76%	−11.52%
	CMI_2015	−2.40%	−2.41%	−2.27%	−2.00%	−1.47%	−3.78%	−9.71%

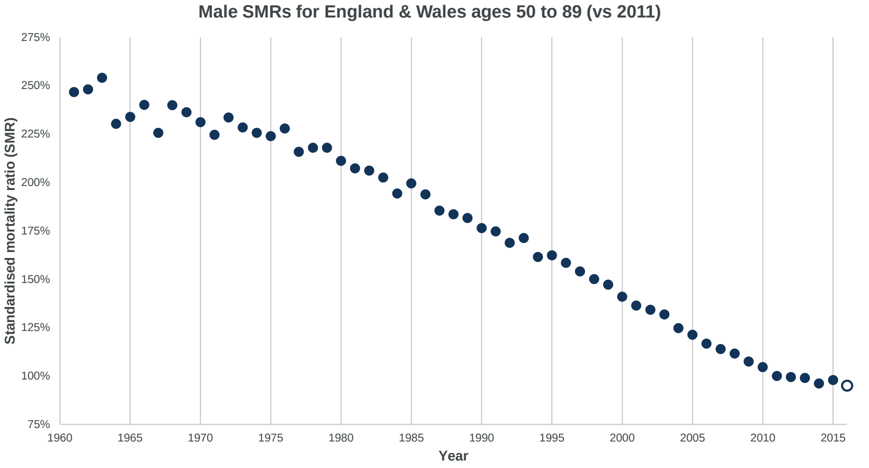
Notes
- Life expectancies are as at 1 January 2017.
- All projections are Core model with a long-term rate of 1.5% p.a.
- Base mortality is S1PxA for CMI_2013 and earlier and S2PxA for CMI_2014 and later.
- Actual PV impact may differ because of e.g. non-zero net discount rate and contingent second life benefits

Key issues in application

1. Blip vs trend?

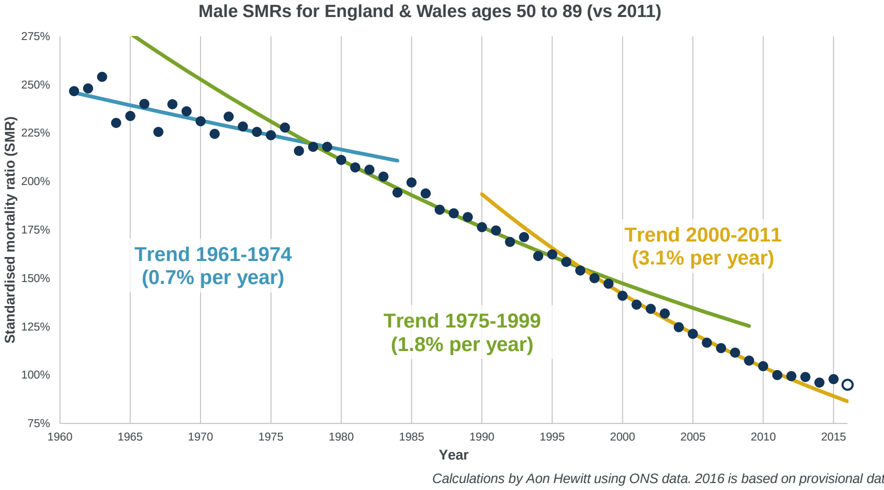
2. Appropriateness for liabilities?

Male standardised mortality ratio (SMR)



Calculations by Aon Hewitt using ONS data. 2016 is based on provisional data

Male standardised mortality ratio (SMR)



Calculations by Aon Hewitt using ONS data. 2016 is based on provisional data

E&W vs SAPS observed improvements

Sex	Year	E&W	SAPS (Lives)	SAPS (Amounts)	Difference (Lives)	Difference (Amounts)
Male	2012	−0.9% (±0.7%)	−0.2% (±1.9%)	+1.4% (±3.9%)	+0.7% (±2.0%)	+2.3% (±4.0%)
	2013	+0.5% (±0.7%)	+2.0% (±2.1%)	+3.5% (±4.2%)	+1.5% (±2.2%)	+3.0% (±4.2%)
	2014	+3.7% (±0.7%)	+4.8% (±2.1%)	+3.3% (±4.6%)	+1.1% (±2.2%)	−0.4% (±4.6%)
	2015	−3.7% (±0.7%)	−2.0% (±4.2%)	−6.8% (±7.9%)	+1.7% (±4.3%)	−3.1% (±8.0%)
	Average	**−0.1% (±0.4%)**	**+1.2% (±1.4%)**	**+0.4% (±2.7%)**	**+1.2% (±1.4%)**	**+0.5% (±2.7%)**
Female	2012	−2.5% (±0.6%)	−1.2% (±1.9%)	−1.2% (±5.3%)	+1.2% (±2.0%)	+1.2% (±5.3%)
	2013	+0.2% (±0.6%)	+3.0% (±2.2%)	+2.8% (±5.2%)	+2.8% (±2.3%)	+2.6% (±5.3%)
	2014	+4.1% (±0.6%)	+5.6% (±2.2%)	+7.8% (±5.5%)	+1.6% (±2.3%)	+3.7% (±5.5%)
	2015	−5.7% (±0.6%)	−0.3% (±4.6%)	+0.8% (±9.2%)	+5.4% (±4.7%)	+6.5% (±9.3%)
	Average	**−0.9% (±0.3%)**	**+1.8% (±1.5%)**	**+2.6% (±3.3%)**	**+2.8% (±1.5%)**	**+3.5% (±3.3%)**

All figures are provisional.

What’s next?

CMI_2016 publication

- ETA is week ending 24 March 2017
- www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation
- Subscriber content

CMI/SIAS meeting at Staple Inn, London on 11 April 2017

- Discuss/debate with (non-CMI) panel
  - mortality improvements over the next decade
  - applicability to liabilities
- sias.org.uk/events/upcoming-events/?ev=301

Questions **Comments**

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