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

- Wholly owned by Institute and Faculty of Actuaries
- Independent executive and management

Funded by subscription but free for academics and non-commercial research

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
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
  – Modeled impacts of late reporting and age mis-statement
  – Closed cohort mortality

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

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>International Database on Longevity 668 supercentenarians across 15 countries 1980-2007</td>
<td>Canadian church parish registers 2,198 French-Canadian Catholics born in Quebec between 1870 and 1896, dying between 1970 and 2009</td>
<td>HMD Data from seven large countries (France, West Germany, Italy, Japan, Spain, UK, USA) over 1980 - 2010</td>
</tr>
<tr>
<td>Age range focus</td>
<td>110-115</td>
<td>100-115</td>
<td>80-109</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Gompertz good fit</td>
<td>Observe deceleration</td>
<td>Deceleration models fit $\mu$ plateau 0.8 for females and 1.2 for males</td>
</tr>
<tr>
<td>Features</td>
<td>Concerns with incomplete data Pre 1885 cohorts excluded No context from younger ages</td>
<td>Relatively clean data - match birth dates with baptismal certificate Low number of deaths</td>
<td>Test model fit: Gompertz vs Gompertz Makeham (plus makehum variant)</td>
</tr>
</tbody>
</table>

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

Graduated rates set with reference to portfolio data

Graduation typically curtailed below maximum age with reliable data

Proposed framework: 2- Analyse convergence

Does ratio of portfolio mortality to (fitted) population mortality converge as age increases? What is the (weighted average) rate of convergence at the highest ages? What rate of convergence do other (related) graduations show?
Example: Analyse convergence

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

Proposed framework: 3- Extend graduation

Extend graduation assuming assessed rate of convergence to (fitted) population mortality (which could be nil if not converging) continues.
Sub-Portfolios: 1- Analyse convergence

Analyse convergence between sub-portfolio and (fitted) portfolio mortality, in same way as for portfolio and population.

Sub-Portfolios: 2- Extend graduation

Extend graduation assuming assessed rate of convergence to (fitted) portfolio mortality (which could be nil if not converging) continues.
# Population exposure modelling

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

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

<table>
<thead>
<tr>
<th>Variant</th>
<th>Description and Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality trend</td>
<td>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.</td>
</tr>
<tr>
<td>Parameters k and m</td>
<td>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.</td>
</tr>
<tr>
<td>Join age</td>
<td>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).</td>
</tr>
<tr>
<td>Lexis adjustments to death data</td>
<td>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.</td>
</tr>
<tr>
<td>Exposure adjustments</td>
<td>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.</td>
</tr>
</tbody>
</table>

Life expectancy impact – ONS male data

Note: Impact on period life expectancy below age 85 is less than 0.5%
**Current Kannisto-Thatcher methodology**

![Diagram showing the Current Kannisto-Thatcher methodology](image)

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**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)

Balancing factor at different join ages, ONS Data, males

Average adjustment at different join ages, ONS Data, males

Current Kannisto-Thatcher methodology

Exposures at these ages provided by ONS data
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
The CMI Model

Tim Gordon
Chair, CMI Mortality Projections Committee
What’s changed – big picture

1. Data
   (a) Raw death and population data for England & Wales
   (b) Population data at high ages constructed by CMI using ONS methodology
   (c) CMI caps unlikely data points using a simpler method

2. Fit P-spline surface to estimate smooth mortality rates
3. Derive annual mortality improvements
4. Determine age-period / cohort decomposition
5. Projection
   (a) Step back two years for initial rates
   (b) Sum separate projections of age-period and cohort components

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:
  $$MI_{xt} = -\beta_x + (\kappa_{t-1} - \kappa_t) + (\gamma_{t-x-1} - \gamma_{t-x})$$
- Fit by maximising log likelihood (or $-\frac{1}{2}$ deviance) less smoothness penalty:
  $$\sum_{xt} (D_{xt} \log m_{xt} - n_{xt} m_{xt})$$
  $$-\frac{1}{2} 10^{Sx} \sum_x (\Delta^3 \alpha_x)^2 - \frac{1}{2} 10^{Sb} \sum_x (\Delta^3 \beta_x)^2 - \frac{1}{2} 10^{Sz}\sum_{b=1}^z (\Delta^3 \gamma_b)^2 - \frac{1}{2} 10^{Sk} \sum_t (\Delta^2 \kappa_t)^2$$

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.
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.
**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**

- 1965
- 1985
- 2005

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**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**

- 1965
- 1985
- 2005
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

Mortality improvements by age

APCI age component and LTR shapes

- 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.

Projection – impact
Male improvements (using data to end 2015)

CMI_2015 method*

WP90/91 method

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

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Male improvements (using data to end 2015)

CMI_2015 method*

CMI_2016 (WP93) method

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

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## CMI_2016 impact on life expectancies

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

### 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.

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### Key issues in application

1. Blip vs trend?
2. Appropriateness for liabilities?
Male standardised mortality ratio (SMR)

Trend 1961-1974 (0.7% per year)
Trend 1975-1999 (1.8% per year)
Trend 2000-2011 (3.1% per year)

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

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E&W vs SAPS observed improvements

<table>
<thead>
<tr>
<th>Sex</th>
<th>Year</th>
<th>E&amp;W</th>
<th>SAPS (Lives)</th>
<th>SAPS (Amounts)</th>
<th>Difference (Lives)</th>
<th>Difference (Amounts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2012</td>
<td>-0.9% (±0.7%)</td>
<td>-0.2% (±1.9%)</td>
<td>+1.4% (±3.9%)</td>
<td>+0.7% (±2.0%)</td>
<td>+2.3% (±4.0%)</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>+0.5% (±0.7%)</td>
<td>+2.0% (±2.1%)</td>
<td>+3.5% (±4.2%)</td>
<td>+1.5% (±2.2%)</td>
<td>+3.0% (±4.2%)</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>+3.7% (±0.7%)</td>
<td>+4.8% (±2.1%)</td>
<td>+3.3% (±4.6%)</td>
<td>+1.1% (±2.2%)</td>
<td>-0.4% (±4.6%)</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>-3.7% (±0.7%)</td>
<td>-2.0% (±4.2%)</td>
<td>-6.8% (±7.9%)</td>
<td>+1.7% (±4.3%)</td>
<td>-3.1% (±8.0%)</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>-0.1% (±0.4%)</td>
<td>+1.2% (±1.4%)</td>
<td>+0.4% (±2.7%)</td>
<td>+1.2% (±1.4%)</td>
<td>+0.5% (±2.7%)</td>
</tr>
<tr>
<td>Female</td>
<td>2012</td>
<td>-2.5% (±0.6%)</td>
<td>-1.2% (±1.9%)</td>
<td>-1.2% (±5.3%)</td>
<td>+1.2% (±2.0%)</td>
<td>+1.2% (±5.3%)</td>
</tr>
<tr>
<td></td>
<td>2013</td>
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<td>+2.8% (±2.3%)</td>
<td>+2.6% (±5.3%)</td>
</tr>
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<td></td>
<td>2014</td>
<td>+4.1% (±0.6%)</td>
<td>+5.6% (±2.2%)</td>
<td>+7.8% (±5.5%)</td>
<td>+1.6% (±2.3%)</td>
<td>+3.7% (±5.5%)</td>
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<td>-5.7% (±0.6%)</td>
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<td>+2.8% (±1.5%)</td>
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</tr>
</tbody>
</table>

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
Colour palette for PowerPoint presentations

- **Dark blue**: R17 G52 B88
- **Gold**: R217 G171 B22
- **Mid blue**: R64 G150 B184

Secondary colour palette

- **Light grey**: R220 G221 B217
- **Pea green**: R121 G163 B42
- **Forest green**: R0 G132 B82
- **Bottle green**: R17 G179 B162
- **Cyan**: R0 G156 B200
- **Light blue**: R124 G179 B225
- **Violet**: R128 G118 B207
- **Purple**: R143 G70 B147
- **Fuscia**: R233 G69 B140
- **Red**: R200 G30 B69
- **Orange**: R238 G116 29

Dark grey: R63 G69 B72