Beyond the limits: Modelling and forecasting longevity

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We’re living longer than ever...

Jeanne Calment, died at 122 (1997)
Longest-lived person

Christina Cock, died at 114 (2002)
Longest-lived Australian

Jiroemon Kimura, died at 116 (2013)
Longest-lived man

Florence Finch, died at 113 (2007)
Longest-lived New Zealander
... and populations are ageing

Predictions of 3.7 million centenarians worldwide by 2050

Source: UN Dept of Economic and Social Affairs, *World Population Prospects: 2015 Revision*. 

The combined impact is huge

“If everyone lives three years longer than now expected - the average underestimation of longevity in the past – the present discounted value of the additional living expenses amounts to between 25 and 50% of GDP. On a global scale, that increase amounts to tens of trillions of U.S. dollars, boosting the already recognized costs of ageing substantially.” (IMF 2012)

“This Longevity Tsunami] resulting from life expectancies rising much faster than commonly understood, has serious social policy implications, especially in economic, retirement incomes, health and welfare policy” (Australian Actuaries Institute 2012)

Outline

• How has mortality been changing?
• How might mortality change in future?
• How can longevity risk be estimated and managed?
how has mortality been changing?
Life expectancy at birth

Life expectancy at birth
NZ

Life expectancy at birth

AUSTRALIA

Life expectancy at birth

JAPAN

Life expectancy at birth

USA


FACULTY OF BUSINESS AND ECONOMICS | DEPARTMENT OF APPLIED FINANCE AND ACTUARIAL STUDIES
Life expectancy at birth

NZ

Average 2.0 years per decade (2.9 since 1979)
88% of NZ males survive to 65

Average 1.9 years per decade (2.0 since 1979)
92% of NZ females survive to 65

Average 2.3 years per decade (2.9 since 1979)

88% of Australian males survive to 65

93% of Australian females survive to 65

Sex differential in life expectancy

Sex differential in life expectancy
NZ, AUSTRALIA

Increasingly older ages are driving longevity change

<table>
<thead>
<tr>
<th></th>
<th>Percentage of change in Australian life expectancy attributable to</th>
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<tbody>
<tr>
<td></td>
<td>ages 65 and over</td>
<td>ages 85 and over</td>
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<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>1921-1971</td>
<td>1</td>
<td>15</td>
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<tr>
<td>1971-1979</td>
<td>36</td>
<td>50</td>
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<td>1979-2011</td>
<td>48</td>
<td>59</td>
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Causes driving longevity change

AUSTRALIAN MALE LIFE EXPECTANCY GAIN 1979-2011 = 9.5 YEARS

Causes driving longevity change

AUSTRALIAN FEMALE LIFE EXPECTANCY GAIN 1979-2011 = 6.9 YEARS

The average doesn’t apply to all

- Indigenous mortality, e.g.
  - in Australia the life expectancy gap is ≈ 10 years (AIHW 2016). Potential undercounting of Indigenous deaths is an issue (Madden et al 2012).

- Socio-economic status, e.g.
  - life expectancy gap between the richest 10% and poorest 10% exceeds 4 years in the UK (Buck and Maguire 2015)
  - and between the richest 1% and poorest 1% is estimated at 10 years for women and almost 15 years for men in the US (Chetty et al 2016)

- Smokers and non-smokers
  - a life expectancy gap of about 10 years (Doll et al 2005)

- ... and other factors

how might mortality change in the future?
New advances ...

• Genomics
• Synthetic biology
• Tissue engineering, 3-D organ printing
• Stem cells
• Lab-on-a-chip
• Medical imaging
• e-Health
• Tailored medicine
• Big Data

big dollars…

“Fixing the ‘problem’ of ageing is the mission of Silicon Valley, where billions is pouring into biotech firms working to ‘hack the code’ of life”

theguardian Jan 11 2015

AncestryDNA And Google’s Calico Team Up To Study Genetic Longevity
Jul 21, 2015

The Obsession With 'Curing' Aging Is Now Big Business

FORTUNE Magazine, March 7 2016
Aubrey de Grey, an English biomedical gerontologist, has stated that he believes that the first human to live 1,000 years is probably already alive and may even be aged between 50 and 60.

"If you ask me today, is it possible to live to be 500? The answer is yes" Bill Maris, founder and first CEO of Google Ventures (GV)
“Fiery debate” between experts

Olshansky et al. (1990): “it seems highly unlikely that life expectancy at birth will exceed the age of 85”

Vaupel et al. (2009): “most babies born since 2000 in countries with long-lived residents will celebrate their 100th birthdays if present ... growth continues”

Past forecasts got it wrong

“experts have repeatedly asserted that life expectancy is approaching a ceiling: these experts have repeatedly been proven wrong.”

“[forecast limits between] 1928 [and] 1990 have been broken, on average 5 years after publication”.

Forecasting approaches

Booth and Tickle (2008) categorise mortality forecasting methods as falling into one or more of three broad approaches:

- expectation
- extrapolation
- explanation

The Lee-Carter (1992) method ushered in a period of very active interest in extrapolative forecasting methods:

\[ \ln m_{xt} = a_x + b_x k_t + \varepsilon_t \]

where \( m_{xt} \) is the central mortality rate at age \( x \) in year \( t \), \( a_x \) and \( b_x \) are age-related parameters, \( k_t \) is an index of overall mortality in year \( t \), and \( \varepsilon_t \) is the error.

Illustrative NZ projection ages 50+*

LC PARAMETERS: $a_x$ (left), $b_x$ (middle), $k_t$ (right)

* This is a projection assuming 1985-2013 trends continue, **not** a forecast/prediction. Source: Authors own calculations.
## Illustrative NZ projection*

### Period and cohort age at death

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<td></td>
<td>50</td>
<td>85.1</td>
<td>87.5</td>
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<td></td>
<td>65</td>
<td>86.6</td>
<td>88.5</td>
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<tr>
<td></td>
<td>75</td>
<td>88.5</td>
<td>89.9</td>
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<td>85</td>
<td>91.9</td>
<td>92.5</td>
<td>92.0</td>
<td>92.4</td>
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<td>90</td>
<td>94.6</td>
<td>94.9</td>
<td>94.6</td>
<td>94.7</td>
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<td>50</td>
<td>82.2</td>
<td>85.5</td>
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<td>65</td>
<td>84.1</td>
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<td>90</td>
<td>94.0</td>
<td>94.4</td>
<td>94.1</td>
<td>94.2</td>
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## Illustrative NZ projection*

Cohort survival probabilities

<table>
<thead>
<tr>
<th>Age limits of survival</th>
<th>Cohort: age in 2014</th>
<th>85</th>
<th>75</th>
<th>65</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Female</strong></td>
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</tr>
<tr>
<td>From current age to 75</td>
<td></td>
<td>0.90</td>
<td></td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>From current age to 85</td>
<td></td>
<td>0.73</td>
<td>0.70</td>
<td>0.74</td>
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<tr>
<td>From current age to 90</td>
<td></td>
<td>0.62</td>
<td>0.47</td>
<td>0.48</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>Male</strong></td>
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<td></td>
</tr>
<tr>
<td>From current age to 75</td>
<td></td>
<td>0.87</td>
<td></td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>From current age to 85</td>
<td></td>
<td>0.62</td>
<td>0.60</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>From current age to 90</td>
<td></td>
<td>0.53</td>
<td>0.36</td>
<td>0.37</td>
<td>0.45</td>
</tr>
</tbody>
</table>

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New developments

NEW/IMPROVED LEE-CARTER-TYPE METHODS

• Optimising the choice of fitting period
• Adding additional terms to better capture trends
• Allowing for the effect of cohort year of birth, which is significant in some countries
• Improving the estimation basis, e.g. assuming deaths are Poisson and using MLE
• Imposing smoothness on (or using a parametric form for) the age-parameters
• Different time series options for forecasting $k_t$
• Incorporating explanatory factors, e.g. GDP
New developments

JOINT MODELS / METHODS

• Recent interest in joint mortality models / methods, e.g. for insured and population lives, males and females, regions in a country

• An advantage is that ‘coherence’ is imposed on forecasts

• Can forecast a small population by reference to a larger population

• Joint methods explicitly model the differential, which is also useful for applications such as estimating longevity basis risk

• Examples include:
  ➢ common factor model of Li and Lee (2005), Li (2013)
  ➢ complex Lee-Carter method of de Jong, Tickle and Xu (2016)
  ➢ product-ratio method of Hyndman, Booth and Yasmeen (2013)

how can longevity risk be estimated and managed?
Managing longevity risk

- Longevity risk is the risk that pension funds and annuity portfolios may pay out more than expected.
- Systematic longevity risk cannot be diversified by pooling.
- Options for managing longevity risk:
  - *traditional reinsurance* allows insurers to pass longevity risk to reinsurers, but reinsurers often have limited appetite.
  - *natural hedging* exploits the opposite movements in the values of annuities and life insurances, but it is only viable for certain large insurers.
  - *capital market solutions* such as insurance securitisation, longevity-linked / mortality-linked securities / derivatives (which may also be attractive to investors seeking a new uncorrelated market sector).
- LLMA was established in 2010 to promote the development of a liquid ‘life market’.
Managing longevity basis risk

A perceived major obstacle to widespread use of index-based hedges is longevity basis risk, i.e. the mismatch between:

- mortality in the reference population on which the security is based
- mortality in the population being hedged

→ Longevity Basis Risk Project funded by LLMA and UK Institute and Faculty of Actuaries (IFoA) to develop a ‘readily-applicable methodology for quantifying basis risk from index-based longevity hedges’:

- Phase 1 (reported Dec 2014), conducted by Cass Business School and Hyams Robertson LLP in the UK. Reviewed mortality changes in population subgroups, reviewed two-population mortality models, and proposed a methodology

- Phase 2 (July 2016-April 2017), led by Macquarie University (Jackie Li, Leonie Tickle), with University of Waterloo Canada (Johnny Li), ANU (Chong It Tan) and Mercer Australia (Richard Boyfield, David Knox, Anne Wilson). Will determine and apply metrics for longevity risk and hedging effectiveness.
Longevity basis risk project
Phase 1

Extensions of the
Lee-Carter (non-
parametric age term)

Common factor
$log \mu_{it} = \alpha_i + \beta_t \kappa_t$
Carter and Lee (1992), Li and Lee (2005), Li and Hardy (2011)

Stratified Lee-Carter
$log \mu_{it} = \alpha_i + \alpha^1 + \beta_t \kappa_t$
Butt and Haberman (2009), Debon et al (2011)

Piggyback model
$log \mu_{it} = \alpha_i + \beta_t \kappa_t + a' + b' t$
Curne (2009)

Relative P-Splines
Bustat and Curne (2015)

Multipopulation GLM
Karnkosulos and Haberman (2013), Ahmadi and Li (2014)

Other models

Plat + Lee-Carter

SAINT model

Co-integration
Galée and Lisset (2013)

Lee-Carter + VAR/ECM
$log \mu_{it} = \alpha_i + \beta_t \kappa_t$
Zhou et al (2014)

Cointegrated Lee-Carter
$log \mu_{it} = \alpha_i + \beta_t \kappa_t$

Bayesian two population
$log \mu_{it} = \alpha_i + \kappa_t + \gamma_i \kappa_t$
Li and Lee (2005), Li and Hardy (2011), Hyndman et al (2013)

Augmented-Common Factor
$log \mu_{it} = \alpha_i + \beta_t \kappa_t + a' + b' t$
Vilegas and Haberman (2014)

Gravity model
$log \mu_{it} = \alpha_i + \kappa_t + \gamma_i \kappa_t$
Deo et al (2011)

Two population M7
$logit \ q_{it} = k^{(1)} + (x - \bar{x}) k^{(1)} + (x - \bar{x})^2 k^{(2)} + \gamma_i \kappa_t$
Li et al (2014)

Two population M6
$logit \ q_{it} = k^{(1)} + (x - \bar{x}) k^{(2)} + \gamma_i \kappa_t$
Li et al (2014)

Relative Lee-Carter + Cohort
$log \mu_{it} = \alpha_i + \beta_t \kappa_t + \gamma_i \kappa_t + \phi t$
Vilegas and Haberman (2014)

Figure 5.1: Universe of multi-population models

Longevity basis risk project – Phase 2 early results

• Early results on interim data suggest a longevity risk reduction of:
  ➢ around 55-60% for a large annuity portfolio
  ➢ around 25-45% for smaller portfolios

(based on CMI pensioner data and EW reference population, ages 60-89, for 1980-).

• Risk reduction is calculated as: 1 – risk (hedged) / risk (unhedged), and a variety of risk measures are being trialled.

• Final results due April 2017.
Thank you