Session 122 PD - Living to 100: Mortality Modeling

Moderator:
R. Dale Hall, FSA, CERA, MAAA

Presenters:
Andrew Cairns
Stephen C. Goss, ASA, MAAA
Living to 100: Mortality Modelling

Modelling, Measurement and Management of Longevity Risk

Andrew J.G. Cairns

Heriot-Watt University, Edinburgh

Director, Actuarial Research Centre, IFoA

Society of Actuaries Annual Meeting, Boston, October 2017
The Actuarial Research Centre (ARC) is the Institute and Faculty of Actuaries’ (IFoA) network of actuarial researchers around the world. The ARC seeks to deliver cutting-edge research programmes that address some of the significant, global challenges in actuarial science, through a partnership of the actuarial profession, the academic community and practitioners. The 'Modelling, Measurement and Management of Longevity and Morbidity Risk' research programme is being funded by the ARC, the SoA and the CIA.

www.actuaries.org.uk/arc
ARC research program themes

- Improved models for mortality
- Key drivers of mortality
- Management of longevity risk
- Morbidity risk modelling for critical illness insurance
Outline

- Part 1: All cause mortality modelling
  - Introduction to stochastic mortality models
  - Why?
  - Example applications
- Part 2: Key drivers
  - Education level
  - Cause of death
  - Health inequalities
Part 1: All Cause Mortality Modelling
US Historical Death Rates

US Males Aged 20

Year
1940 1960 1980 2000 2020 2040

Death Rate (log scale)
0.0010 0.0025

US Males Aged 40

Year
1940 1960 1980 2000 2020 2040

Death Rate (log scale)
0.002 0.004 0.008

US Males Aged 60

Year
1940 1960 1980 2000 2020 2040

Death Rate (log scale)
0.010 0.020 0.040

US Males Aged 80

Year
1940 1960 1980 2000 2020 2040

Death Rate (log scale)
0.005 0.010 0.020
Graphical Diagnostics

- Mortality is falling
- Different improvement rates at different ages
- Different improvement rates over different periods
- Improvements are random
  - Short term fluctuations
  - Long term trends

All *stylised facts*

- Other countries:
  - Some similarities
  - Some different patterns
Why do we need stochastic mortality models?

Data ⇒ future mortality is uncertain

- Good risk management
- Setting risk reserves
- Regulatory capital requirements (e.g. Solvency II)
- Life insurance contracts with embedded options
- Pricing and hedging mortality-linked securities
Modelling

Aims:
- to develop the best models for forecasting future uncertain mortality;
  - general desirable criteria
  - complexity of model $\leftrightarrow$ complexity of problem;
  - longevity versus brevity risk;
- measurement of risk;
- valuation of future risky cashflows.
Aims:
- active management of mortality and longevity risk;
  - internal (e.g. product design; natural hedging)
  - over-the-counter deals (OTC)
  - securitisation
- part of overall package of good risk management.
Stochastic Mortality Models

Two basic examples:
- Lee-Carter Model (1992)
- Cairns-Blake-Dowd Model (CBD) (2006)

Stochastic model:
- Central forecast
- Uncertainty around the central forecast

Good ERM ⇒ Use a combination of stochastic projections \textit{plus} some deterministic scenarios or stress tests
The Lee-Carter Model

Death rate:

\[ m(t, x) = \frac{D(t, x)}{E(t, x)} = \frac{\text{deaths}(t, x)}{\text{average population}(t, x)} \]

Year \( t \); Age \( x \).

LC: \( \log m(t, x) = \alpha(x) + \beta(x)\kappa(t) \)

- \( \alpha(x) = \) base table; age effect
- \( \beta(x) = \) age effect
- \( \kappa(t) = \) period effect
The Lee-Carter Model

$$\log m(t, x) = \alpha(x) + \beta(x) \kappa(t)$$

- Estimate $\alpha(x), \beta(x), \kappa(t)$ from historical data
- “Traditional” model:
  - Fit a random walk model to historical $\kappa(t)$
  - Simulate future scenarios for $\kappa(t)$
  - Calculate future mortality scenarios given $\kappa(t)$
- Alternative models for $\kappa(t)$ can be used
The CBD Model

$q(t, x) = \text{Probability of death in year } t \text{ given initially exact age } x.$

$q(t, x) \approx 1 - \exp[-m(t, x)]$

$\text{logit } q(t, x) = \log \left( \frac{q}{1 - q} \right) = \kappa_1(t) + \kappa_2(t)(x - \bar{x})$

- $\kappa_1(t) = \text{period effect; affects level}$
- $\kappa_2(t) = \text{period effect; affects slope}$
- $\bar{x} = \text{mean age}$
- Captures big picture at higher ages
Comparison

- LC $\Rightarrow$ all mortality rates dependent on a single $\kappa(t)$
  $\Rightarrow$ rates at all ages perfectly correlated
- CBD $\Rightarrow$ simpler age effects ($1$ and $x - \bar{x}$)
  but two period effects
  $\Rightarrow$ richer correlation structure
- CBD linearity $\Rightarrow$
  not good for younger ages
- Historical data:
  Different improvements at different ages over different time periods
  $\Rightarrow$ need more than one period effect
Applications: Scenario Generation

Example: the Lee Carter Model

- (Applied to a synthetic dataset)
- \( \log m(t, x) = \alpha(x) + \beta(x)\kappa(t) \)
- Choose a time series model for \( \kappa(t) \)
- Calibrate the time series parameters using data up to the current time (time 0)
- Generate \( j = 1, \ldots, N \) stochastic scenarios of \( \kappa(t) \)

\[ \kappa_1(t), \ldots, \kappa_N(t) \]
Applications: Scenario Generation

- Generate $N$ scenarios for the future $m(t, x)$
  $m_j(t, x)$ for $j = 1, \ldots, N$, $t = 0, 1, 2, \ldots,$
  $x = x_0, \ldots, x_1$

- Generate $N$ scenarios for the survivor index,
  $S_j(t, x)$

- Calculate financial functions

  \[ + \] variations for some financial applications.


Applications: Scenario Generation, $\kappa(t)$

$\kappa(t)$: Generate scenario 1

$\kappa(t)$: Generate scenario 1

Historical Simulated Period Effect: One Scenario
Applications: Scenario Generation, $\kappa(t)$
Applications: Scenario Generation, $\kappa(t)$

Period Effect: Fan Chart

-30 -20 -10 0 10 20 30
-1.0 -0.5 0.0 0.5

Historical Simulated

Period Effect, $\kappa(t)$
Applications: Scenario Generation, Future $m(t, x)$

Death Rates, Age 65: One Scenario

Death Rate (log scale)

Time

Andrew J.G. Cairns
Modelling Longevity Risk
Applications: Scenario Generation, Future $m(t, x)$

Death Rates, Age 65: Multiple Scenarios

Death Rate (log scale)

Time

Death Rates, Age 65: Multiple Scenarios

Andrew J.G. Cairns
Modelling Longevity Risk
Applications: Scenario Generation, Future $m(t, x)$

Death Rates, Age 65: Fan Chart

Time

Death Rate  (log scale)

0 5 10 15 20 25 30

0.006 0.008 0.012 0.016

Death Rates, Age 65: Fan Chart

Andrew J.G. Cairns

Modelling Longevity Risk
Annuity Pricing Requires Cohort Rates

Extract Cohort Death Rates, $m(t, x+t-1)$

Time
Age

0 5 10 15 20 25 30
65 70 75 80 85 90

Annuity valuation ⇒ follow cohorts

$m(0, x) \rightarrow m(1, x + 1) \rightarrow m(2, x + 2) \ldots$
Annuity Pricing Requires Cohort Rates

Annuity valuation ⇒ follow cohorts

\[ m(0, x) \rightarrow m(1, x + 1) \rightarrow m(2, x + 2) \ldots \]
Annuity Pricing Requires Cohort Rates

Cohort Death Rates From Age 65: Multiple Scenarios

Death Rate (log scale)

Cohort Age
Annuity Pricing Requires Cohort Rates

Cohort Death Rates From Age 65: Fan Chart

Death Rate (log scale)

Cohort Age

Andrew J.G. Cairns
Modelling Longevity Risk
Cohort death rates $\rightarrow$ cohort survivorship

**Cohort Survivor Index**

**Survivorship From Age 65:**

*One Scenario*

![Graph showing survivorship from age 65 with a log scale for the survivor index and cohort age.](image-url)
Survivorship From Age 65: Multiple Scenarios

Cohort Survivor Index

Survivor Index (log scale)

Cohort Age

Andrew J.G. Cairns
Modelling Longevity Risk
Cohort survivorship → ex post cohort life expectancy
Equivalent to a continuous annuity with 0% interest
Annuity Reserving

- Annuity of 1 per annum payable annually in arrears
- Interest rate: 2%
A Real Example: US Male Period Life Expectancy

Extract Period Death Rates, \( m(t,x+t-1) \)
A Real Example: US Male Period Life Expectancy

US Male Period Life Expectancy From Age 65
(Stochastic Model: CBD–X–K3–G)

Mortality improvement rate ≈ 1.7% p.a. at ages 65-85.
How to incorporate Expert Judgement?

- E.g. CBD model ⇒
  - $m^j_{CBD}(t, x)$ scenarios
  - $\bar{m}_{CBD}(t, x)$ central forecast
- Expert judgement ⇒
  - $\hat{m}(t, x)$ (central) forecast

- Blending ⇒ stochastic scenario $j$ becomes

$$
m^j(t, x) = \frac{m^j_{CBD}(t, x)}{\bar{m}_{CBD}(t, x)} \times \hat{m}(t, x)
$$

- Fully stochastic ⇒ full risk assessment
How to incorporate Expert Judgement?

- A variation on this is required by UK life insurance regulators

⇒ Don’t ignore stochastic models simply because you disagree with the central forecast!

- Additionally: new approaches to bring the two together are being developed
Part 2: Key Drivers
Drill into the Detail of US Data

- Level of educational attainment ⇒ predictor
- Individual cause of death ⇒ outcome

- Beware of grade inflation
- Help to understand trends in national data and subpopulations (e.g. white collar pension plan)
Data Sources

- Total Exposures: Human Mortality Database (smoothed to mitigate anomalies)
- CDC deaths: cause of death + education (+ ethnic group)
- CPS survey data: education proportions

Research ⇒

- smart synthesis of three data sources
- improved, less noisy, exposures by education level
Purpose of looking at cause of death data

- What are the key drivers of all-cause mortality?
- How are the key drivers changing over time?
- Which causes of death have high levels of inequality:
  - by education
  - other predictors
- Insight into mortality underpinning life insurance and pensions
- Insight into potential future mortality improvements

Beware of

- changes in ICD classification of deaths (e.g. 1999)
- drift in how deaths are classified
- changing education levels (grade inflation)
## Education Levels

<table>
<thead>
<tr>
<th>Education</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low education</td>
<td>Primary and lower secondary education</td>
</tr>
<tr>
<td>Medium education</td>
<td>Upper secondary education</td>
</tr>
<tr>
<td>High education</td>
<td>Tertiary education</td>
</tr>
</tbody>
</table>
# Cause of Death Groupings

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Infectious diseases incl. tuberculosis</td>
<td>2</td>
<td>Cancer: mouth, gullet, stomach</td>
</tr>
<tr>
<td>3</td>
<td>Cancer: gut, rectum</td>
<td>4</td>
<td>Cancer: lung, larynx, ..</td>
</tr>
<tr>
<td>5</td>
<td>Cancer: breast</td>
<td>6</td>
<td>Cancer: uterus, cervix</td>
</tr>
<tr>
<td>7</td>
<td>Cancer: prostate, testicular</td>
<td>8</td>
<td>Cancer: bones, skin</td>
</tr>
<tr>
<td>9</td>
<td>Cancer: lymphatic, blood-forming tissue</td>
<td>10</td>
<td>Benign tumours</td>
</tr>
<tr>
<td>11</td>
<td>Diseases: blood</td>
<td>12</td>
<td>Diabetes</td>
</tr>
<tr>
<td>13</td>
<td>Mental illness</td>
<td>14</td>
<td>Meningitis + nervous system (Alzh.)</td>
</tr>
<tr>
<td>15</td>
<td>Blood pressure + rheumatic fever</td>
<td>16</td>
<td>Ischaemic heart diseases</td>
</tr>
<tr>
<td>17</td>
<td>Other heart diseases</td>
<td>18</td>
<td>Diseases: cerebrovascular</td>
</tr>
<tr>
<td>19</td>
<td>Diseases: circulatory</td>
<td>20</td>
<td>Diseases: lungs, breathing</td>
</tr>
<tr>
<td>21</td>
<td>Diseases: digestive</td>
<td>22</td>
<td>Diseases: urine, kidney,...</td>
</tr>
<tr>
<td>23</td>
<td>Diseases: skin, bone, tissue</td>
<td>24</td>
<td>Senility without mental illness</td>
</tr>
<tr>
<td>25</td>
<td>Road/other accidents</td>
<td>26</td>
<td>Other causes</td>
</tr>
<tr>
<td>27</td>
<td>Alcohol → liver disease</td>
<td>28</td>
<td>Suicide</td>
</tr>
<tr>
<td>29</td>
<td>Accidental Poisonings</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
US Education Data

- Males and Females (2)
- Single ages 55-75 (21)
- Single years 1989-2015 (27)
- Causes of death (29)
- Low, medium & high education level (3)

Note: HMD’s *Human Cause of Death Database* ⇒ All ages (5’s), 1999-2015, No education
US Education Data: Growing Inequality, Males

Male All Cause Death Rates by Education Group
For 1989 and 2015

Death Rate (log scale)

Age

Low Ed 1989
Low Ed 2002
Low Ed 2015
High Ed 1989
High Ed 2002
High Ed 2015
US Education Data: Growing Inequality, Females

Female All Cause Death Rates by Education Group
For 1989 and 2015

Death Rate (log scale)
Age

Low Ed 1989
Low Ed 2002
Low Ed 2015
High Ed 1989
High Ed 2002
High Ed 2015
Proportion of Males with Low Education

US Males 1989–2015 Ages 55–75:
Proportion of Population with Low Education

Year 1989–2015
Age
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75

30
40
50
60
70
80

Cohort diagonals ⇒ falling percentage
US Education Data: CoD Death Rates

Widening gap

Year 2000
Ischaemic heart diseases

Year 2015
Ischaemic heart diseases

CoD Death Rate

Low Edu
Medium
High

Age
US Education Data: CoD Death Rates

Year 2000
Cancer: lung, larynx, ..

Year 2015
Cancer: lung, larynx, ..

Widening gap
US Education Data: CoD Death Rates

Year 2000
Diabetes

Year 2015
Diabetes

Widening gap; Mixed improvements
US Education Data: CoD Death Rates

Year 2000
Meningitis + nervous system (Alzh.)

Year 2015
Meningitis + nervous system (Alzh.)

Widening gap; almost no improvements
Case & Deaton (2015) ⇒ Accidental poisoning
US Education Data: CoD Death Rates

Year 2000
Alcohol -> liver

Year 2015
Alcohol -> liver

Widening gap
US Education Data: CoD Death Rates

Year 2000
Cancer: prostate, testicular

Year 2015
Cancer: prostate, testicular

Denmark ⇒ almost NO gap by education;
Denmark ⇒ small gap by affluence; smaller than US by education
Some causes of death have no obvious link to lifestyle/affluence/education
e.g. Prostate Cancer

CancerUK: Prostate cancer is not clearly linked to any preventable risk factors.

But education level ⇒ inequalities

Possible explanations (a very non-expert view)

- **onset** is not dependent on lifestyle/affluence/education
- **BUT** lower educated ⇒
  - ??? poorer health insurance coverage
  - ??? later diagnosis
  - ??? engage less well with treatment process
  - ??? lower quality housing/diet etc.
US Males: Low versus High Education

Do Low and High education groups have the same CoD rate?

- Four \times 5\text{-year age groups
- 29 causes of death
- Signs Test (count low edu. > high edu. mort.)
- \(29 \times 4 = 116\) individual tests
- Reject equality hypothesis \textit{in all but one test}
- Accept \(H_0\) \((p = 0.08)\) for only one pairing: Meningitis + nervous system (Alzh.), 70-74
- Most \(p\)-values < \(10^{-6}\)
Summary

- Future work
  - Analysis of sub-national datasets
    - e.g. SoA Group and Individual Annuity data
    - e.g. individual pension plan data
  - Multiple population modelling

E: A.J.G.Cairns@hw.ac.uk  W: www.macs.hw.ac.uk/~andrewc
Thank You!

Questions?

E: A.J.G.Cairns@hw.ac.uk   W: www.macs.hw.ac.uk/~andrewc
Medicare kicks in after age 65
But no obvious impact on inequality gap
Although inequality gap naturally narrows with age
CoD Death Rates: Different Shapes & Patterns

Infectious diseases incl. tuberculosis

Meningitis + nervous system (Alzh.)

Ischaemic heart diseases

Diseases: circulatory

Diseases: lungs, breathing

Diseases: urine, kidney,...
CoD Death Rates: Different Shapes & Patterns

- Cancer: gut, rectum
- Cancer: lung, larynx, ...
- Cancer: prostate, testicular
- Cancer: bones, skin

Death Rate (log scale)

Andrew J.G. Cairns
Modelling Longevity Risk
Shapes: Conclusions

- Typically:
  - Non-cancerous diseases ⇒ approximately exponential growth
  - Neoplasms (cancers) ⇒ subexponential polynomial

- What does this reveal about different disease mechanisms?
Declining Mortality (Increasing Longevity): At What Rate?

Steve Goss, Chief Actuary
Social Security Administration
Session 122
Society of Actuaries Annual Meeting
October 17, 2017
Perspective: “Aging” Not Mainly from Mortality

Aging (change in age distribution) mainly due to drop in birth rates
Various Alternative Projection Approaches Using Data

- Extrapolating past trends:
  1) Age setback (*early method*)
  2) Mortality rate by age and sex (*Lee/Carter*)
  3) Life expectancy at birth (*Vaupel/Oeppen*)
  4) Mortality rate by trend all ages (*2011 Technical Panel, CBO 2013-5*)

- Or reflect changing conditions:
  5) Improvement by cohort (*UK CMI, SOA*)
  6) Mortality rate by age, sex, cause (*OCACT/TR, 2015 Technical Panel*)
2) Extrapolation by Age and Sex

- Example: Lee and Carter
- Fit the average trend of a selected period
- Future conditions must replicate the past—on average
- Age gradient never changes
- No deceleration in mortality decline
Mortality Decline Varies Over Time
Conditions: Antibiotics/economy 1936-54; Medicare/Medicaid 1968-82

Female Historical and Projected (2014 Trustees Report)
Annual Percent Reduction in U.S. Mortality Rates

Male Historical and Projected (2014 Trustees Report)
Annual Percent Reduction in U.S. Mortality Rates
3) Will Life Expectancy Rise Linearly?
Vaupel/Oeppen 2002; Best Nations

- Requires *accelerating* rate of decline in mortality rates if retain age gradient
- LE most affected by lowest ages—only so much gain possible
- Most disagree
  - Vallin/Meslé
4) Extrapolate All Ages the Same

- Ignores historical age gradient
- Result:
  - Substantial bias for population age distribution
- Thus, large bias for cost as % of payroll
  - Less mortality decline at young ages raises cost
  - More mortality decline at higher ages raises cost
Appropriate Data: by Age Critical

Age-gradient in past reduction is clear

Long-Term Historical Average Annual Rates of Reduction in Mortality 1929 to 2009

Recent Historical Average Annual Rates of Reduction in Mortality 1982 to 2009
5) Extrapolation by Cohort

- U.K. (& SOA-RPEC): “Phantoms never die” data issues
- Post-WW2 births: antibiotics young, statins later
- What does change up to age x say above age x?
  - Is cohort healthier at x if lower mortality up to x?
  - Or is cohort compromised by impaired survivors?
  - What does one cohort imply for the next cohort?
- Period effects from known changes in conditions are stronger—especially in the U.S.
6) Projection by Age, Sex, Cause

- SSA/OCACT/Trustees Reports (2015 Technical Panel)
- Requires selecting ultimate rates of decline
- Allows change in age gradient
- Results in deceleration in mortality decline

### Comparison of Historical, 2015 Trustees Report, and Ron Lee*

<table>
<thead>
<tr>
<th>Historical (Dec 2015 data)</th>
<th>AGE</th>
<th>Ron Lee</th>
<th>2015TR Intermediate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982-99</td>
<td>2.79</td>
<td>2.77</td>
<td>2.72</td>
</tr>
<tr>
<td>1999-2009</td>
<td>1.22</td>
<td>2.74</td>
<td>2.72</td>
</tr>
<tr>
<td>2009-13</td>
<td>2.14</td>
<td>1.07</td>
<td>1.05</td>
</tr>
<tr>
<td>0-14</td>
<td></td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>15-49</td>
<td>0.63</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>50-64</td>
<td>0.61</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>1.27</td>
<td>0.05</td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>65-84</td>
<td></td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>0.92</td>
<td>0.91</td>
<td>0.99</td>
<td>0.94</td>
</tr>
<tr>
<td>-0.18</td>
<td>1.30</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>1.30</td>
<td>-0.11</td>
<td>0.64</td>
<td>0.63</td>
</tr>
<tr>
<td>0.18</td>
<td>0.48</td>
<td>0.88</td>
<td>0.85</td>
</tr>
<tr>
<td>65+</td>
<td></td>
<td>0.99</td>
<td>0.94</td>
</tr>
<tr>
<td>Total</td>
<td>0.51</td>
<td>0.96</td>
<td>0.94</td>
</tr>
</tbody>
</table>

* Fit 1950-2011, using Medicare-enrollment data for 65 and over, rather than HMD data

See Actuarial Note 158 https://www.ssa.gov/oact/NOTES/pdf_notes/note158.pdf
Age-adjusted Death Rates for Heart Disease, Cancer, Stroke, and Unintentional Injuries: United States, 1900-2015

(courtesy Robert Anderson, NCHS)

Rate per 100,000 standard population

NOTE: Data prior to 1933 contain death-registration States only. Data for 2015 is provisional.
Mortality Decline by *Cause* of Death:

*Rate of change from 1979 to 2013*

### Female

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Cardiovascular</th>
<th>Cancer</th>
<th>Violence</th>
<th>Respiratory</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 15</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>-2</td>
</tr>
<tr>
<td>15-49</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>50-64</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-2</td>
<td>-3</td>
</tr>
<tr>
<td>65-84</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>-3</td>
<td>-4</td>
</tr>
<tr>
<td>85+</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>-4</td>
<td>-5</td>
</tr>
</tbody>
</table>

### Male

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Cardiovascular</th>
<th>Cancer</th>
<th>Violence</th>
<th>Respiratory</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 15</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>15-49</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>-2</td>
</tr>
<tr>
<td>50-64</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>65-84</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>85+</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Age-Sex Extrapolation vs. Age-Sex-Cause Projection

Lee maintaining full age-gradient offsets lack of deceleration
Result: OASDI actuarial deficit unchanged using Lee estimates

Mortality Rate Comparison Age 0-14 Unisex

Mortality Rate Comparison Age 65+ Unisex
Endorsed projections by cause with age-gradient

Suggested *average* age-adjusted 1% annual rate of decline
  – To match average rate since 1950, overall
  – Understood this incorporated deceleration

Chairperson Alicia Munnell, after TR 2016, said she was glad Trustees did not adopt the 1% rate of decline
Mortality Experience: All Ages

Reductions continue to fall short of expectations
Mortality Experience: Ages 65 and Older

Reductions since 2009 continue to fall short of expectations
Developing Assumptions by Cause

- Scientific approach reflecting biology
- Trustees and SSA/OCACT develop in consultation with other experts
- Johns Hopkins recent survey of medical researchers and clinicians came to very similar medium term expectations—individually
  - Trustees’ medium-term rates by cause had not been published
Cardiovascular: JHU Less Optimistic than Trustees over Age 50 for Next 30 Years

Cardiovascular Disease-Female
Average Annual Percent Reduction
JHU values are for the period 2009-2040

- Under Age 15
- Ages 15 - 49
- Ages 50 - 64
- Ages 65 - 84
- Ages 85 and older
- Total

Cardiovascular Disease-Male
Average Annual Percent Reduction
JHU values are for the period 2009-2040

- Under Age 15
- Ages 15 - 49
- Ages 50 - 64
- Ages 65 - 84
- Ages 85 and older
- Total

Graphs showing average annual percent reduction for cardiovascular disease by age group and gender, with JHU values for different time periods.
### Respiratory: JHU More Optimistic under Age 50, Less Optimistic over Age 85

#### Respiratory-Female

*Average Annual Percent Reduction*

JHU values are for the period 2009-2040

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Average Annual Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Age 15</td>
<td>JHU 1.7</td>
</tr>
<tr>
<td>Ages 15 - 49</td>
<td>JHU 0.8</td>
</tr>
<tr>
<td>Ages 50 - 64</td>
<td>JHU 0.5</td>
</tr>
<tr>
<td>Ages 65 - 84</td>
<td>JHU 0.1</td>
</tr>
<tr>
<td>Ages 85 and older</td>
<td>JHU 0.1</td>
</tr>
<tr>
<td>Total</td>
<td>0.1</td>
</tr>
</tbody>
</table>

#### Respiratory-Male

*Average Annual Percent Reduction*

JHU values are for the period 2009-2040

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Average Annual Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Age 15</td>
<td>JHU 1.5</td>
</tr>
<tr>
<td>Ages 15 - 49</td>
<td>JHU 0.8</td>
</tr>
<tr>
<td>Ages 50 - 64</td>
<td>JHU 0.4</td>
</tr>
<tr>
<td>Ages 65 - 84</td>
<td>JHU 0.4</td>
</tr>
<tr>
<td>Ages 85 and older</td>
<td>JHU 0.4</td>
</tr>
<tr>
<td>Total</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Cancer: JHU Very Similar to Trustees’ Expectations

**Cancer-Female**

Average Annual Percent Reduction

JHU values are for the period 2009-2040

- 1979 to 2010
- 2010 to 2038
- 2038 to 2088

**Cancer-Male**

Average Annual Percent Reduction

JHU values are for the period 2009-2040

- 1979 to 2010
- 2010 to 2038
- 2038 to 2088
How Future Conditions Might Change

- Smoking decline for women
  - Started and stopped later than men
- Obesity—sedentary lifestyle
- Difference by income/earnings
- Health spending—must decelerate
  - Advances help only if apply to all
- Human limits
  - Increasing understanding of deceleration

Sam Preston 2010—must consider cumulative effects

Increasing duration of obesity for aged in future
Death Rates Vary by Career Earnings Ranking

Difference has increased

Female 65-69 Retired-Worker
Relative Death Rates by AIME Quartile
Does Health Spending Affect Mortality?

*Note rise, at least through 2009*
Health Spending Cannot Continue to Rise at Historical Rates

*Note Trustees’ deceleration*

**Annual Percent Change in Medicare Cost per Beneficiary Relative to GDP per Worker: 2015 TR**

- 1970-1980: 5%
- 1980-2010: 3%
- 2010-2040: 1%
- 2040-2070: 0%
- 2070-2085: -1%
Is There an Omega?

*It appears we are rectangularizing the survival curve?*
Death Rates Will Continue to Decline: But How Fast and for Whom?

- Must understand past and future conditions
  - Persistent historical “age gradient”
  - Avoid simple extrapolation of past periods
    » Cannot ignore changing conditions
      - “Limits” on longevity due to physiology
      - Latter half of 20th century was extraordinary
    » So deceleration seems likely
  - Cause-specific rates allow basis for assumptions
- Results: in the 1982 TR, we projected LE65 in 2013 to be 19.0; actual was 19.1
For More Information…

http://www.ssa.gov/oact/

- Documentation of Trustees Report data & assumptions

- Historical and projected mortality rates
  https://www.ssa.gov/oact/HistEst/DeathHome.html

- Annual Trustees Reports
  https://www.ssa.gov/oact/TR/index.html