Prospective Longevity Risk Analysis

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‘It should be noted that models investigated in this chapter do not attempt to incorporate assumptions about advances in medical science or specific environmental changes: no information other than previous history is taken into account.’

‘The tacit underlying assumption is that all of the information about the future is contained in the past observed values of the death rates.’
Historical mortality improvements in England & Wales

Smoothed annual mortality improvement for England & Wales
Males aged 65

Averages over 20, 50, 100 and 160 years

- 3.25%
- 2.00%
- 1.25%
- 0.75%

Historical mortality improvements in England & Wales
Knowing more about future journey times

South African rail company Transnet Freight Rail (Transnet) recently announced a R300 billion, seven-year capital investment programme aimed at revolutionising South African rail.

7 June 2012
Knowing more about genetics

Genomics England is set up to sequence 100,000 genomes. Initially the focus will be on rare disease, cancer and infectious disease. The project will be completed by the end of 2017.
Knowing more about causes of disease

Online sharing of individual medical history is helping to find common causes of disease, identify genetic factors, and discover improved treatments.
Conditioning on future medical progress

- Actuarial projections are conditional on the historical record of mortality:
  \[ \text{Prob} \text{ (future mortality | historical record of mortality)} \]

- Medical-based models are conditional also on what is known of the path of future medical advancement.
  \[ \text{Prob} \text{ (future mortality | historical record of mortality & information about future medical progress)} \]
Knowing more about the medical basis of longevity

- Demographers and actuaries have run scenarios to explore the consequences of medical progress.

- But no prospective stochastic model of longevity has been constructed within the demographer/actuarial community.
Lee-Carter demographic model (1992)

The mortality rate at age $x$, in the future calendar year $t$ is a stochastic process denoted by $m_x(t)$.

The Lee-Carter method of mortality forecasting combines an empirical demographic model of mortality with time series methods of forecasting:

$$\ln m_x(t) = a_x + b_x * k(t) + \text{residual}$$

In this model, mortality rate changes according to an index $k(t)$, modulated by an age response $b_x$. 
Lee-Carter index $k(t)$

Pandemic spike in 1918

$k(t)$ can be modelled as a random walk with drift $d$:

$$k(t) = k(t-1) + d + e(t)$$
Randomness in medical discovery

• Investigations that seemed totally irrelevant to any practical objective have yielded most of the major discoveries of medicine: penicillin, cortisone, etc..

• Medical discovery has the characteristics of a random walk superposed on a rising trend towards making progress, but with the possibility of setbacks from unintended consequences and societal concerns.

Meyers, 2007
Serendipity in medical research

• In 1916, a US medical student was assigned a research project to find a natural bodily substance to clot blood. Setting out to characterize factors that promote clotting, he discovered the exact opposite – heparin, a powerful anti-coagulant.

• In 1964, Jerome Horwitz synthesized a new compound AZT for cancer treatment. This was a failure. But two decades later, it had efficacy against AIDS.

• In 2010, aspirin given to patients for its cardio-vascular benefits was revealed to have cancer therapeutic value.
Serendipity in anti-ageing research: Rapamycin

- Fungus in soil taken from Easter Island in 1965 contained an antibiotic, named rapamycin.
- It is used as an immuno-suppressant for transplant patients.
- Fed to 20-month old mice, rapamycin has led to a lifespan increase of 14% for females and 9% for males.
The serendipitous discovery of penicillin

• According to the biographer of Alexander Fleming, the discovery of penicillin was ‘a series of chance events of almost incredible improbability’.

• It was like ‘drawing the winners of seven consecutive horse races in the right order from a hat containing all the runners’.

• With just four horses per race, the odds are six billion to 1.
Tough for drugs companies to pick winners

- Lipitor (atorvastatin) is in the group of statin heart drugs. It reduces levels of "bad" cholesterol, while increasing levels of "good" cholesterol.
- Lipitor had annual sales for Pfizer of $13 billion, but it came off patent in November 2011.
- Billions were spent on a successor to Lipitor, but this surprisingly failed in Phase III trials, due to excess deaths.
Hit-and-miss approach to drug discovery and approval

Source: Pharmaceutical Research and Manufacturers of America
Randomizing the medical research process

Big Pharmaceutical Company
Centralized Research Laboratory

Diversified Research Strategy

Small Biotechnology Companies
No consensus on random phenomena

‘The major disadvantage is that there is no consensus on future medical developments.’

2007 Dutch AG mortality and life expectancy report

Serendipity is the art of finding what we are not looking for by looking for what we are not finding’ (Quéau, 1986).
Randomness not ignorance

• Previous attempts at projecting medical advances have framed this essentially as an ignorance problem.
• The lack of consensus amongst medical researchers is not due to lack of expert knowledge, but the serendipitous randomness of the medical discovery process.
• It is this inherent randomness which makes it possible to construct a parsimonious stochastic meta-model of medical advancement.
GEROSCIENCE: the study of the interface between normal ageing and ageing diseases

“We should be prepared to adjust for significant increases in lifespan during this century.”

Gordon Lithgow
Buck Institute
GASP model

• **Geroscience**: The interdisciplinary science of ageing, and age-related diseases, provides the knowledge basis for future longevity scenarios.

• **Advancement**: Future advancement in medical technology and healthcare is taken into account in forward modeling.

• **Stochastic**: The evolution of future longevity involves intrinsic randomness and is fundamentally stochastic.

• **Process**: Developments in longevity are process-driven.
Vitagions: agents for mortality change

1: Lifestyle
2: Health Environment
3: Medical Intervention
4: Regenerative Medicine
5: Anti-Ageing

Medical Science Progress
Vitagions: agents for mortality change

Lifestyle
• Smoking
• Obesity
• Other lifestyle trends

Health Environment
General impact of
• Healthcare provision
• Sanitation and housing
• Other environmental factors

Medical Intervention
Treatments for specific conditions:
• Cardiovascular Disease
• Cancers
• Respiratory Disease
• Dementia
• Other key diseases
• Accident & Trauma

Regenerative Medicine
New classes of treatment for repairing damaged systems e.g.
• Stem cell therapy
• Nanomedicine
• Individualized gene therapy
• Improvements in transplantation

Anti-Ageing Processes
Treatments to extend life through slowing natural processes of ageing, e.g:
• Telomere Shortening
• Caloric restriction
Each vitagion reduces mortality over time

- Mortality Reduction
- Slowest Trend
- Expected Trend
- Fastest Trend

Maximum reduction possible (Vmax)

2014 Convention knowing more 22-23 October, Cape Town
Modelling causes of death

Cancer
- Lung
- Bowel
- Breast
- Pancreas
- Oropharyngeal
- Oesophageal
- Liver
- Laryngeal
- Cervical
- Uterine
- Ovarian
- Prostate
- Kidney
- Bladder

Cardio-Vascular Disease
- Stroke
- Heart Attack
- Ischaemic Heart Disease
- Atherosclerosis
- Aneurysm

Other causes of Death
- Pulmonary Disease
- Alzheimer’s & Dementia
- Influenza & Pneumonia
- Cirrhosis
- Chronic Pancreatitis
- Accidents & Violence
Estimating Vmax

By how much could each cause of death ultimately be reduced by lifestyle changes?

Vmax = 50%
- Cancer reduced by - - 20%
- CVD reduced by - - - 80%
- Other reduced by - - - 50%
Stochastic model for mortality reduction

\[ F_j(x, t) = 1 - tr_{j,x}(t) \cdot V_{MAX_{j,x}} \]

Reduction in base mortality for vitagion \( j \) at age \( x \), and time \( t \)

A stochastic process: percentage of \( V_{MAX_{j,x}} \) achieved at time \( t \)

The base mortality of a portfolio is an input that typically reflects client experience, standard industry tables, or population statistics.
Stochastic trend model

\[ tr_{j,x}(t) = 1 - \exp(-u_{j,x} \cdot r_{j,x} \cdot (t - t_0 + n_{j,x}(t))) \]

- **Expected trend towards** \( V_{MAX_{j,x}} \)
- **Stochastic process:** percentage of \( V_{MAX_{j,x}} \) achieved at time \( t \)
- **A lognormally distributed factor with unit mean capturing vitagion trend volatility.**
- **Brownian motion with zero mean capturing vitagion path volatility.**
Including the cohort effect

\[ m(x, t) = m(x, t_0) \cdot \prod_{j=1}^{5} F_j(x, t) \cdot \exp(O(x) \cdot \gamma(t - x)) \]

This factor modifies the resulting mortality forecast for each year of birth \((t-x)\) cohort to ensure historically-observed differences in generational mortality are preserved in the projection.
Longevity model linkage

GASP \rightarrow \text{Lee - Carter}

The structured RMS longevity risk model with its random walk for the path volatility of vitagions provides the underlying rationale for the functionality of the demographers’ Lee-Carter mortality model.

Lawrence Carter battled with multiple sclerosis for nearly twenty years before his premature death at the age of 68 in 2011. Whilst gradual progress has been made in understanding the basis of this disease, a cure may depend on some serendipitous discovery.
Mortality improvement outlook by vitagion driver

Geroscience is the climate change of longevity

- Anti-ageing
- Regenerative medicine
- Medical intervention
- Lifestyle
- Health environment
1-in-200 extreme longevity tail risk scenario

% reduction in mortality rate for a 75 year old Male

Fast Increase in healthier lifestyle
Smoking becomes de-normalized;
Obesity trends slow dramatically.

Rapid Progress in Medical Intervention
Cancer management improves dramatically.
New monoclonal antibody drugs are effective and cheap.
Continued rapid reduction of premature deaths from cardiovascular disease

Lifestyle
Health
Environment
Medical Intervention
Regenerative Medicine
Anti-ageing
Shift in the modal age of death

Distribution of the ages at death in Switzerland:
1876-1880, 1929-1932, 1988-1993

J.M. Robine, The Longevity Revolution (LSE, 2011)

Key domain for mortality models
EQ5D health questionnaire

- Any problems with mobility
- Any problems with self-care
- Ability to perform usual activities
- Pain or discomfort
- Anxiety or depression
A systems perspective on human resilience

What (above the neck) keeps people alive?

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Survival Enhancement Factors</th>
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<tbody>
<tr>
<td>Age</td>
<td>Cognitive functioning</td>
</tr>
<tr>
<td>Gender</td>
<td>Psychological well-being</td>
</tr>
<tr>
<td>Smoking</td>
<td>Social functioning</td>
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<tr>
<td>Blood Pressure</td>
<td></td>
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<tr>
<td>Cholesterol ratio</td>
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<tr>
<td>Diabetic</td>
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<tr>
<td>Etc.</td>
<td></td>
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</tbody>
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The Resiliency Index is parameterized from longitudinal studies published since 2000.
Difficulty of forecasting life expectancy for 90 year-olds

At age 90, Jeanne Calment reverse mortgaged her apartment to an astute lawyer, 47 year-old Andre-Francois Raffray, who relied upon a 1960s actuarial table. He agreed to pay a life annuity of about 10% value of the apartment until she died.

Jeanne liked alcohol, cigarettes, chocolates and sweets.

Highly resilient, she had excellent cognitive functioning with a famously sharp wit.

She had a very positive outlook and was immune to any stress.
Application of the Resiliency Index

A study of elderly resilience has been undertaken by Connie Springer, who has identified a string of personality traits associated with successful ageing. These traits include the underlying cognitive, psychological and social factors governing the Resiliency Index.


Application of the Resiliency Index to the US actuarial tables gives close agreement with actual survival statistics.
Wealth distribution for an individual at age 95

Wealth Shortfall

Relative Likelihood

Wealth Shortfall

-£100K 0 £100K £200K £300K
Decision analytics for retirees

The financial problem facing retirees may be expressed in general terms as optimal wealth decumulation, given their utility of consumption.

As with insurers, a retiree’s aversion to financial ruin or wealth shortfall should be an important consideration in retirement planning.

The lifetime ruin probability will depend on the annual spending rate, the riskiness of asset allocation, and the individual’s future survival probability.
Summary

• Purely statistical approaches have a poor track record in predicting mortality.

• A prospective longevity risk model is structured by representing the drivers of mortality change: vitagions.

• These drivers of mortality change should be recognized in prudent longevity risk management.

• Retirement planning for robust individuals should reflect their cognitive, psychological and social resilience.