Prolonging Life by Vitagions: Modelling Mortality Improvement Shocks

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Longevity19
Amsterdam
September 17, 2024

Agenda

Background

Individuals live longer and enjoy better health and quality of life in their later years.

Remarkable decrease in mortality rates at all ages:

- Significant declines due to medical discoveries, vaccines, antibiotics
- Reduction in infectious diseases (e.g., smallpox, polio)
- Advances in treating cardiovascular diseases and cancers

The Vitagion Categories

A combination of social, economic, and medical factors drives mortality improvements.

The so-called '*vitagions*' can be considered as drivers of mortality improvement. They are defined as '*individual sources of mortality improvements*' ([1] Blake et *al*. 2013, [2] Blake et *al*. 2019), or, with the same meaning, as '*agents for prolonging life*' ([13] Woo 2014).

They are classified into five groups:

- Lifestyle trends, including smoking prevalence
- Health environment
- Disease reduction
- Regenerative medicine such as stem cell research, gene therapy and nanomedicine
- Anti-ageing, including telomere shortening and caloric restriction

Research Aims

How to model mortality by considering future mortality improvements deriving from advancements in healthcare, medical discovery, and technology.

Specifically, we focus on the issue of incorporating the *vitagion categories* in the model and projecting how they might impact mortality.

Literature Background

Most methods of forecasting mortality rates are extrapolative in nature.

The most well-known method is the Lee-Carter model.

Various extensions have been proposed, including a family of models to take into account mortality improvements ([11] Renshaw and Haberman 2000, [12] Renshaw and Haberman 2003), a range of multi-factor models ([5] Cairns et al. 2009, [10] Plat 2009), and also parametric mortality projection models ([9] Haberman and Renshaw 2011).

To include mortality improvements due to vitagions, mortality models that are process-based and causal should be considered ([1] Blake et *al*. 2013, [2] Blake et *al*. 2019).

Vitagion Mortality Reduction Factors

Refer to [13] *Prospective Stochastic Longevity Modelling*, where each vitagion is represented by a stochastic process.

For any vitagion, there is assumed an ultimate limit to the mortality reduction benefit associated with it. This is denoted by $VMAX_{j,x}$, namely the maximum plausible mortality reduction at age x due to the vitagion j.

The reduction in base mortality for vitagion j at age x and time t is:

$$F_{j,x}(x,t) = 1 - tr_{j,x}(t) \cdot VMAX_{j,x}$$

where
$tr_{j,x}(t)$ expresses the percentage of $VMAX_{j,x}$ achieved at time t.

Vitagion Mortality Reduction Factors

The mortality reduction factors from the five vitagions are combined multiplicatively with the base mortality $m(x, t_0)$ to produce a mortality forecast:

$$m(x,t) = m(x,t_0) \cdot \prod_{j=1}^{5} F_j(x,t)$$

Frailty-based Lee Carter Model

Let z_t be the latent variable measuring the mortality heterogeneity by time, obtained as the average value for each age x for each time t

$$z_t = \frac{1}{\omega} \sum_{x=1}^{\omega} \zeta_{x,t}, t = 1, ..., T$$

where $\zeta_{x,t}$ is the latent variable of frailty measuring mortality heterogeneity for age x at time t.
We define the Frailty-based Lee-Carter model as follows ([6] Carannante et al. 2023)

$$y_{x,t} = \log(m_{x,t}) = a_x + b_x k_t + g_x z_t + \epsilon_{xt}$$

where g_x measures the average impact of frailty by age.

Vitagion functional form hypothesis

Based on the [13] *Prospective Stochastic Longevity Modelling*, we hypothesise an exponential stochastic process for mortality improvements

$$tr_x(t) = (1 - \exp[-u_x \cdot r_x \cdot (t - t_0) + n_x(t)])$$

Where u_x is a zero-mean log-normal random variable representing the mortality heterogeneity, r_x is the time variation for age x and $n_x(t)$ is the Brownian motion.
$tr_x(t)$ is defined to obtain different trajectories by age, modeling mortality heterogeneity by u_x and assuming the persistence of positive shocks by $n_x(t)$.

Vitagion functional form hypothesis

In the literature there are various hypotheses of improvements that can be the basis for the definition of trend $r_{x,t}$. To evaluate the effect on model estimation, we consider both model and stochastic process.

$r_{x,t}$ based on Best Practice hypothesis

We consider Best practice model, based on an annual increase of 20% ([7] Debonneuil, E., Loisel, S., Planchet, F. 2018, [3] Bongaarts, J., 2014)

$$r_{x,t} = A + B(x + st)$$

where $s = 0.2$. This model assume a unique trajectory for all the ages.

Vitagion functional form hypothesis

In the literature there are various hypotheses of improvements that can be the basis for the definition of a variable $r_{x,t}$. To evaluate the effect on model estimation, we consider both model and stochastic process.

$r_{x,t}$ based on Exponential jump diffusion hypothesis

We consider Deng et al. 2012 [8] and Brockett et al. 2013 [4] Exponential jump diffusion hypothesis to model the mortality improvement

$$r_{x,t} = \sum_{i=1}^{N(t)} \left(V_{i,x} - 1 \right), x = 50, \ldots \omega$$

where $N(t)$ is a Poisson process and V_i a random variable where $\Upsilon_x = \log(V_x)$ is an exponential distribution for each age x.

Numerical application

Data

Country: England and Wales
Time period: 2002-2019
Ages: 50-90
Source: Human Mortality Database for exposures and death rates
English Longitudinal Study of Ageing (ELSA) for frailty

Baseline model

Age-specific and Temporal Frailty Lee–Carter ([6] Carannante et al. 2023)

Improvement corrections

100 simulation for each age of stochastic process determining $F_{j,x}(x,t)$. Following [13] case study, we consider 100 year projections from 2019, and $VMAX$ is assumed to be 0.04.

Preliminary results

ATFLCA and LCA comparison

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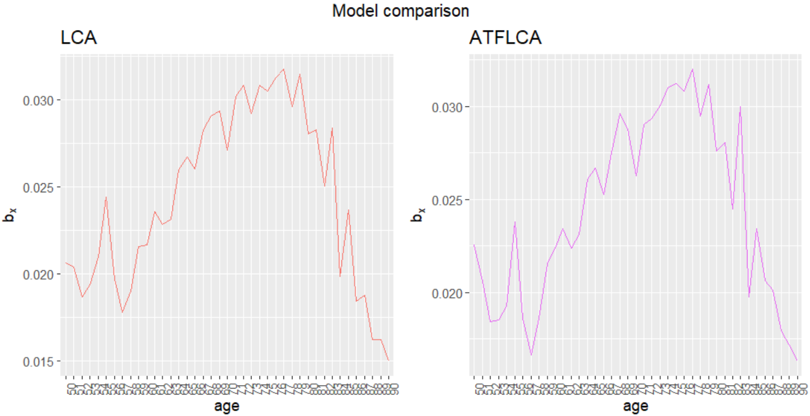
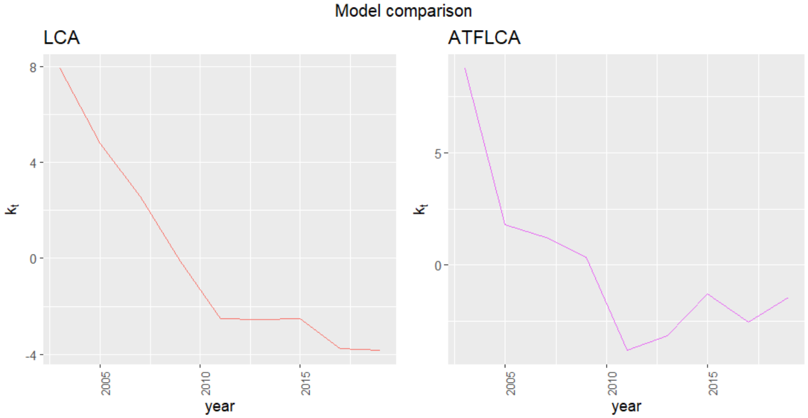
ATFLCA and LCA comparison



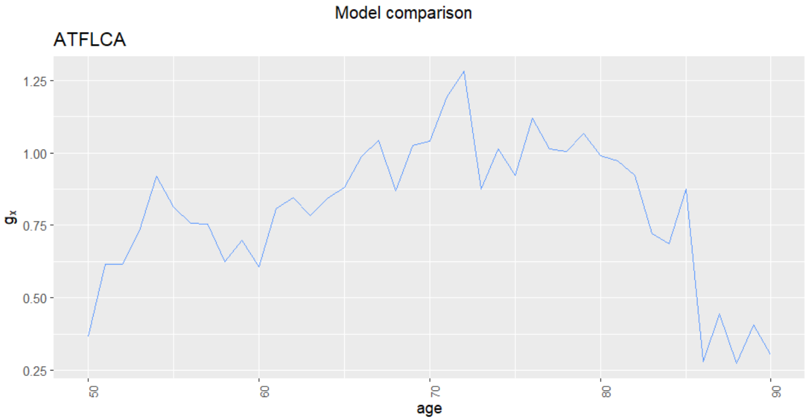
Preliminary results

ATFLCA and LCA comparison



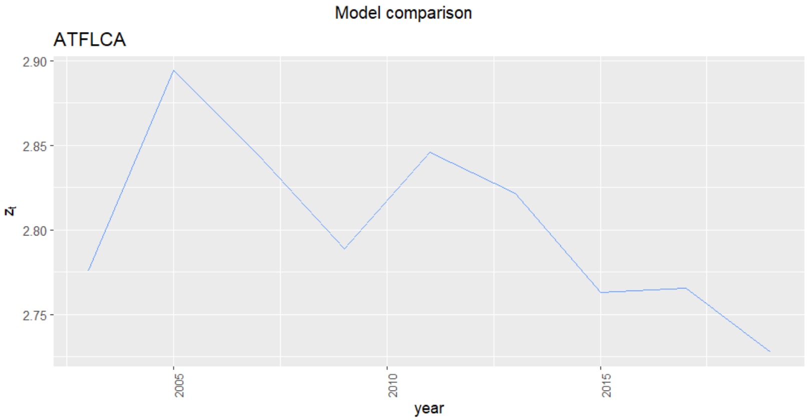
Preliminary results

ATFLCA frailty parameters



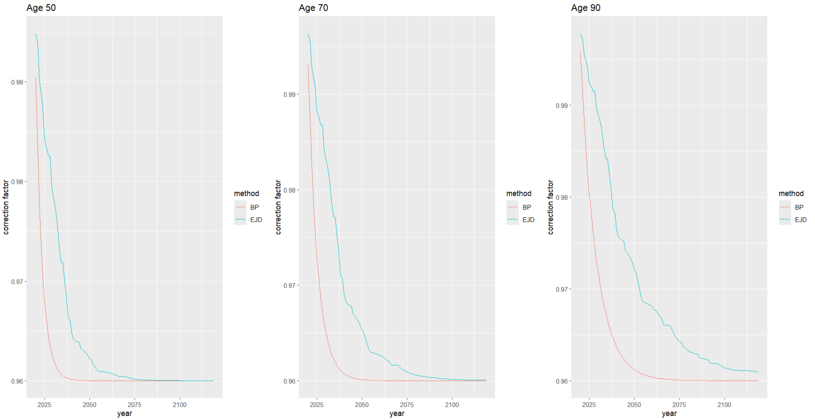
Preliminary results

ATFLCA frailty parameters



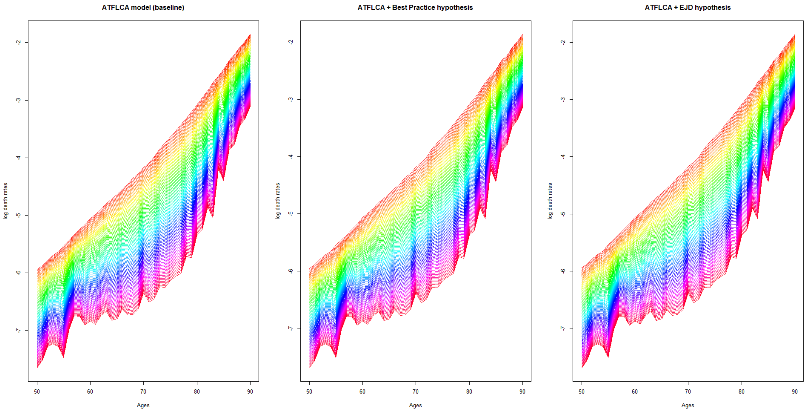
Preliminary results

Improvement correction projections for 50, 70 and 90 aged



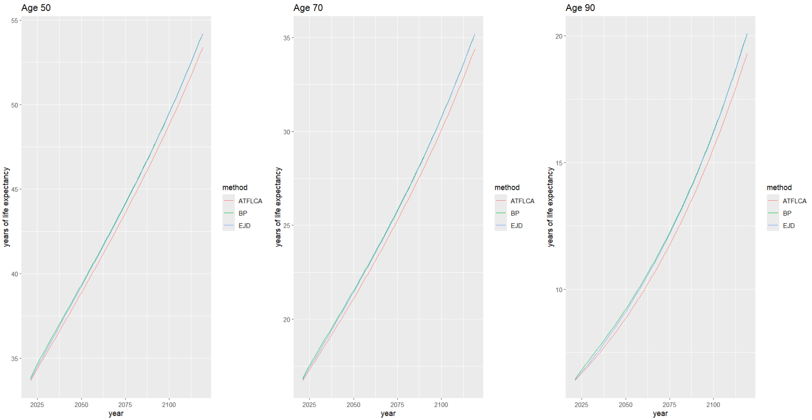
Preliminary results

$y_{x,t}$ projections



Preliminary results

$e_{x,t}$ estimations



Conclusions

- Models based only on historical trends cannot fully represent the projected future mortality
- Need to model future mortality recognizing that mortality improvements attributable to the vitagion categories are not deterministically predictable but rather to be considered as stochastic processes.
- The model presented uses a stochastic process to incorporate vitagions to the basic projected trend of the mortality improvement.
- Future works will consider further model refinements and move from single-population to multi-population models.

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