Projecting Life Expectancy Using Cause-of-Death-Specific Mortality Scenarios

Kleinow, Torsten
Research Centre for Longevity Risk - University of Amsterdam

joint work with Alex Yiu and George Streftaris

Longevity 17 - September 2022

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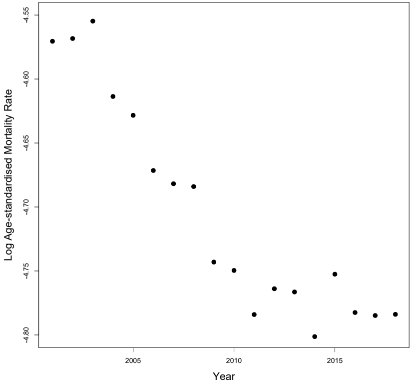
Age-standardised mortality rates up to 2018 in England and Wales



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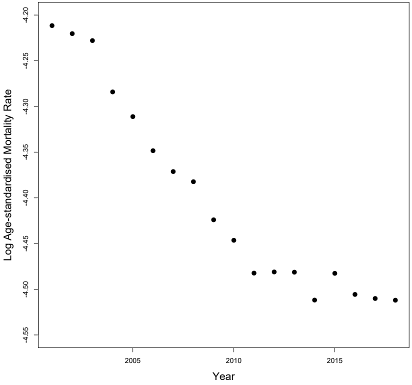

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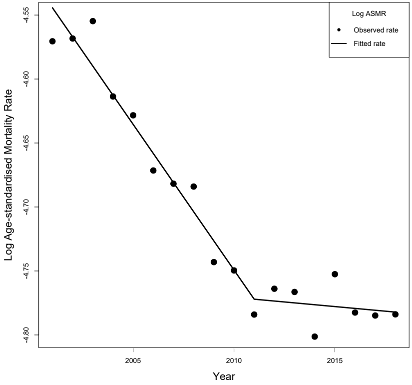

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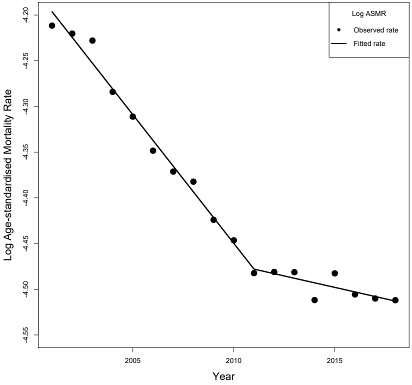

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The Slowdown of Mortality Improvement Rates in England and Wales

- At around 2011 the temporal trend of mortality rates changed in England and Wales.
- To learn more about the change we consider different causes of death.
- We use a GLM to model mortality by age group and cause.

Cause Specific Rates - Data

- Ages are grouped into infants (< 1), 1-4, 85+ and five year age groups
- Let $d_{x,t}^{[c]}$ denote the observed death counts in age group x in calendar year t due to cause-of-death c.
- Death from all causes: $d_{x,t} = \sum_c d_{x,t}^{[c]}$
- Exposure data (mid-year population estimates) are denotes by $E_{x,t}$.
- All data are obtained from the ONS, the UK Office for National Statistics.
- Calendar years: 2001 - 2018
- Causes of death were classified according the International Classification of Diseases (ICD)

Groups of Causes of Death

We group causes into 12 groups.

Cancers (Neoplasms)	Circulatory
Digestive	Endocrine and Blood
External	Genitourinary
Infectious	Mental
Musculoskeletal and skin	Nervous
Respiratory	Other

Cause Specific Rates and ASMR

Mortality Rates (cause-specific and all-cause):

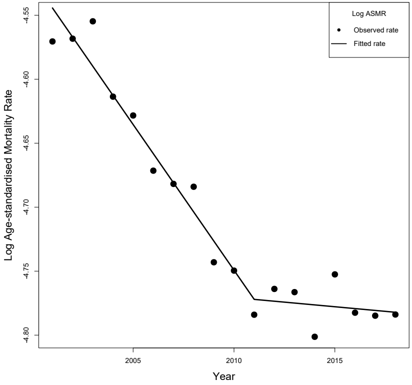
$$\widetilde{m}_{x,t}^{[c]} = \frac{d_{x,t}^{[c]}}{E_{x,t}}, \text{ and } \widetilde{m}_{x,t} = \frac{d_{x,t}}{E_{x,t}} = \sum_{c} \widetilde{m}_{x,t}^{[c]}$$

Age-standardised mortality rate in calendar year t:

$$ASMR_t = \sum_{x} w_x \widetilde{m}_{x,t} \text{ with } w_x = \frac{E_x^S}{\sum_x E_x^S}.$$

E_x^S refers to the European Standard Population in 2013

The Slowdown of Mortality Improvement Rates - ASMR



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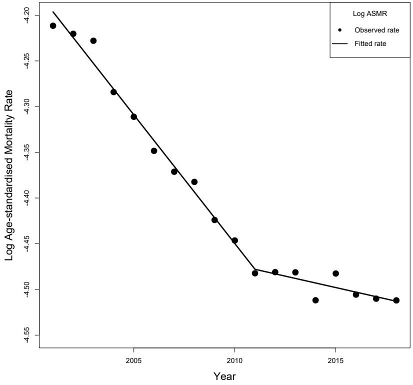

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GLM for Cause-specific Mortality

The number of deaths is modelled with a Negative Binomial Distribution

$$D_{x,t}^{[c]} \sim NB(E_{x,t} m_{x,t}^{[c]}, \theta_x^{[c]}),$$

where $\theta_x^{[c]}$ is a cause and age-specific dispersion parameter. and

$$\log(m_{x,t}^{[c]}) = \beta_{0,x}^{[c]} + \beta_{1,x}^{[c]} t + \left[\beta_{2,x}^{[c]}(t - 2011) + \beta_{3,x}^{[c]}\right] \mathrm{I}(t \geq 2011).$$

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Alternatively:

$$D_{x,t}^{[c]} \sim Poisson(E_{x,t} m_{x,t}^{[c]})$$

Fitted mortality rates

$$\widehat{m}_{x,t}^{[c]} = \exp\left(\widehat{\beta}_{0,x}^{[c]} + \widehat{\beta}_{1,x}^{[c]} t + \left[\widehat{\beta}_{2,x}^{[c]}(t - 2011) + \widehat{\beta}_{3,x}^{[c]}\right] \mathrm{I}(t \geq 2011)\right)$$

Contribution of a Single Cause to the Slowdown

Thought experiment: What would mortality rates look like if for a specific cause, k, the pre-2011 trend had persisted up to 2018?

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In the scenario for this specific cause k, scenario mortality rates, $\tilde{m}_{x,t}^{[c,k]}$, are defined as follows

$$\log \tilde{m}_{x,t}^{[c,k]} = \begin{cases} \log \widehat{m}_{x,t}^{[c]} & , c \neq k \\ \widehat{\beta}_{0,x}^{[k]} + \widehat{\beta}_{1,x}^{[k]} t + \widehat{\beta}_{3,x}^{[k]} \mathrm{I}(t \geq 2011) & , c = k \end{cases}$$

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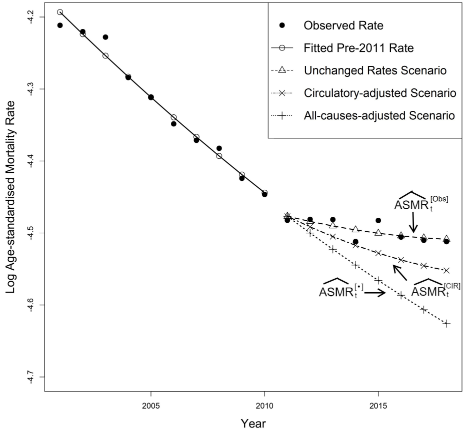
$$\tilde{m}_{x,t}^{[\cdot,k]} = \sum_{c} \tilde{m}_{x,t}^{[c,k]} = \tilde{m}_{x,t}^{[k,k]} + \sum_{c \neq k} \widehat{m}_{x,t}^{[c]}$$

Scenario-specific ASMR

Age-standardised mortality rates using the European standard population E_x^s

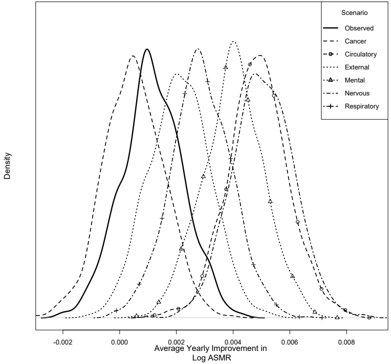
$$\widehat{ASMR}_t = \frac{\sum_x \widehat{m}_{x,t} E_x^S}{\sum_x E_x^S} \qquad \text{and} \qquad \widehat{ASMR}_t^{[k]} = \frac{\sum_x \tilde{m}_{x,t}^{[\cdot,k]} E_x^S}{\sum_x E_x^S}$$

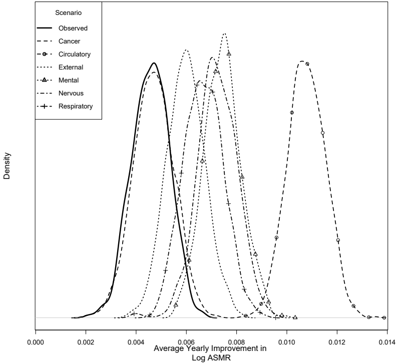
Scenario-specific ASMR



Negative binomial fitted log age-standardised mortality rates under various scenarios - Males

Cause-Reverted ASMR Improvement Rates - Females, Poisson





Average yearly improvement in log age-standardised mortality rates post-2011, females (left) and males (right).

Cause-Reverted ASMR Improvement Rates - Males, Poisson

The changing trend in the mortality from circulatory system diseases has a significant impact on the slowdown of overall rates for both sexes: while the actual annual improvement in mortality rates for men is 0.00457 (95% CI: 0.00316, 0.00596), it would have been 0.01078 (0.00937, 0.01219) if the temporal trends in the circulatory system deaths did not change after 2011.

For females, the annual improvement would have been 0.00485 (0.00284, 0.00707), compared to the actual improvement of 0.00107 (-0.00100, 0.00325).

Life Expectancies

The probability for a person who is h years old in year t to survive for a further n years is obtained by

$$ {}_n p_{h,t} = \exp\left(-\sum_{i=0}^{n-1} m_{h+i,t}\right). $$

Curtate expectation of life, the total full years of life an individual aged h is expected to survive:

$$ e_{h,t} = \sum_{n=1}^{\infty} {}_n p_{h,t}. $$

Assuming that deaths are evenly distributed throughout the year, the period complete expectation of life at age h in calendar year t, is approximated as

$$ \mathring{e}_{h,t} = e_{h,t} + \frac{1}{2}. $$

Life Expectancies

- As the observations are grouped in five-year age groups, the mortality rates in each group are assumed to be constant across all ages in that group.
- The mortality rates $m_{x,t}$ for all ages h greater than the maximum age of 85 are also assumed to be constant and equal to the rate at age 85, that is, $m_{h,t} = m_{85,t}$ for all $h \geq 85$.

Period Life Expectancies based on Fitted Mortality Rates without adjustments

Increase in period life expectancy from birth:

- for men: 3.872 (3.773, 3.971) months per year until 2011, while post-2011 it was just 0.656 (0.544, 0.813) months per year on average.
- for women: the pre-2011 annual improvement was 3.023 (2.928, 3.111) months per year, dropping to 0.234 (0.133, 0.387) months post-2011.

If the pre-2011 trends had persisted past 2011, the average annual improvement from 2011 to 2018 would have been 2.986 (2.885, 3.088) months per year for men and 1.992 (1.896, 2.008) months per year for women.

Life Expectancy in Future Mortality Scenarios

We consider projected mortality rates:

$$\begin{aligned}\log m_{x,t}^{[c]} &= \log \widehat{m}_{x,t}^{[c]} + \beta_{4,x}^{[c]}(t-2018)\mathbb{I}(t \geq 2018)\\ &= \widehat{\beta}_{0,x}^{[c]} + \widehat{\beta}_{1,x}^{[c]} t + \left(\widehat{\beta}_{2,x}^{[c]}(t-2011) + \widehat{\beta}_{3,x}^{[c]}\right)\mathbb{I}(t \geq 2011)\\ &\quad + \beta_{4,x}^{[c]}(t-2018)\mathbb{I}(t \geq 2018)\end{aligned}$$

where $\widehat{\beta}_{0,x}^{[c]}$, $\widehat{\beta}_{1,x}^{[c]}$, $\widehat{\beta}_{2,x}^{[c]}$, and $\widehat{\beta}_{3,x}^{[c]}$ are obtained from fitting a Poisson or negative binomial GLM

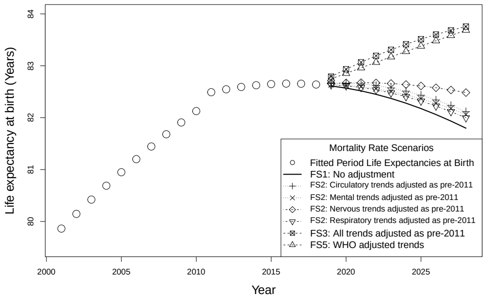
- $\beta_{4,x}^{[c]}$ generates different scenarios for cause-specific trends.

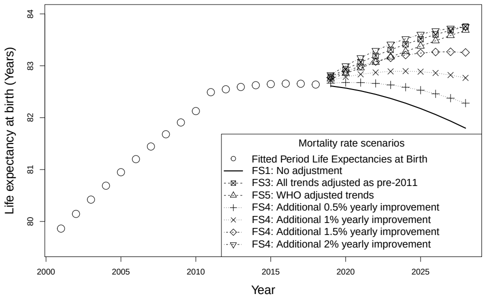
Scenarios for Future Mortality Developments

$$\widehat{\beta}_{0,x}^{[c]} + \widehat{\beta}_{1,x}^{[c]} t + \left(\widehat{\beta}_{2,x}^{[c]}(t - 2011) + \widehat{\beta}_{3,x}^{[c]}\right) \mathrm{I}(t \geq 2011) + \beta_{4,x}^{[c]}(t - 2018)\mathrm{I}(t \geq 2018)$$

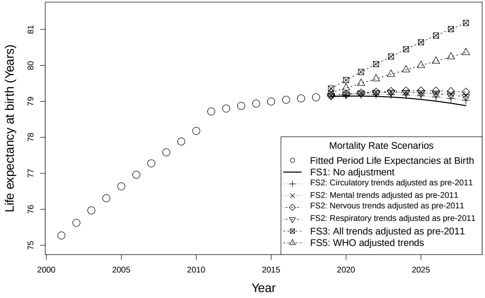
1. No changes in mortality trends. $\beta_{4,x}^{[c]} = 0$ for all causes c and age groups x.
2. Reversion of trend for a single cause k to pre-2011 rates: $\beta_{4,x}^{[k]} = -\widehat{\beta}_{2,x}^{[k]}$ for all x and $\beta_{4,x}^{[c]} = 0$ for all other causes $c \neq k$.
3. All of the cause-specific mortality trends are reverted to pre-2011 rates. $\beta_{4,x}^{[c]} = -\widehat{\beta}_{2,x}^{[c]}$ for all c and all x.
4. All-cause mortality rates at each age are reduced by an additional rate of z per year. $\beta_{4,x}^{[c]} = \log(1 - z)$ for all causes c and age groups x.
5. A WHO scenario was developed following projections from the World Health Organization for high income countries.

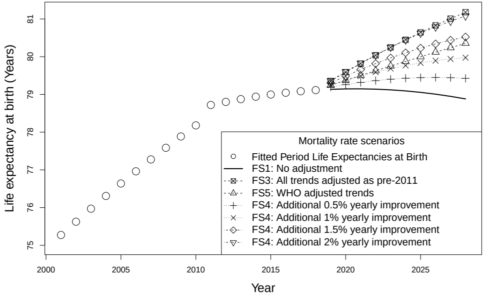
Life Expectancy in Future Mortality Scenarios - Women





Life Expectancy in Future Mortality Scenarios - Men





Conclusions

Cause specific mortality scenarios allow for

- a more detailed explanation of observed trend changes
- a more detailed description of projected mortality rates and life expectancies, and the quantification of uncertainty about projected rates
- incorporating "Expert judgement", like medical expertise about specific causes into mortality projections

Conclusions

Our empirical results show

- the slowdown in improvement rates of mortality from diseases of the circulatory system are the main reason for the observed overall slowdown 2011 to 2018
- Diseases of the nervous system and mental diseases are becoming increasingly more common causes of death, and developments in those will have a strong impact on overall mortality rates
- Improvement rates for those “up-and-coming” causes will need to be at least as strong as those observed for deaths from diseases of the circulatory system for LE improvements to return to pre-2011 levels