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# A FINE SCALE



**Elena Kulinskaya, Ilyas Bakbergenuly**  
and **Lisanne Gitsels** revisit longevity modelling

Life expectancy (LE) and its changes are crucial to the pensions and insurance industry, society and government. Longevity-trend projections are used to manage longevity risk in pricing and reserving for insurance and annuity products, as well as for costing public and private pensions. Changes in mortality projections directly affect annuities costs, especially in the decreasing interest rates environment.

LE is also a consideration for individuals planning their financial goals and retirement strategies. Previously, a vast majority of people would buy a lifetime annuity with their pension pot. However, the introduction of pension freedoms in 2015 resulted in the emergence of a variety of flexible retirement options, from drawdown to fixed-term annuities. This has necessitated dynamic decision-making both by individuals and companies.

Many financial tasks, from underwriting to retirement planning, need to account for a large number of important and time-varying determinants of health and longevity, such as socio-economic factors (income or residence), health status (new conditions and/or prescriptions) and lifestyle factors (smoking, obesity, alcohol usage), as well as their interactions. In addition, they must take into account the medical advances and public health interventions that are aimed at increasing the health of populations.

Our research, funded by the Actuarial Research Centre, concentrates on dynamic statistical modelling of population-based individual-level data, collected over the long term and recorded in electronic health records (EHRs). Dynamic statistical analysis allows us to make more accurate predictions, based on real-time data, dynamic risk

stratification and more personalised service. Traditional statistical methods use the baseline data for long-term outcome predictions (often beyond the study's range). For instance, a person's characteristics at retirement age are used to infer their hypothetical longevity. Dynamic analysis allows for changing personal circumstances and age-dependent changing risks, and incorporates them into more precise modelling.

The age-varying survival benefits or harms of various predictors obtained from dynamic statistical modelling of big health data can be used to obtain finely differentiated projections of life expectancy for numerous subpopulations. We provide a case study on statins.

### Cox regression and landmark analysis

Survival analysis, or time-to-event analysis, investigates the effects of various risk factors on mortality. The

type of regression model typically used in survival analysis in medicine is the Cox proportional hazards regression. The Cox model factorises the hazard or force of mortality  $\mu_i(x)$  for a subject  $i$  with risk factors  $Z_i$  at age  $x$  into an age-varying baseline hazard  $\mu_0(x)$  and a constant subject-specific risk score.

The risk score is a log-linear regression term which includes relevant risk factors, so that

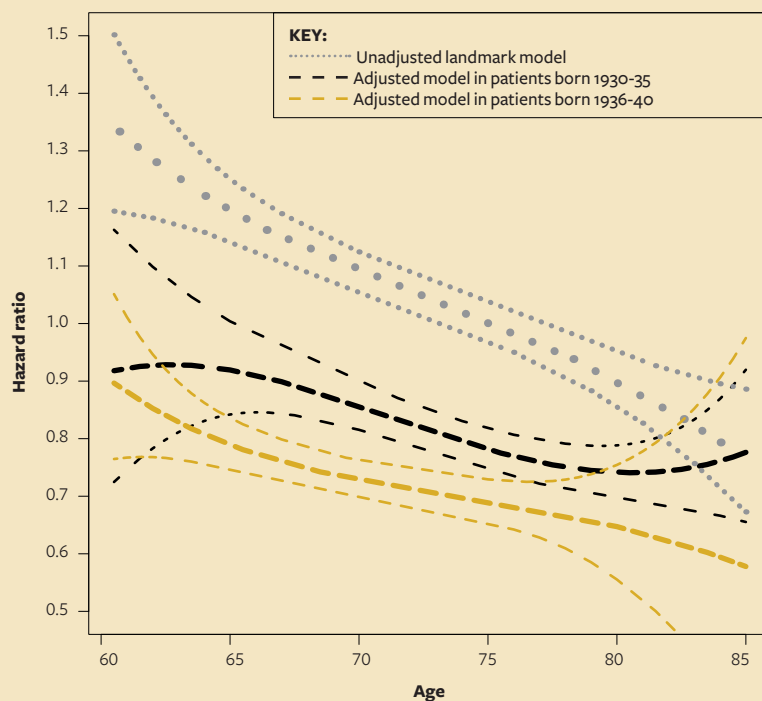
$$\mu_i(x, \beta, Z_i) = \mu_0(x) e^{Z_i \beta}$$

Taking a ratio of the hazard functions for two subjects, the hazard ratio

$$\frac{\mu(x, \beta, Z)}{\mu_j(x, \beta, Z_j)} = e^{\beta(Z-Z_j)}$$

is constant over time and does not depend on the baseline hazard. This proportional hazards assumption, if true, allows to easily estimate hazard ratios for various combinations of risk factors, regardless of the parametric form of the baseline hazards.

**FIGURE 1:** Hazard ratio of all-cause mortality associated with statin prescription compared to no prescription, for two birth cohorts of 1930-35 and 1936-40, from the landmark analysis with 30-year window. Results were adjusted for cardiac risk at three levels, sex, birth cohort, Townsend deprivation quintile, chronic kidney disease, diabetes, treated hypertension, hypercholesterolemia, aspirin, BMI, alcohol use, smoking status and general practice.



However, the main assumption of the Cox model – that the risk score does not change over the age span – is rightly distrusted by actuaries. Landmark analyses is a recent statistical method used to dynamically predict the survival effects associated with changing risk factors. This method builds a series of  $L$  Cox models, each in a sliding window of width  $w$  from the landmark age  $x_{LM} = s_j$  to  $s_j + w$ , for  $l = 1, \dots, L$ , and then smoothes the obtained trajectories. This means that the latest medical history at the landmark age  $x_{LM}$  is used to predict survival conditional on survival to the landmark, thereby allowing for time-dependent covariates and time-dependent survival effects (Van Houwelingen and Putter, 2011).

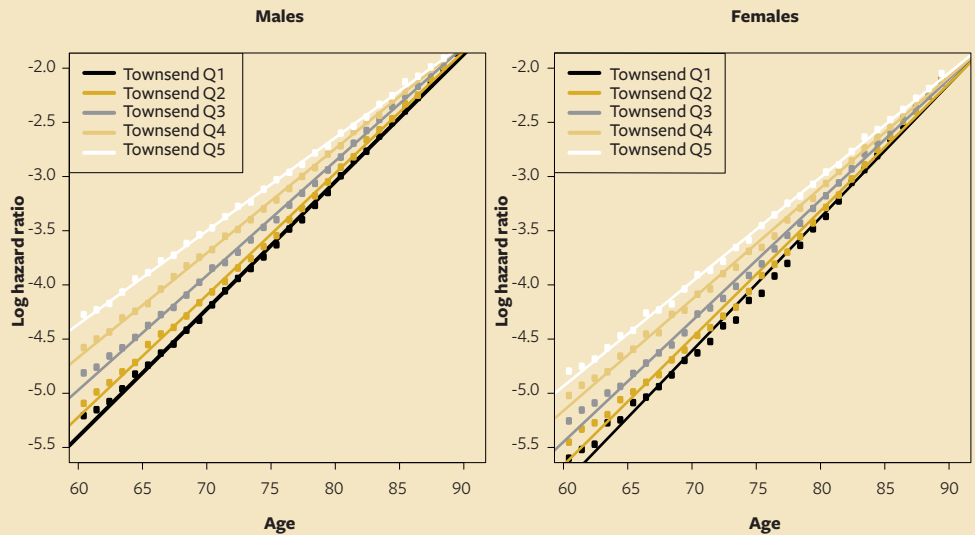
**Landmark analysis of statins**

We have recently completed a landmark analysis on the survival benefits of statins, a medication used to lower the lipid levels in the blood. We followed up a cohort of 110,000 healthy people who hit 60 between 1990 and 2000 for the next 25 years, updating their health status and statins use every six months (51 time points) (Gitsels et al, 2020). The time-varying hazards of all-cause mortality for two birth cohorts (1930-1935 and 1936-1940) are depicted in Figure 1.

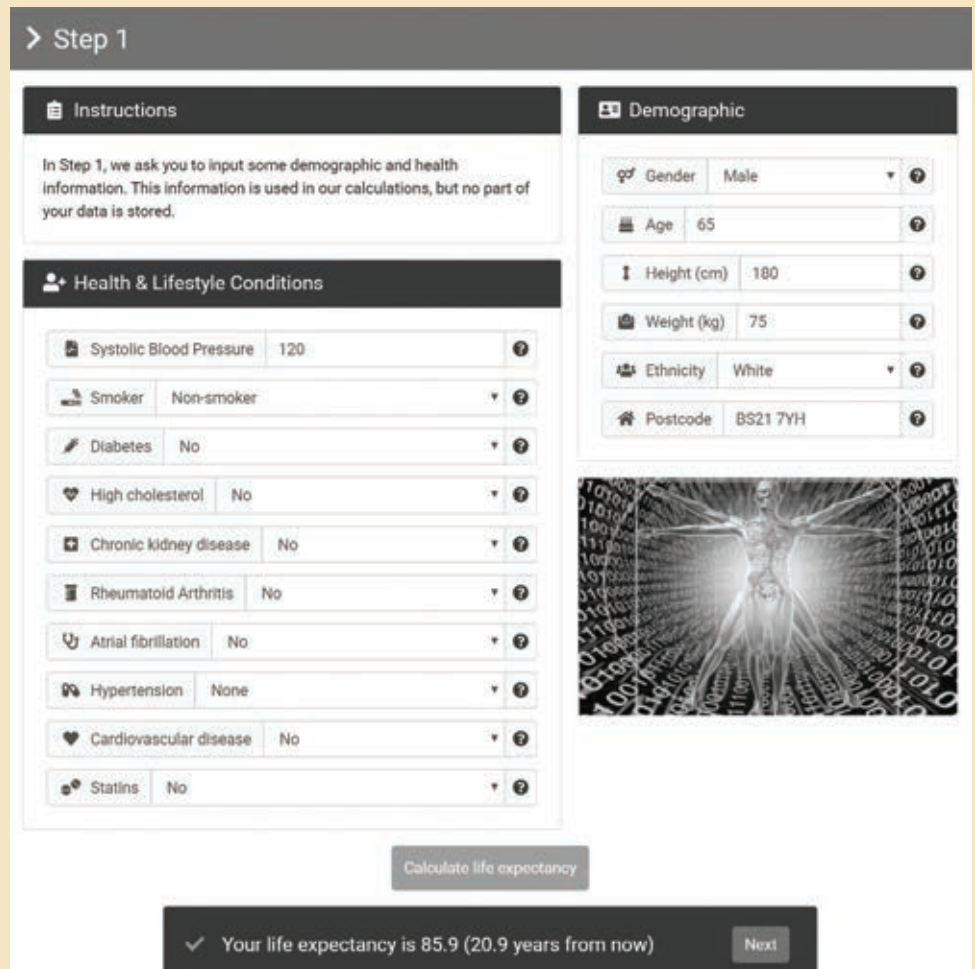
The results show that statin therapy is associated with increasing survival benefits in older ages: age 65 hazard ratio  $HR = 0.86$  (95% confidence interval of 0.78-0.94), age 75  $HR = 0.81$  (0.74-0.89), age 80  $HR = 0.72$  (0.62-0.84) and age 85  $HR = 0.57$  (0.35-0.91). The survival benefit of statin therapy differed by birth cohort, but not by sex or cardiac risk. The 1936-40 cohort showed larger survival benefits than the 1930-1935 cohort, probably due to more efficient drugs or higher dosages.

For statins, the results of analyses based on a window width of five, 10

**FIGURE 2:** Log-hazards between ages 60-80 years from the ONS period life table centred at 2010 (circles) and fitted regressions by Townsend score quintiles (Q1 least to Q5 most deprived area) and sex (lines).



**FIGURE 3:** Screenshot from Step 1 of the mylongevity.org/v2 life expectancy calculator.



**FIGURE 4:** Life expectancy at age 65 by Townsend score quintiles (Q1 least to Q5 most deprived area) and sex.

TOWNSEND SCORE QUINTILE / SEX	HEALTHY STATIN		DIABETES STATIN		SMOKER STATIN	
	N	Y	N	Y	N	Y
Q1/F	87.8	89.5	84.6	86.2	81.9	83.5
Q1/M	86.4	88.1	83.1	84.8	80.4	82.0
Q5/F	87.1	89.1	83.3	85.2	80.4	82.1
Q5/M	84.8	86.9	81.0	82.9	78.1	79.8

and 30 years are very similar. This is also true, say, for diabetes, but not for smoking, where the hazards are significantly higher for a five-year window than for a 30-year window, at 2.95 (2.77, 3.15) vs 2.34 (2.26, 2.42) at age 65. This is because in the landmark analysis, only the risk profile at the start of a window is used, and while a chronic condition such as diabetes will not go away, people may change their lifestyle choices (eg give up smoking) in the longer term.

### Calculating life expectancy

To estimate life expectancy, we need to make an assumption about the baseline hazards. We use the Gompertz baseline hazards,  $\mu_0(x) = e^{a+bx}$  which describe well the mortality between ages 50 and 95 and increase log-linearly between these ages (Brenner et al., 1993; Spiegelhalter, 2016). Under the Gompertz law, the increase in the annual hazard of mortality associated with ageing one year is approximately constant. However, it is well known that the force of mortality differs by gender and by deprivation.

To measure area deprivation, we use the Townsend score, obtained from the UK Census 2001 and available from the UK Data Service. Gompertz log-hazards for different deprivation levels measured by the Townsend score quintiles are depicted in Figure 2.

Combining age-varying hazard ratios obtained from landmark

analysis with the Gompertz baseline hazards, we obtain cumulative hazard functions, and hence life expectancy.

The overall life expectancy is a weighted average of LEs of people with different socio-economic and health profiles. Our methodology (Kulinskaya et al., 2020) allows to subdivide it into component LEs for people with particular risk profiles. The weights, based on the counts of people with the specific covariate values, are also estimated from the EHR data.

As an application of our methodology, we are developing a life expectancy calculator, available at [mylongevity.org](http://mylongevity.org) (web developer George Oastler). Results of our

**“Dynamic statistical analysis allows us to make more accurate predictions, based on real-time data, dynamic risk stratification and more personalised service”**

landmark analysis are translated into LEs for 648 different risk profiles at different ages within each sex and deprivation quintile. The list of risk factors we use include hypertension, diabetes, hypercholesterolemia, BMI category, QRISK2 (the risk of a cardiac event within 10 years), smoking status and statin use.

As an example (Figure 4), for a healthy 65-year-old female who is resident in the least deprived postcode, our calculator provides a LE of 87.8 vs 89.5 years with or without statins; for a male, those numbers are 86.4 vs 88.1 years. Diabetes decreases LE by more than three years; among diabetics, statins increase the LE from 84.6 to 86.2 years for females and from 83.1 to 84.8 years for males. Smoking decreases LE by approximately six years; among smokers, statins increase the LE from 81.9 to 83.5 years for females and from 80.4 to 82.0 years for males. Deprivation decreases LE by one to 1.5 years for healthy people, but by two to 2.5 years for people with diabetes or for smokers.

These life expectancies do not take future health and lifestyle choices into account. If we assume the same health and lifestyle continuing to age 85, life expectancies for healthy and prosperous people on statins increase to 91.9 for females and 90.1 for males.

LE calculation at such a fine scale will not only be useful for individuals and their physicians for improving life expectancy via healthy lifestyle changes, but also for individuals, independent financial advisors and the insurance industry for financial planning and reserving of actuary products. Our R software, which will enable bulk calculation of LE, is due to be released later in the year.



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