Maximum human lifespan: Will the records be unbroken?

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EXTENDED ABSTRACT

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Abstract

If we limit ourselves to cases that have been well verified, the oldest persons who have ever lived – one woman and one man – died in the late 1990s. Jeanne Calment was born in 1875 and died in 1997 at the age of 122.5 years; Chris Mortensen was born in 1882 and died in 1998 at the age of 115.7 years. It seems notable (and perhaps curious) that the world record in human longevity has not been broken for more than 13 years for either men or women. Indeed, this observation may be disconcerting for those who follow such trends closely. Does it raise doubts about the authenticity of those two cases? What is the likelihood that such records would be unbroken by chance alone over this time interval? In general, what is the expected waiting time between the breaking of such records? In this paper, we will attempt to answer such questions by building on our previous work on this topic. In particular, we will extend the model developed by Wilmoth and Robine (2003) to approximate the global trend in the maximum human lifespan, using that model here to estimate the probability of observing new world records over a given time period.

Introduction

The verified world record of human lifespan has not been broken for more than 13 years for either men or women, as the oldest persons who have ever lived – one woman and one man – both died in the late 1990s. Jeanne Calment was born in 1875 and died in 1997 at the age of 122.5 (Robine and Allard 2001); Chris Mortensen was born in 1882 and died in 1998 at the age of 115.7 (Wilmoth et al. 1996). Both records still stand to this day.

Previous studies of the trend in the maximum age at death for national populations with reliable data indicate that the maximum lifespan has been rising steadily in industrialized countries for more than a century (Wilmoth and Lundström 1996). Moreover, the increase in the maximum age at death in Sweden, the country with the longest series of reliable data, has accelerated since 1969 (Wilmoth et al. 2000). Why, then, are these two records still unbroken? Is this an unusual or unexpected outcome, possibly raising doubts about the authenticity of the two cases in question? Or is it, perhaps, entirely consistent with existing models of the trend in maximum human lifespan?

In this paper we will attempt to answer such questions by building on our previous work on this topic (Wilmoth and Lundstrom 1996, Wilmoth et al. 2000, Wilmoth and Robine 2003). It is worth noting from the start the claim by Wilmoth and Robine that the case of Jeanne Calment was truly exceptional, with the probability of observing such an event for the global cohort of 1875 being a minuscule 2.19×10^{-4}. The exceptional longevity of Jeanne Calment was thus the kind of event that should occur only once every 4500 years, if the mortality conditions experienced by her particular cohort were held constant over time. With continued reductions in mortality rates at older ages, we should expect to see a repeat of Jeanne Calment's exceptional longevity sooner than that. But how much sooner?

Previous modeling has not included separate calculations for men, and thus our existing models represent trends in maximum lifespan for men and women together; thus, in effect they represent the female trend. For this reason we do not possess a similar statistic about the probability of observing Chris Mortensen's exceptional longevity. It seems likely that his case is much less extreme than that of Jeanne Calment, which makes the unbroken record perhaps more suspicious for males than for females. We cannot know the answer, however, because we have never made the appropriate calculations separately for males. In this paper we will extend the work in this important direction. At the same time, for both men and women we will derive probabilistic statements about the likelihood of observing a repetition of the extreme longevity of Calment or Mortensen over various time periods.

Data and Methods

Our analysis relies mostly on Swedish cohort data beginning with the 1751 birth cohort, as available in the Human Mortality Database (HMD). The reporting of age at death at the highest ages for these cohorts, even those born in the 18th century, appears to be highly reliable (Wilmoth and Lundstrom 1996). The existence of a unified national statistical system in Sweden dates from 1749. As a result, it has been possible to verify ages at death even for very old persons beginning around the year 1860. It seems likely that data quality from this time forward was enhanced also by the founding in 1860 of the present-day National Central Bureau of Statistics (known commonly today as Statistics Sweden).

We intend to supplement observed Swedish cohort data by the use of projected data. We will consider three scenarios regarding future mortality trends at the oldest ages: (1) stabilization since 2010; (2) continued slow decline at post-1970 historic levels; and (3) faster decline at twice the historic level. For scenario (1), we will assume that the cohort's unobserved death and exposure data at each age equal the average of those quantities for the most recent ten-year cohort available. For scenarios (2) and (3), unobserved death rates at older ages will be projected using the Lee-Carter (LC) model (Lee and Carter 1992). According to this model, variation in death rates by ages and time is defined as

$$\ln \mu_{x,t} = a_x + b_x k_t + \varepsilon_{x,t}$$

where a_x is an average age effect, k_t captures how mortality changes over time, and b_x represents the age pattern of decline. When k_t and b_x are scaled properly, b_x represents the average annual rate of mortality decline for the given age group over the observation period.

The LC model identification for scenario (2) will be done using observed Swedish death rates from 1970 to 2010. The LC-projected death rates for 2011–2065 and ages up to 99 will be calculated with fixed $\mathrm{a_x}$ and b_x values (i.e., those estimated with the 1970–2010 data). The k_t values will be extrapolated according to the usual random walk with drift. For scenario (3), which assumes a faster decline of mortality at twice the historic level, we will simply double the estimated rate of decline, $\hat{b}_x$, from scenario (2).

As in our previous work, we will treat the observed maximum age at death in a given birth cohort as a random variable with a theoretical probability distribution. More specifically, if $S(x)$ represents the probability of survival from birth to age x for any random individual belonging to a cohort of N births, then the probability that the observed maximum age at death for that cohort is greater than age x corresponds to

$$S^N(x) = 1 - [1 - S(x)]^N.$$ [1]

Thus, the probability distribution of the maximum age at death of a given birth cohort is determined both by the distribution of ages at death for its members and its initial size.

To estimate the probability distribution given by equation (1) for each Swedish cohort, death rates below age 80 will be taken directly from the HMD (or from the various projected scenarios for non-extinct cohorts), while death rates above age 80 will be estimated using a logistic model fitted to observed (or projected) death rates. The use of such a model will substantially reduce the typical erratic behaviour of death rates at older ages and will allow us to extrapolate the fitted logistic mortality curve to age 120 and above. Age-specific death rates over the entire age range

[1] In order to account for in- and out- migration of each cohort, a small correction will be applied to *N*.

will then be transformed into cohort probabilities of survival and used to compute the probability distribution of the maximum age at death for each birth cohort.

From these estimated probability distributions, pth percentiles will be computed. By definition, the pth percentile of a given cohort's distribution of the maximum age at death corresponds to the age x such that $S^N(x) = 1 - \frac{p}{100}$. Plotting the various percentile trends over successive birth cohorts illustrates the direction towards which the distribution of upper limits of achieved life-spans is heading in Sweden, as well as where it is positioned in the range of extreme ages for each cohort.

In order to move from the Swedish population to a broader universe, namely the universe from which known cases of extreme longevity such as Jeanne Calment and Chris Mortensen may have been drawn, we will borrow Wilmoth and Robine's preferred model of the maximum age at death for the human population. In that analysis we assumed that the trend in the maximum age at death in Sweden was typical of other countries capable of producing (including documenting) world records of human longevity, but also argued that differences should be observed in the level of this trend across populations (with larger populations at higher levels, given equal mortality). We suggested that the global trend in the maximum age at death might lie parallel to the Swedish trend, but perhaps 6-7 year higher due mostly to the increased size of the "eligible" population. This earlier work provides existing models (for sexes combined) of the percentile trends in exceptional survivorship. The work we propose here will involve updates and extensions of this work to answer further questions.

We will, first, extend old results by adding roughly 10 more years of data and by making calculations separately by sex. Second, we will compute probabilities of observing cases like Calment and Mortensen within a given year or over some stretch of years. For example, let

$$p_t = \Pr[X_{\max}(t) > 122.5] = S^N(122.5, t)$$

be the calculated probability that the oldest surviving individual in cohort t (of size N) dies at some age greater than 122.5 years. One minus this amount gives the probability of *not* observing a human lifespan above the Calment limit in the given cohort. Thus, over some span of years represented by Y, the probability of *not* observing a new world record would be as follows:

$$\Pr[X_{\max}(t) \leq 122.5 \text{ for all } t \in Y] = \prod_{t \in Y} (1 - p_t).$$

One minus this amount would be the probability of someone breaking Jeanne Calment's record over some span of time.

Preliminary Results

Here we give preliminary results for the first steps of these calculations, consisting mostly of updates of previous calculations. For example, Figure 1 presents an updated version of the historical trend in the maximum age at death attained in Sweden by year of birth for both sexes, along with percentiles of the estimated probability distribution of this random variable. Previously, this figure covered the 1756–1884 extinct birth cohorts (Wilmoth et al. 2000). Although the upward percentile trends continued for cohorts born after 1884, this new figure suggests that the pace of increase slowed substantially.

This deceleration is reflected also in Figure 2, which provides an update of a figure by Wilmoth and Robine (2003) showing percentile trends for the so-called A scenario of "3-star validated" cases. The slowdown in the rising percentile trends after the cohort of 1884 is probably due to the similar slowdown in the pace of mortality decline at older ages in more recent years.

We are still working on the final step of these calculations to obtain probabilities of observing exceptional cases over various time periods, as described above. At this moment we are checking our preliminary results very closely and trying to understand them.

References

Human Mortality Database, HMD. University of California, Berkley (USA), and Max Planck Institute for Demographic Research (Germany). Available at http://www.mortality.org or http://www.humanmortality.de (data downloaded on 7/18/2011).

Lee, Ronald D. and Lee R. Carter. 1992. "Modeling and forecasting U.S. mortality," *Journal of the American Statistical Association* 87(419): 659–671.

Robine, Jean-Marie and Michel Allard. 2001. "Jeanne Calment: Validation of the duration of her life," in Bernard Jeune and James W. Vaupel (eds.), *Validation of Exceptional Longevity*, Odense, Denmark: Odense University Press, pp. 145–162.

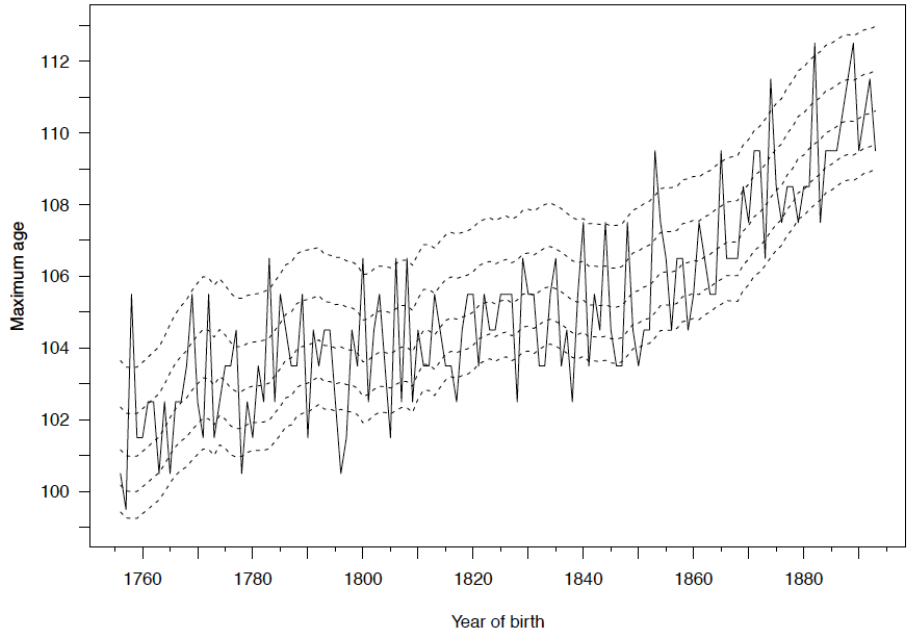
Wilmoth, John R., Leo J. Deegan, Hans Lundström, and Shiro Horiuchi. 2000. "Increase of maximum life-span in Sweden, 1861–1999," *Science* 289: 2366–2368.

Wilmoth, John R. and Hans Lundström. 1996. "Longevity in five countries: Presentation of trends with special attention to issues of data quality," *European Journal of Population* 12(1): 63–93.

Wilmoth, John R. and Jean-Marie Robine. 2003. "The world trend in maximum life span," in: James R. Carey and Shripad Tuljapurkar (eds.), *Life Span: Evolutionary, Ecological, and Demographic Perspectives*, supplement to vol. 29, *Population and Development Review*, pp. 239–257.

Wilmoth, John R., Axel Skytthe, Diana Friou, and Bernard Jeune. 1996. "The oldest man ever? A case study of exceptional longevity," *The Gerontologist* 36(6): 783–788.

Figure 1: Annual maximum ages at death (sexes combined) of Swedish birth cohorts born 1756 to 1893 with percentiles of estimated probability distribution



Note: Dotted lines correspond to the 10th, 25th, 50th, 75th, and 90th percentiles of the estimated distribution of the maximum age at death for each birth cohort.

Figure 2: Percentiles of estimated probability distribution (sexes combined) of birth cohorts 1756 to 1893, 3-star validated A countries