Record measures of longevity

(draft)

Vladimir Canudas-Romo John R. Wilmonth

Abstract

Life expectancy at birth is the most widely used demographic measure. It is calculated as the mean age at death of the life table distribution of deaths. This single number is frequently taken as a representation of the mortality situation in a country, while other measures of central tendency are seldom studied. This article reviews the trend over time of two other measures of the "typical" longevity experienced by members of a population (i.e. the median and modal ages at death). The paper also analyses trends in record values observed for all three measures. We review the trend over time in record life expectancy at different ages, and compare it with the pattern over time in other record longevity measures. The record life expectancy at birth for females increased from a level of 45 years in 1840 to 85 years in 2004. The record median age at death and remaining life expectancies show similar increasing patterns as those observed in the life expectancy at birth. However, the record modal age at death changes very little until the second half of the twentieth century: after the 1940s it moved from a plateau level around age 80, to having the same pace of increase observed by the rest of the measures in most recent years. Our findings explain the previously observed uninterrupted increase in the record life expectancy. The cause of this increase has changed over time from a dominance of child mortality reductions to a dominance of adult mortality reductions, which became evident by studying trends in the record modal age at death.

Record measures of longevity
(draft)

INTRODUCTION

Median and modal ages at death are seldom proposed as measures to study the distribution of deaths. The mean age at death, or life expectancy, is generally preferred because it includes all ages at death for its calculation. However, all three measures of central tendency are important. They supplement each other with information on the "center" of the distribution. Therefore, in an analysis of trends of mortality over time it is relevant to include all three measures to understand the dynamic of these most representative values.

Survivorship improvements, and mortality reductions, dictate the changes in the measures of central tendency. These changes in survivorship and mortality result from developments in public health, medicine, economic development, nutrition, education, and household conditions (Riley 2001). As long as the decline in mortality continues (and it does not worsen at other ages) all measures of longevity will keep their upward trend. Yet, the pace of these trends is dependent on the ages at which improvements are occurring (Wilmoth 2000).

Previous studies demonstrated that the trend over time of the record life expectancy is a measure of the continuous progress in mortality that has on a regular pace kept improving (Oeppen and Vaupel 2002). In the present paper we study the trends of the record measures of the three central tendency measures. Also here the record remaining life expectancies at ages one, thirty, fifty and seventy are included. The different time-trends in these measures enable us to understand the strong impact of the continuous progress in mortality and of the ages at which these improvements are occurring.

The following part of the paper introduces the calculations needed to obtain the measures of central tendency and their application is illustrated with the case of Swedish data in the third section. Next, we expand these concepts to analyze time trends on a global level by looking at record measures of longevity. The age-contribution to the change in longevity measures and the countries holders of the record measures of central tendency are presented in the last sections.

Our results are based on the total population of each country, but similar patterns were observed when analyzing females and males separately.

CALCULATIONS

To simplify many of the mathematical developments presented here let the radix of the life table be equal to one, $l(0,t)=1$. The life table density function describing the distribution of deaths (i.e., life spans) is denoted as $d(x,t)$ at age *x* and time *t*. From this distribution life expectancy at birth is calculated as the mean age at death:

$$e^{0}(t)=\int_{0}^{\omega} x d(x,t) dx \qquad (1)$$

where ω is the highest age attained and the denominator of this measure is equal to one, $\int_{0}^{\omega} d(x,t)dx=1$.

The median age at death, $Md(t)$, is the age when half of the population has died, that is when the survival function is equal to one half, $l(x,t)=0.5$. When the value of $Md(t)$ is found between two complete single ages *X* and *X+1*, then its value needs to be interpolated as $Md(t)=X+\gamma$, where γ is a function of the survival function and number of deaths at age *X*.

Finally, the modal age at death is the age when most deaths occur, $M(t)=\{x \mid max[d(x,t)]\}$. Two modes should be distinguished in the life table distribution of deaths; one at age zero, when people die immediately after birth and a late mode found at older ages. Given that we are interested in changes over time in the central tendency measures, we will focus on the late modal age at death to analyze changes, $M(t)=\{x \mid max[d(x,t)] \;\; for\; x>5\}$.

To obtain a mode with decimal point precision it is necessary to calibrate the value. To calibrate the modal age at death we use Kannisto's (1996) proposal. Given an initial single age *X* with the highest number of deaths, the modal age at death is found as $M(t)=X+\delta$. With δ giving the desired decimal point precision. Similar results are obtained when a quadratic curve is fitted to the values around the mode, but for simplicity we use here Kannistos's calibration.

The choice between the mean, median and mode depends on the purpose the measure is to serve. For a description of the distribution of deaths, the mode with its easily identified value, once the distribution is plotted, is to be preferred. For example, Figure 1 shows the death distribution for Sweden in 1900 where a bimodal distribution is clearly found at ages 0 and around age 86. In this case the mode is the most informative measure because it denotes where most of the deaths are concentrated. Figure 1 also displays the death distribution for the Swedish population at the end of the twentieth century. This distribution is negatively skewed towards older ages. In this example the median describes the distribution best because it is least affected by extreme ages at death.

[Figure 1]

Life expectancy portrays a mortality situation best when the distribution of deaths is relatively symmetrical. Although, during its change from being bimodal to unimodal, the death distribution never was symmetrical, life expectancy was used for describing its dynamic. Perhaps its predilection comes from the fact that life expectancy is the expected value of the distribution. Predictions and inferences based in the mean will have less total errors than predictions based on the other values. However, a more complete analysis of mortality can be reached when the three measures are included.

DYNAMIC OF MEASURES OF LONGEVITY

It is interesting to observe the pace of change in the three measures of central tendency for a single country. Figure 2 shows the three measures for the Swedish population during the period from 1840 to 2004. Also included in this Figure is the maximum age at death attained from 1861 to 2004 in Sweden (Wilmoth et al. 2000).

[Figure 2ab]

All the measures of longevity increase over time, even when at a different pace and level. The upward trend observed in the maximum age at death is similar to that of the modal age at death, while median and mean of the distribution have comparable patterns. The rise observed in the maximum and modal age accelerates in the second half of the twentieth century, and the median and life expectancy increase at a lower pace over the last decades of the studied period.

The increase in the maximum age at death in the second half of the twentieth century is explained by Wilmoth et al. (2000) as a combination of larger cohorts surviving to old ages, and to improvements in survival after these ages. Of these two components, reductions in mortality above age 70 is the main cause for the increase. In most recent years this factor accounts for 95% of the rise (Wilmoth et al. 2000). This suggests that the understanding of changes in the different longevity measures hinges on the contribution by ages to changes in mortality. This is addressed in a later section of this study.

The overall trends in life expectancy and median age at death are increasing with a more regular and slower pace in the second half of the twentieth century. Similar patterns of change in pace in life expectancy are observed in other industrialized countries (White 2002). Nevertheless, the trend of the record life expectancy is of uninterrupted increase (Oeppen and Vaupel 2002). Given that our interest is in using these measures to study longevity, we will analyze in the next section the record of all these measures in every year.

RECORD MEASURES OF LONGEVITY

Figure 3 shows the record life expectancy at birth, and the record median and modal ages of the death distribution from 1840 to 2000. Each of these records is calculated independently of each other, which is why different countries are holder of the record mode and median ages at death, and life expectancy. The focus on record survival pattern in a country for every given year was introduced by Oeppen and Vaupel (2002). Figure 3 updates their list of record life expectancies from 1840 to 2004, but now using data for the total population. Separate analysis carried out for females and males showed similar patterns as those presented here. Furthermore, Figure 3 compares the result of the record life expectancy with the other two measures of central tendency (Appendix 1 includes the record maximum age at death).

[Figure 3]

The mode is above the median, and the life expectancy has the lowest values during the entire observed period. The mode stagnated at levels around age 80 until the 1940s, while the median and life expectancy increased rapidly from minimums of 50 and 43 in 1840 to age 77 and 73 in 1950s, respectively. Since then the three measures have increased at a similar pace keeping a gap of 4 years on average from mode to median and from median to life expectancy. After 1950, the modal age increases 1.4 years every 10 years, while the pace of the median age is 1.5 years and life expectancy 1.9 years. The accelerated life expectancy is explained by the more symmetrical and unimodal tendency in the distribution of deaths in the record countries, which incidentally will bring the three measures to be equal to the mode.

Figure 4 shows records of remaining life expectancy (LE) at ages 1, 30, 50 and 70. Increases in these LE are observed at different intensities. The only crossover that is observed during the period is in 1966 when life expectancy at birth reached a higher level than LE1.

[Figure 4]

The difference between LE0 and LE30 was 12 years in 1840 and is almost 30 years in 2004. That is, there are no years of life expectancy lost between ages zero and 30 in the record life expectancy and LE30. Similarly remaining life expectancy at 30 increased faster than LE50 from a gap of 14 years in 1840 to 19 years in 2004, with only one year in LE30 lost before age 50. Finally, from LE50 to LE70 the increase is from 11 years to 17 years over the examined period. In other words, the successive remaining life expectancies have increased to levels where few numbers of years are lost before age 70.

The best fitting linear trend observed by Oeppen and Vaupel for the record life expectancy can be used to study the trend in other measures. To account for changes over time in the pace of increase in the above mentioned measures, we look at the best fitting line for every given year between 1840 and 2004, to 2004. For example, the best fitting line to LE0 from 1840 to the year of 2004 has a slope of 0.23, while the best fitting line from 1950 to 2004 has a slope of 0.19. Figure 5ab shows the change over time in the slopes of the best fitting lines for each of the measures mentioned above.

[Figure 5ab]

LE0 increased at a pace around 0.23 until 1860s, and then gradually reduced to 0.22 in 1918. From this year until 1950 a slower pace of increase is observed, reaching in this last year a minimum of 1.9 years of increase every 10 years. LE0 returned to the previous pace of increase in the most recent decades. The steep increase observed in the slopes of the best fitting lines in the last decades are based in the case of 1990 only on 14 points, and should, thus, not be over interpreted. The mode, median, LE1, LE30 and LE50 follow similar patterns of having some level of increase until 1950s when suddenly the slopes accelerated. A second sudden change is observed in the 1970s when the slopes accelerate once more. After this time LE70 has approached to the levels of increase observed in other life expectancies at younger ages.

AGE-CONTRIBUTION TO THE CHANGE IN LONGEVITY MEASURES

As discussed in previous sections reductions in death rates at different ages have different impact on the measures of longevity. During the more than a hundred years analyzed in this study the overall trend has been a decline in mortality at all ages, even when observing fluctuations from year to year. For simplicity, we will here only discuss reductions or stagnation in mortality, not increases.

The age-contribution to the change in life expectancy has been studied extensively by using decomposition methods (Canudas-Romo 2003). As shown in equation (1) all ages are included when calculating this measure and, thus, changes at any age has an impact on the change of life expectancy. This stands in contrast to the case for the other two measures. The median age at death has been examined by methods of decomposition (Horiuchi et al. 2006). It is not difficult to show its strong dependence up to the age where half of the survivors are left. If reductions in mortality occur before the age where the number of survivors is equal to half then the median will increase. However, there are no changes in the median age if mortality remains the same until the age where the number of survivors is equal to half. This is the case even when great reductions in mortality are present at older ages.

The age-contribution to changes in modal age at death has yet to be studied exhaustively. We have divided its analysis in two situations: when changes in mortality occur at younger ages than the modal age and at older ages than the modal age. Let as before M be the modal age at death. The modal age at death is obtained by comparing the number of deaths at all ages. Respectively, the number of deaths is the product of survivors arriving to each age by their death rates. If reductions in mortality only occur at ages younger than M, and no increases in mortality are observed, then the number of deaths found at any age before M, as compared to those at this age, will still be less. A simple argument to illustrate this is that while more survivors arrive to age M, more deaths will also be present at this age, maintaining *M* as the mode (This is analytically demonstrated in Appendix 2). If changes in mortality take place at ages older than M, this could make the modal age change abruptly to lower or higher ages.

To intuitively assess the dynamic of the three longevity measures observed in Figure 3 we examine them by using a simple mortality model. A mortality model proposed by Canudas-Romo and Schoen (2005) combines the model used by Siler (1979) and parameters that account for improvement in mortality over time. In the remaining text we refer to this model as the Siler mortality change model. Let the force of mortality at age *a* and time *t* be denoted as $\mu(a,t)$ and defined under the Siler mortality change model as

$$\mu(a,t) = e^{\alpha_1 - \rho_1 t - \beta_1 a} + e^{\alpha_2 - \rho_2 t} + e^{\alpha_3 - \rho_2 t + \beta_3 a}, \qquad (4)$$

where three constant terms reflect the value of $\mu(0,0) = e^{\alpha_1} + e^{\alpha_2} + e^{\alpha_3}$; the parameters β_1 and β_3 are fixed rates of the mortality decline and increase over age, respectively, and account for infant and senescent mortality; the parameters ρ_1 and ρ_2 are constant rates of mortality decrease over time. Parameters αs and βs stem from the Siler model, while the ρs are used in Gompertz models with a continuous rate of decline (Vaupel 1986; Schoen et al. 2004).

In the model we begin with relatively high infant mortality (175 per thousand), resulting from the values of $e^{\alpha_1} = 0.17$, $e^{\alpha_2} = 0.005$ and $e^{\alpha_3} = 0.0003$. The early decline over age proceeds at a pace of $\beta_1 = 1$ with an overall increase with age at a rate of $\beta_3 = 0.65$. The values for α and β are adapted from a comparison of the Siler model with the different model life tables elaborated by Coale and Demeny (Gage 1986). At time 0, the modal age at death at advanced ages is 80.5, the median age at death is 54.9 and life expectancy is 47.6. These values are comparable to those observed in populations with historical data. For example, the observed record values in 1840 are 72, 51 and 44 years for the modal and median ages and life expectancy, respectively (see Figure 3, values underlying this Figure and others are included in Table 1). For the pace of mortality improvement we have chosen $\rho_1 = 0.015$ and $\rho_2 = 0.01$. These values correspond to a 1.5% decline at younger ages and mortality improvement of one percent at older ages. The actual mortality decline at younger ages in several European countries occurred at an even faster rate (Woods et al. 1988, 1989). Furthermore, the rate of one percent is below the current average mortality decline in the West.

Figure 6 shows the results of the Siler mortality change model for 150 units, here set as years. In the first 100 years the improvement in mortality at adult ages ρ_2 is only used for ages younger than 80 and set to zero thereafter. For the remaining 50 years of time also at ages above 80 there are improvements in mortality, which gradually moves towards a rate of 0.01.

[Figure 6]

The patterns of the three measures of longevity in Figure 6 resemble those observed for the record measures in Figure 3. That is, during the first 100 years there is stagnation in the modal age at death around age 80, while the other two measures increase rapidly from values around age 50 years to ages above 70. For the remaining 50 years, the three measures increase at a similar pace while keeping the same ranking of highest for the modal age and lowest for life expectancy. These changes are related to the reduction in mortality which in the first 100 years occur at ages younger than 80, i.e. below the observed modal age at time zero of 80.5 years. In the last 50 years of the model, when mortality changes also at ages older than the modal age, also the modal age shows an upward trend.

The results of this section are summarized in Table 2 that shows the dynamic in the median, modal and mean ages at death depending of the age when the change occurs. If changes occur at ages younger than the modal age there are no effects in this measure, opposed to the median and mean that will change with reductions at ages younger than them. Inversely, the median shows no perturbations if changes occur at ages older than the median, while the mode and mean do change for this case.

Table 2. Effects in the Measures of Longevity of Changes at Different Ages

Measure X	Changes at ages below X	Changes at ages above X
Modal age at death	NO	YES
Median age at death	YES	NO
Life expectancy	YES	YES

COUNTRY HOLDERS OF THE RECORD MEASURES OF LONGEVITY

As shown by Oeppen and Vaupel (2002), few countries are the holders of the record life expectancy at birth. In this section we show that for the record median and modal ages at death the number of countries holding these records is also a small number. Figure 7 presents the countries holding the record modal and median ages and life expectancy (values underlying Figure 7 are included in Table 1.)

[Figure 7]

It should be noted that Figure 7 only presents countries which hold more than any two record measures. For more than a hundred years, Norway is the leader holder of the modal age at death. Also the record median and life expectancy has been held by Norway, however for these later measures New Zealand (excluding the Maori population) is the record holder from the 1880s up to the 1940s, leaving afterwards Norway the first place again. In the last years the record for all three measures has been held by Japan, but this occurs much earlier for the median and life expectancy than for the modal age at death.

DISCUSSION

The pace of increase in the median age at death and life expectancy at birth show no signs of reduction over the examined period. However, the reasons for this have varied over time. The initial increase in these measures is explained by the strong decline in infant mortality. As infant mortality reached low levels, the explanation of increase in median and life expectancy at birth were found at adult ages. At the time when, mortality improvements were present at older ages, an increase in the modal age at death and remaining life expectancies at older ages was observed. This process has been described as a shifting mortality process where the bulk of bell shaped distribution of deaths around the modal age at death moves towards older ages (Canudas-Romo 2006).

Since 1981, Japan has been the holder of the record life expectancy and median age at death. Only in seven of these years Japan also holds the record for the modal age at death. This illustrates that the modal age at death varies over time in a different way than the median and life expectancies.

The selection between which of the measures of central tendency o use depends on the purpose of the study. Here we have shown that including the three measures helped us observed the relevant effect of the age-contribution of changes in mortality. For countries with high survival the modal age at death will be particularly interesting because this measure is highly sensitive to changes at old ages

Appendix 1: Record Maximum age at death

The accuracy of the maximum age at death in Sweden is well studied. Nevertheless, less accuracy in age registration can be found for other countries (Wilmoth et al. 2000; Wilmoth and Lundstrom 1996). We do not discuss this in the text, but include a graphic representation of the record maximum age at death. Figure A shows the record maximum age at death and the best fitting regression line for these period.

[Figure A]

The pace of increase over time in the record maximum age at death corresponds to 1 year every decade. This is exactly the double of the increase observed in Sweden from 1860s to 1970s, and less than the increase observed in this country over the last part of the twentieth century (Wilmoth et al. 2000). The population register in Sweden is considered to be complete and highly accurate since at least 1861, and thus the proximity of our results to the Swedish numbers suggests the reliability of ours. Several countries reported ages far above the best fitting line. These overstated values should be taken with care. Nevertheless, the overall increase in the record maximum age at death corresponds to the results observed in other measures of longevity and may well be the actual representation for the record maximum age at death.

Appendix 2: Age specific changes in mortality and their effect on the modal age at death.

Let the force of mortality at age *x* and time *t* be denoted as $\mu(x,t)$. The life table survivorship function at age *x* under the rates at time *t* can be written as

$$l(x,t) = e^{-\int_0^x \mu(a,t)da}, \qquad \text{(A1)}$$

which can also be read as the probability of surviving from age birth to age *x*.

Let $d(x,t)$ be the density function describing the distribution of deaths (i.e., life spans) in the life table population at age *x* and time *t*. For every given age, the distribution of deaths is the product of the survival function up to that age multiplied by the force of mortality, $d(x,t) = l(x,t)\mu(x,t)$.

Let as before M(t) be the modal age at death at time t, for short M. For any age x different than M we, thus have

$$d(M,t) = l(M,t)\mu(M,t) > l(x,t)\mu(x,t) = d(x,t). \qquad \text{(A2)}$$

For x younger than M we divide equation (A2) by the survivors at age x and a key relation is obtained. The force of mortality at age M multiplied by the probability of surviving from age x to age M is greater than the force of mortality at age x:

$$\frac{l(M,t)}{l(x,t)}\mu(M,t) > \mu(x,t), \qquad \text{(A3a)}$$

for ages older than M the relation that holds is by using the probability of surviving from age M to age x,

$$\mu(M,t) > \frac{l(x,t)}{l(M,t)}\mu(x,t), \qquad \text{(A3b)}$$

Theorem

If at a future time T there are either reductions or no changes in mortality at ages younger than age M and at older ages there are no changes then the modal age at death continues to be the same as at time t, M(T)=M(t). In other words, equation (A2) holds for time T.

Proof

We here wish to demonstrate that the highest number of deaths at time T is obtained at exactly age M.

We know that the force of mortality at the modal age is not changing from time t to T,

$$\mu(M,T)=\mu(M,t). \tag{A4}$$

We also know that for younger ages there is a reduction in the force of mortality or at least it remains at the same level, that is

$$\mu(x,T)\le\mu(x,t) \text{ for } x\le M. \tag{A5}$$

Relation (A5) holds for all ages between x and M, and the integral of all these values at the respective times are also related as

$$\int_x^M \mu(a,T)da \le \int_x^M \mu(a,t)da. \tag{A6}$$

Multiplying both sides by -1 inverts the relation and exponentiating this result gives

$$e^{-\int_x^M \mu(a,T)da} \ge e^{-\int_x^M \mu(a,t)da}. \tag{A7a}$$

This shows that the probability of surviving from age x to M at time t is less than the probability of surviving between these ages at time T. From the definition of equation (A1) it is possible to rewrite the relation in (A7a) as,

$$\frac{l(M,T)}{l(x,T)} \ge \frac{l(M,t)}{l(x,t)}. \tag{A7b}$$

From equation (A4) and (A7b) we have

$$\frac{l(M,T)}{l(x,T)}\mu(M,T) \ge \frac{l(M,t)}{l(x,t)}\mu(M,t),$$

by applying the relations of (A3a) and (A5) we obtain

$$\frac{l(M,T)}{l(x,T)}\mu(M,T) \ge \frac{l(M,t)}{l(x,t)}\mu(M,t) > \mu(x,t) \ge \mu(x,T),$$

multiplying the first and last terms by the survivors at age x and time T, $l(x,T)$, gives us our desired result of $d(M,T) > d(x,T)$ for ages younger than M.

For ages older than M it is trivial to prove that the relation $d(M,T) > d(x,T)$ holds because the force of mortality at ages M and x and the probability of surviving from age M to age x do not change relation (A3b). Q.E.D.

Acknowledgements

The authors gratefully acknowledge financial support from the National Institute of Aging (grant R01AG11552).

References

Canudas-Romo, V. 2006. “The Modal Age at Death and the Shifting Mortality Hypothesis.” Presented at the PAA conference held in Los Angeles 2006.

--. 2003. *Decomposition Methods in Demography*. Rozenberg. Publishers: Amsterdam, The Netherlands.

Canudas-Romo, V. and R. Schoen. 2005. “Age-Specific Contributions to Changes in the Period and Cohort Life Expectancy.” Demographic Research 13(3): 63-82.

Gage, T. and B. Dyke. 1986. “Parameterizing Abridged Mortality Tables: The Siler Three-Component Hazard Model.” Human Biology 58(2): 275-91.

Horiuchi, S., J.R. Wilmoth and S. Pletcher. “A Decomposition Method Based on a Model of Continuous Change.” Unpublished Manuscript, Rockefeller University, University of California, Berkeley and Baylor College of Medicine.

Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de (data downloaded on [04/02/2006]).

Kannisto, V. 1996. *The Advancing Frontier of Survival.* Odense Monographs on Population Aging 3, Denmark: Odense University Press.

Oeppen J. and Vaupel J.W. 2002. "Broken Limits to Life Expectancy." *Science* 296: 1029-1031.

Riley, J.C. 2001. *Rising Life Expectancy: A Global History*. Cambridge University Press, New York.

Schoen, R., S.H. Jonsson and P. Tufis. 2004. "A Population with Continually Declining Mortality." Working Paper 04-07, Population Research Institute, Pennsylvania State University, University Park PA.

Siler, W. 1979. "A Competing-Risk Model for Animal Mortality." *Ecology* 60(4): 750-57.

Vaupel, James W. 1986. "How Change in Age-Specific Mortality Affects Life Expectancy." *Population Studies* 40:147-57.

Vaupel J.W. and Kistowski K.G. 2005. "Broken Limits to Life Expectancy." Ageing Horizons 3:6-13.

Vaupel J.W., Carey J.R. and Christensen K. 2003. "It's Never too Late." Science 301:1679-1681.

Wilmoth J. R., Deegan L.J., Lundström H. and Horiuchi S. 2000. "Increase of Maximum Life-Span in Sweden, 1861-1999." *Science* 289: 2366-2368.

Wilmoth J. R. and Lundström H. 1996. "Extreme Longevity in Five Countries." *European Journal of Population* 12: 63-93.

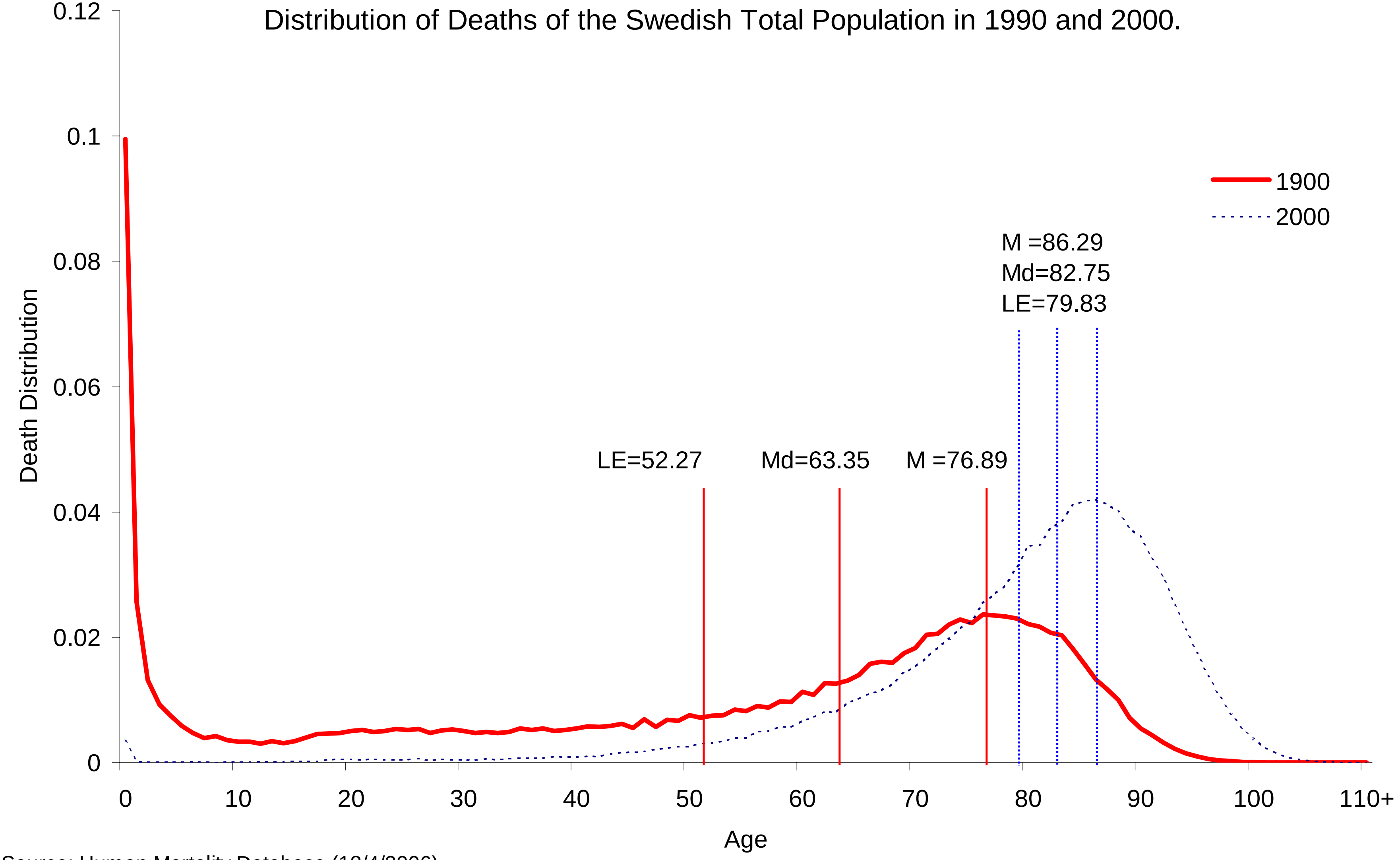
Wilmoth J. R. 2000. "Demography of Longevity: Past, Present and Future Trends." *Experimental Gerontology 35*: 1111-1129.

White K. 2002. “Longevity Advances in High-Income Countries, 1955-96.” *Population and Development Review* 28(1): 59-76

Woods, R.I., P.A. Watterson and J.H. Woodward. 1988. “The Cause of Rapid Infant Mortality Decline in England and Wales, 1861-1921. Part I.” Population Studies 42(3): 343-66.

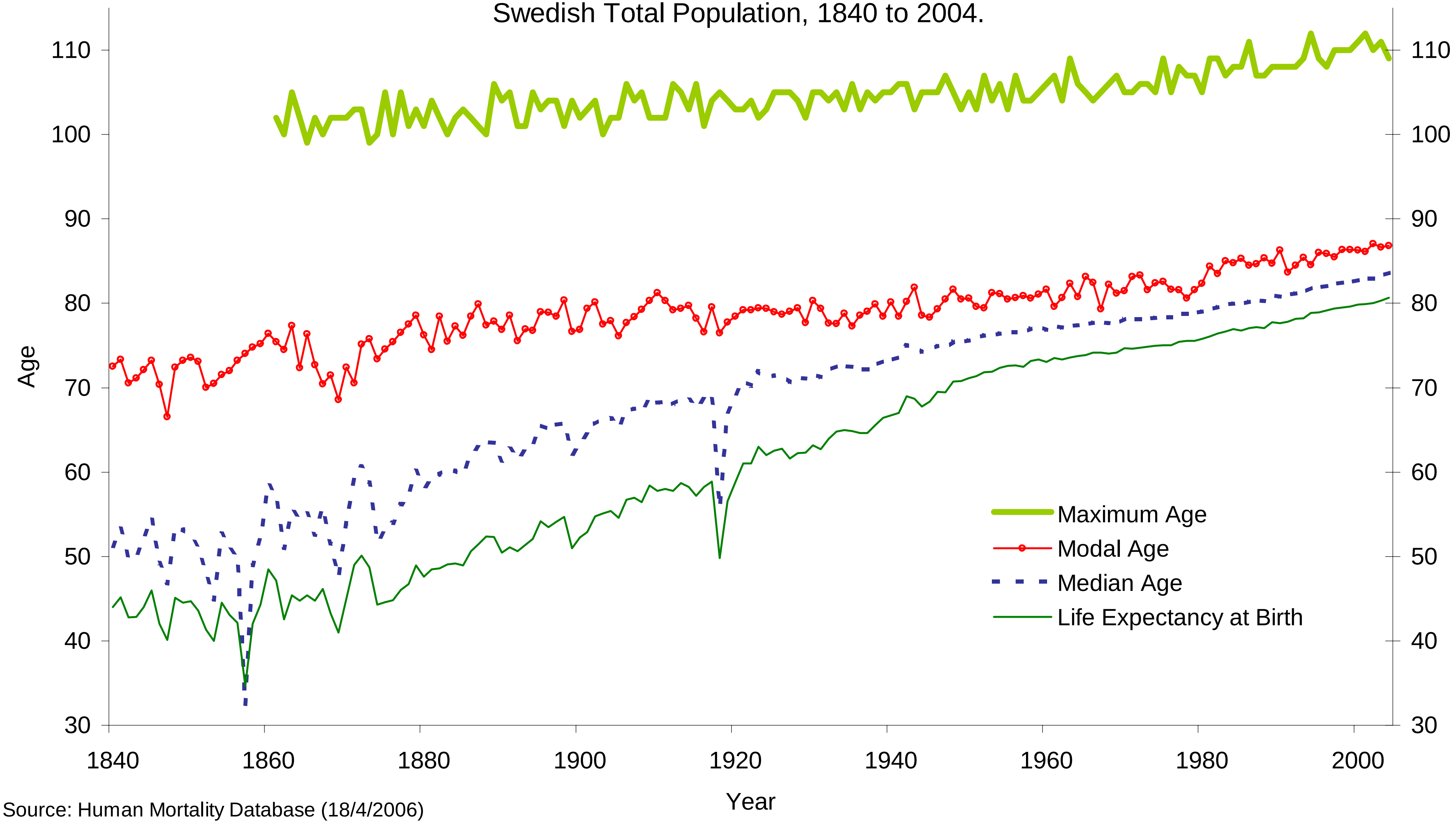
--.1989. “The Cause of Rapid Infant Mortality Decline in England and Wales, 1861-1921. Part II.” Population Studies 43(1): 113-32.

Figure 1. Mode (M) and Median (Md) Ages at Death, and Life Expectancy (LE) for the Age Distribution of Deaths of the Swedish Total Population in 1990 and 2000.



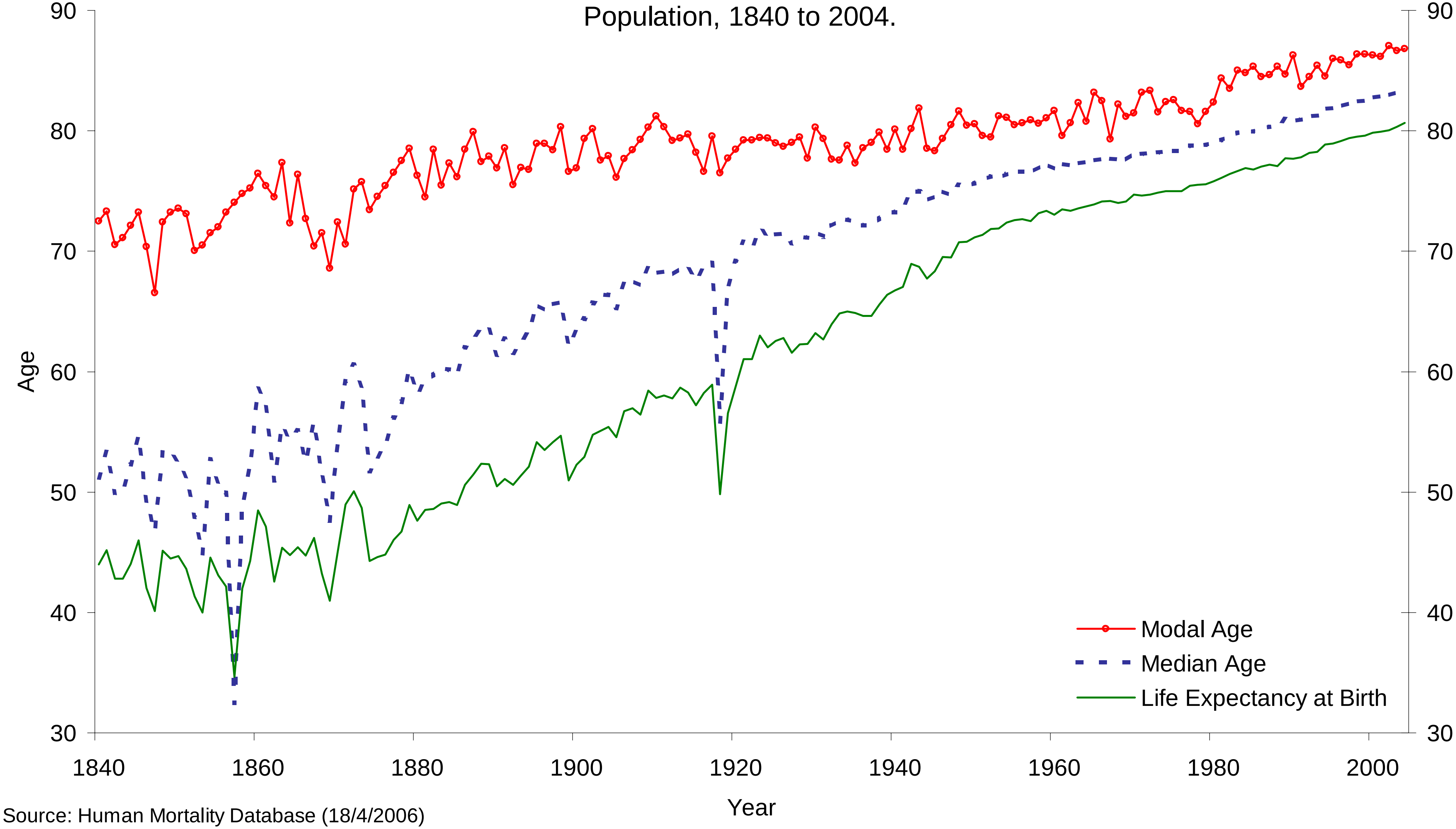
Source: Human Mortality Database (18/4/2006)

Figure 2a. Maximum, Modal and Median Ages at Death, and Life Expectancy at Birth for Swedish Total Population, 1840 to 2004.



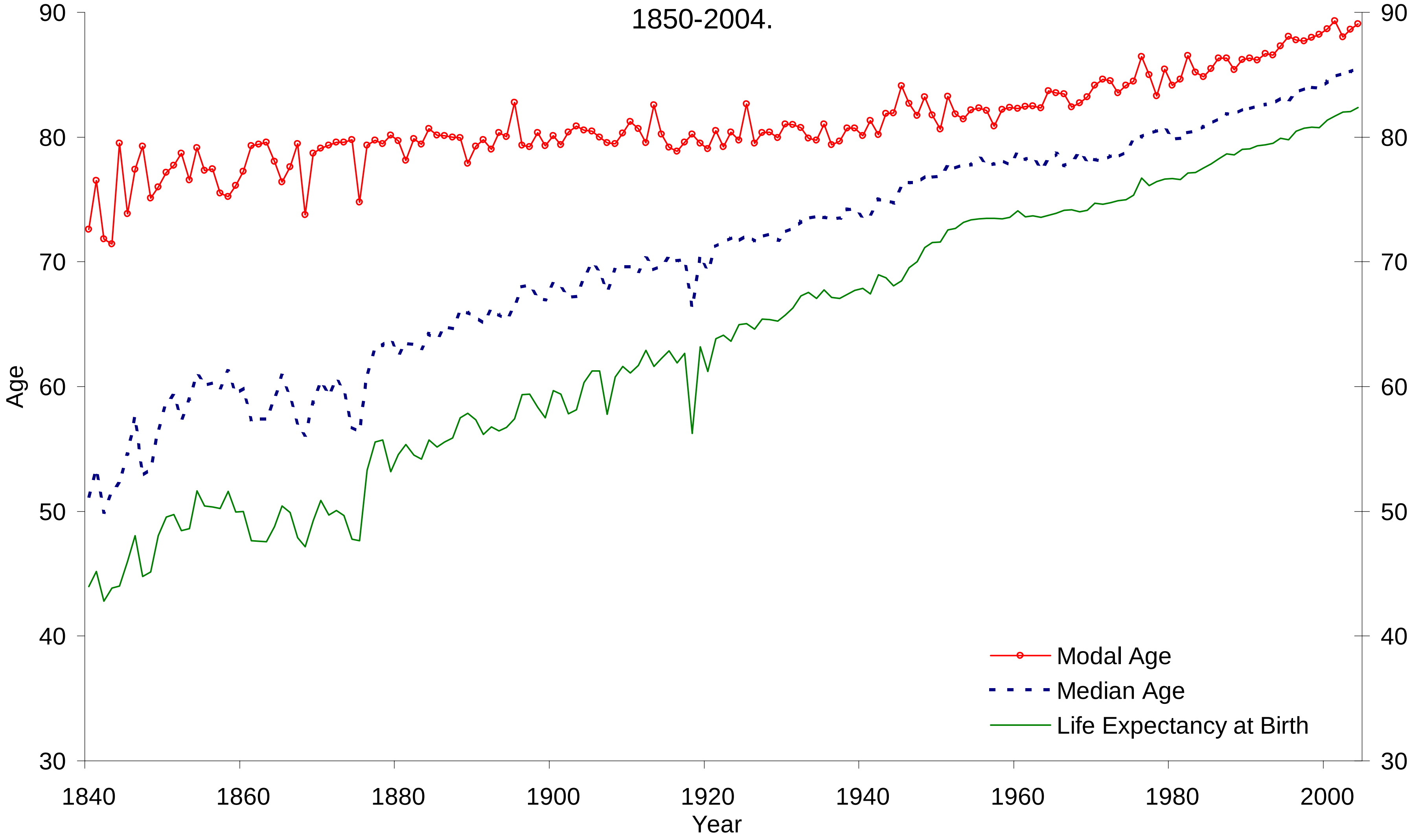
Source: Human Mortality Database (18/4/2006)

Figure 2b. Modal and Median Ages at Death, and Life Expectancy at Birth for Swedish Total Population, 1840 to 2004.



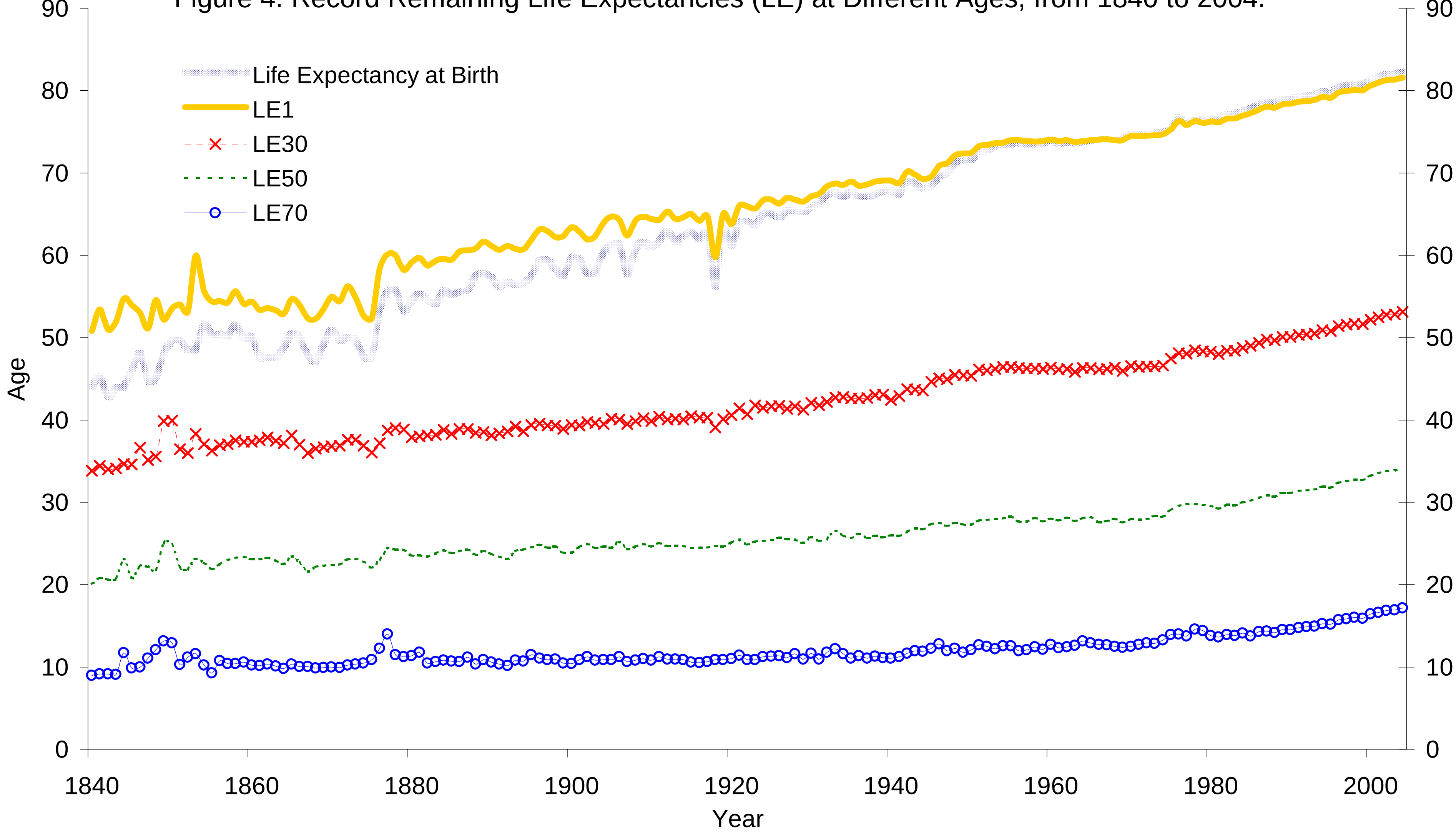
Source: Human Mortality Database (18/4/2006)

Figure 3. Record Life Expectancy at Birth, Modal and Median Ages at Death, 1850-2004.



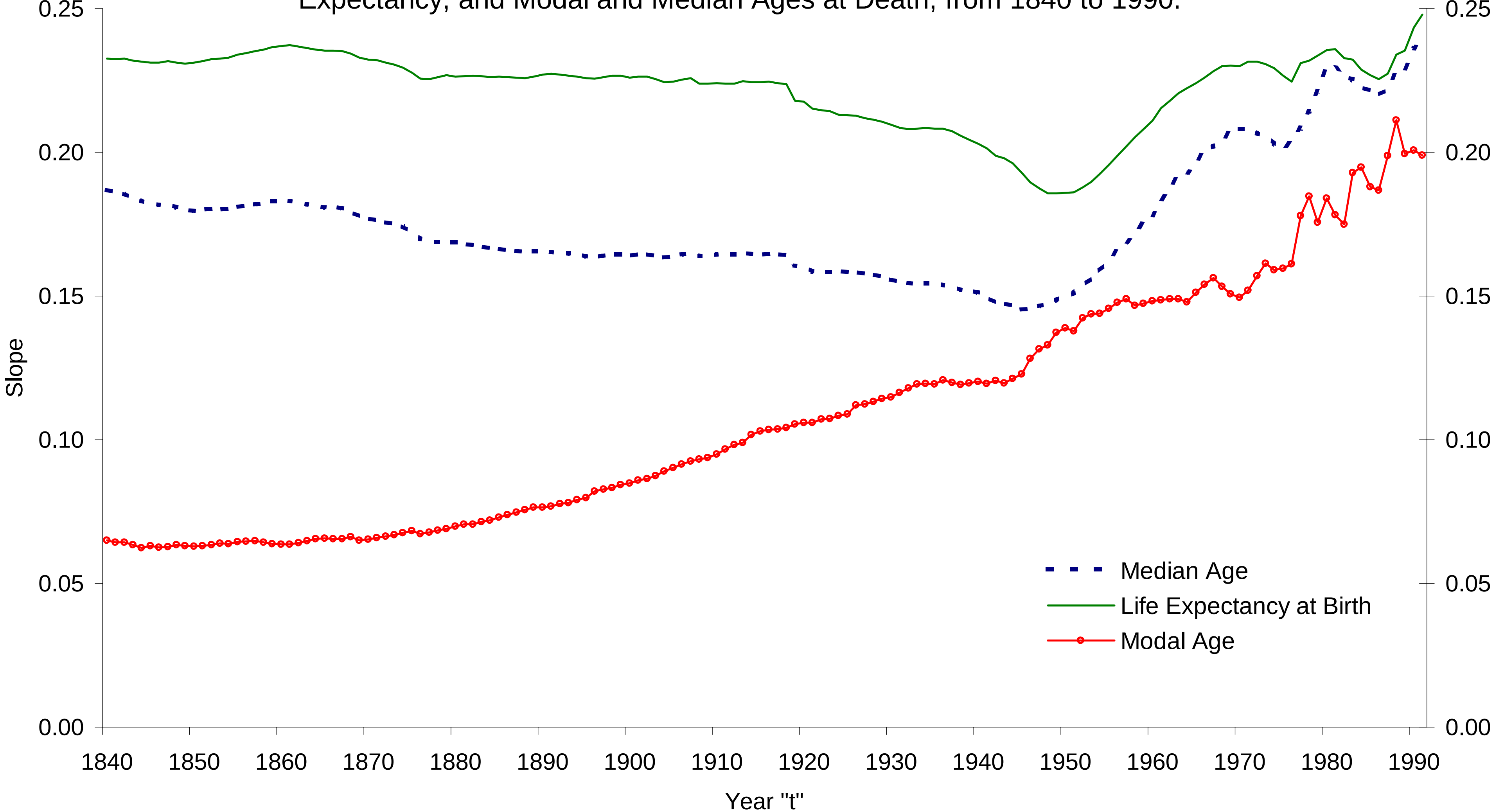
Source: All countries and for all the years available in the Human Mortality Database (18/4/2006)

Figure 4. Record Remaining Life Expectancies (LE) at Different Ages, from 1840 to 2004.



Source: All countries and for all the years available in the Human Mortality Database (18/4/2006)

Figure 5a. Slope in Year t of the Best Fitting Line from Year t to 2004 for the Record Life Expectancy, and Modal and Median Ages at Death, from 1840 to 1990.



Source: All countries and for all the years available in the Human Mortality Database (18/4/2006)

Figure 5b. Slope in Year t of the Best Fitting Line from Year t to 2004 for Remaining Life Expectancies at Ages 1, 30, 50 and 70, from 1840 to 1990.

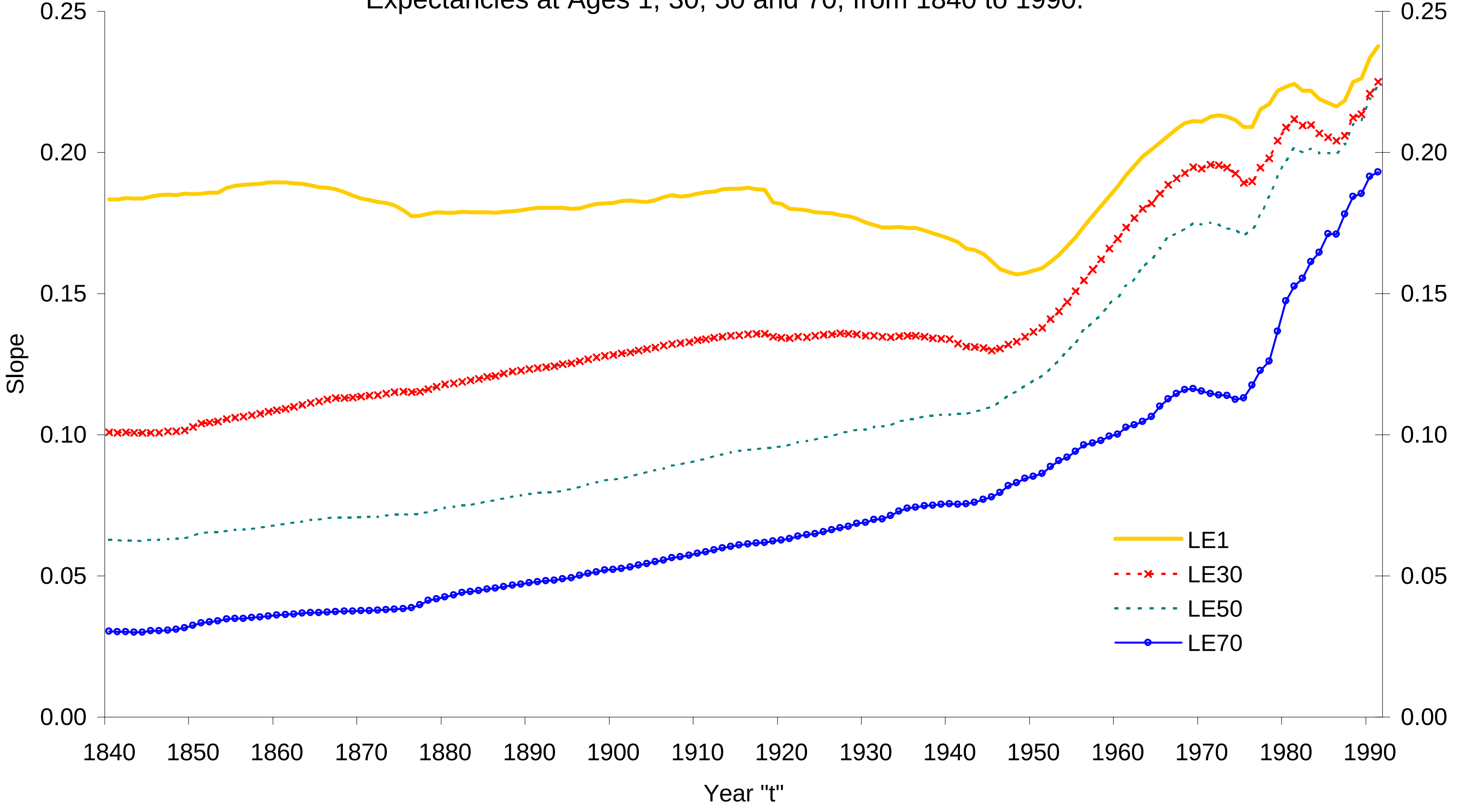


Figure 6. Modal and Median Ages at Death and Life Expectancy under the Siler Mortality Change Model.

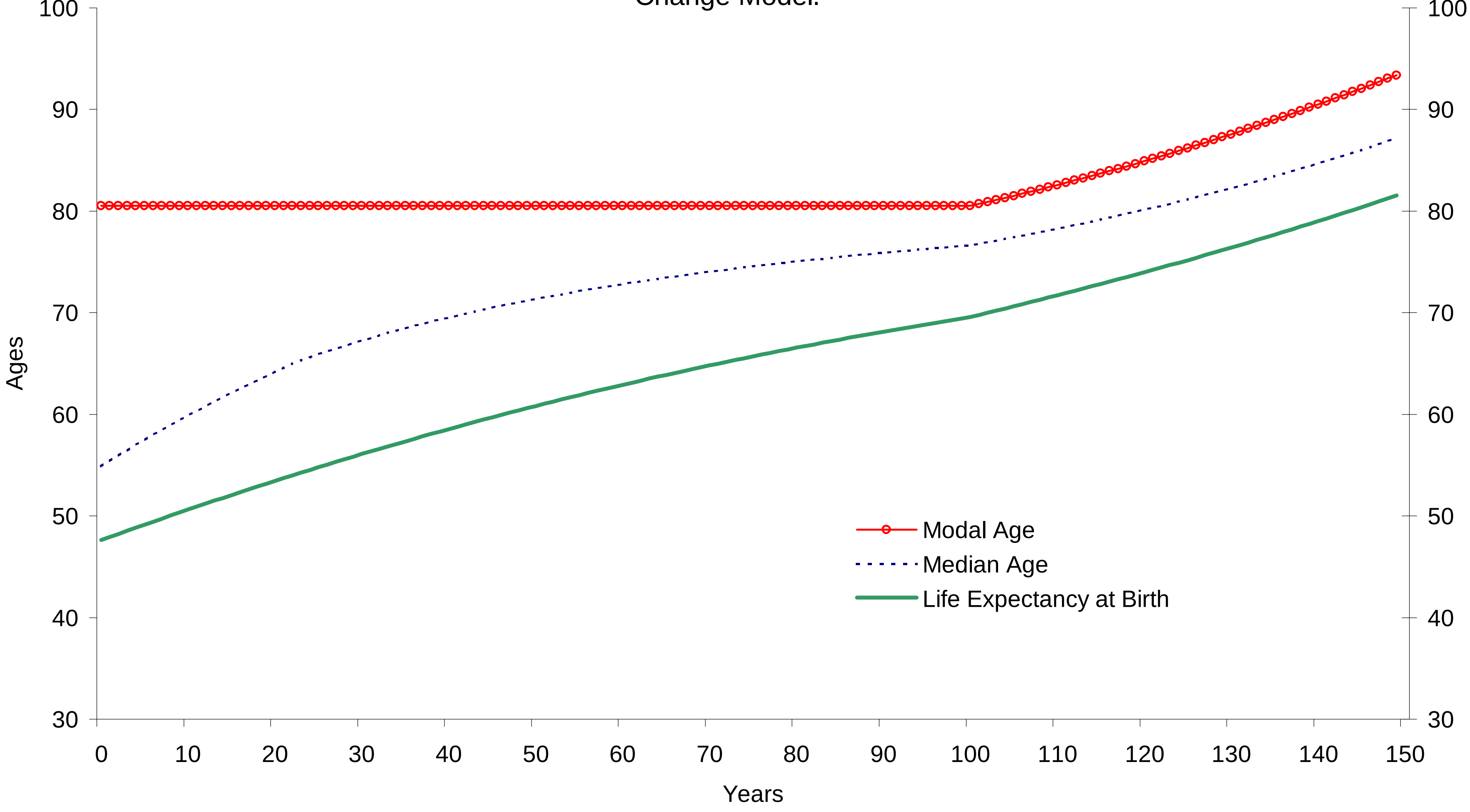
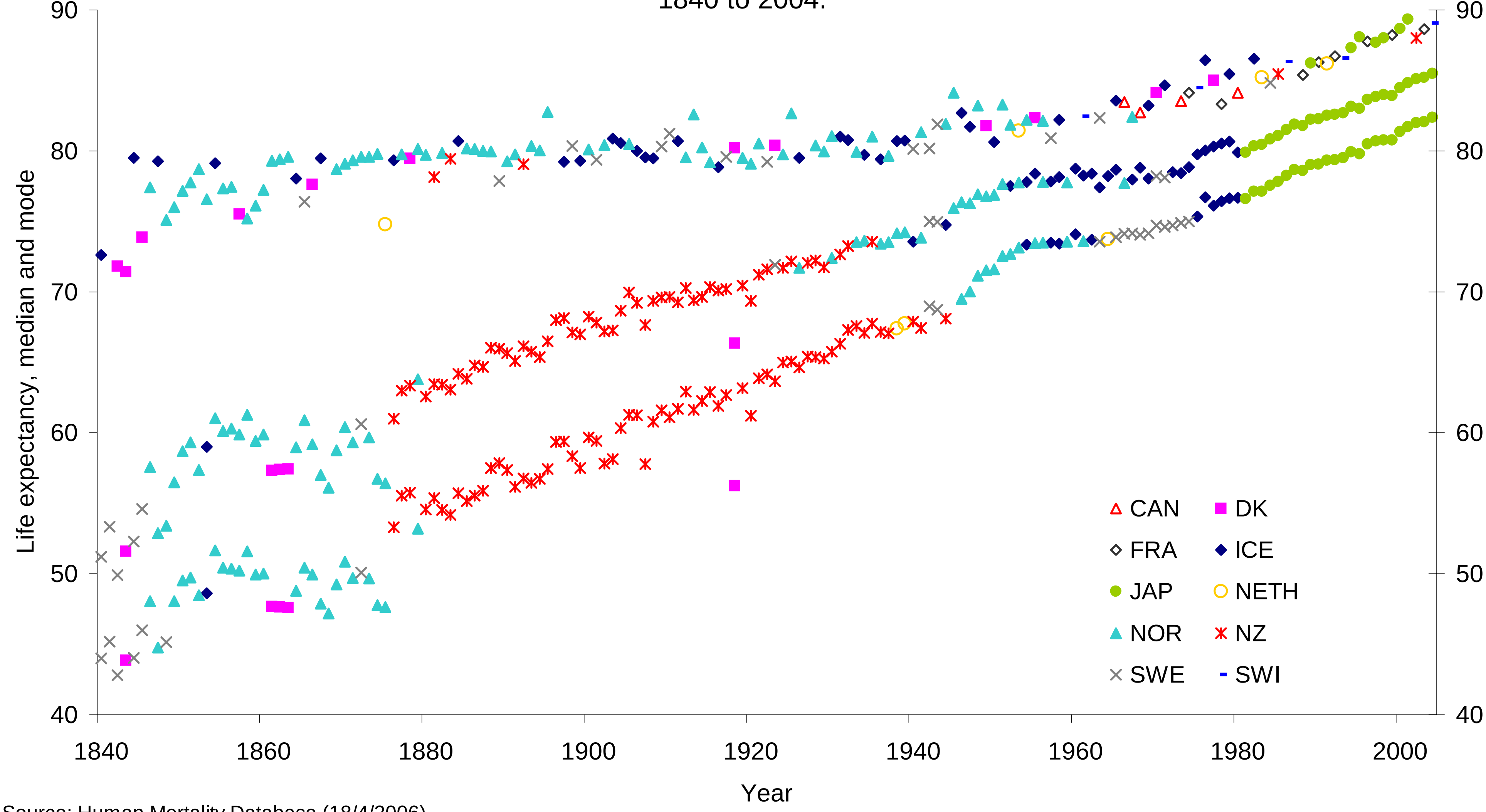
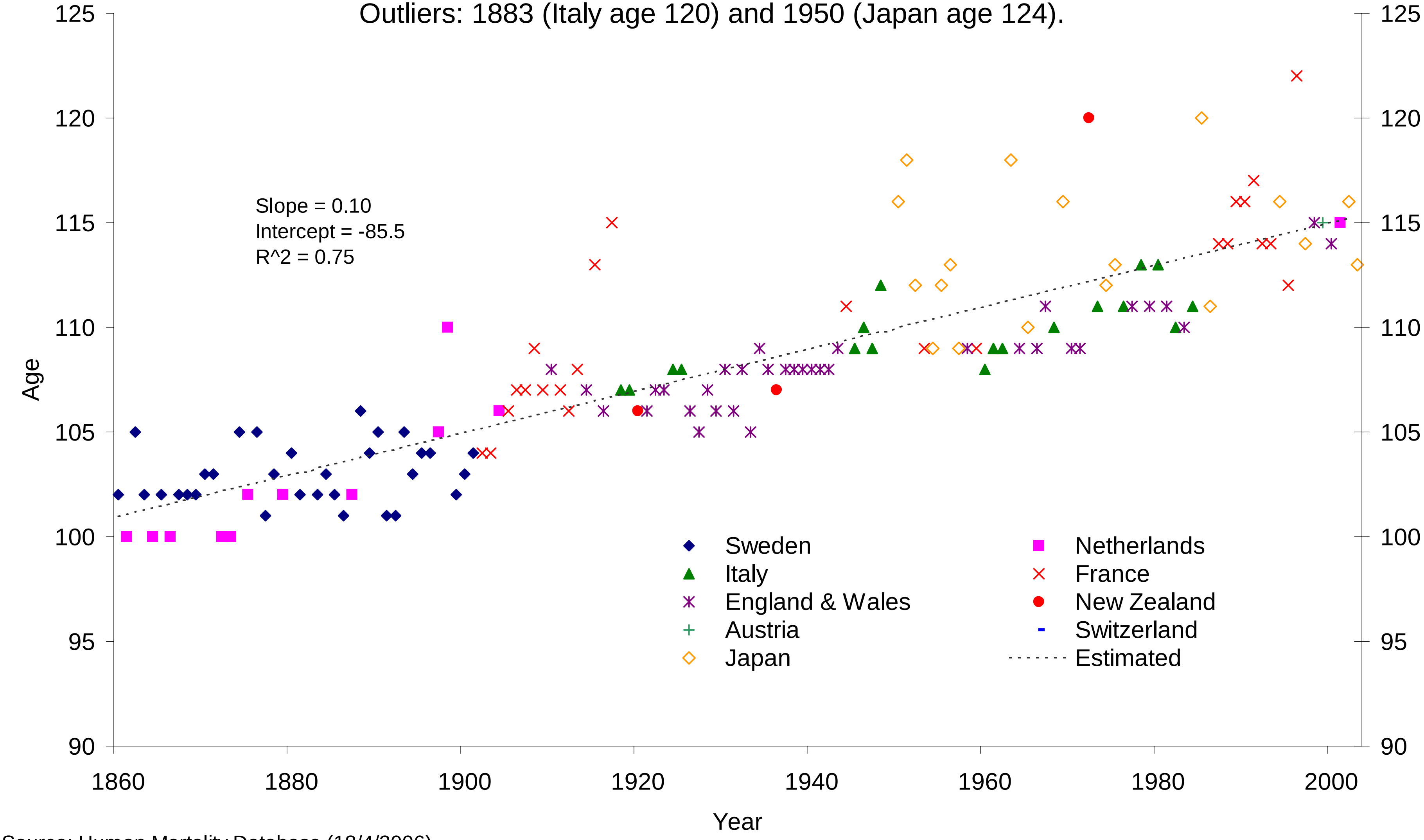


Figure 7. Country Holders of the Record Modal and Median Ages at Death and Life Expectancy 1840 to 2004.



Source: Human Mortality Database (18/4/2006)

Figure A. Record Maximum Age at Death 1861 -2004 and Best Fitting Line, without Two Outliers: 1883 (Italy age 120) and 1950 (Japan age 124).



Source: Human Mortality Database (18/4/2006)

Table 1. Record Modal and Median Ages at Death and Life Expectancy, and Country Holders of the Records.

	RECORD			COUNTRY HOLDER		
Year	Modal Age	Median Age	Life Expec.	Modal Age	Median Age	Life Expec.
1840	72.60	51.19	43.98	ICE	SWE	SWE
1841	76.50	53.33	45.17	EW	SWE	SWE
1842	71.82	49.92	42.80	DK	SWE	SWE
1843	71.43	51.57	43.86	DK	DK	DK
1844	79.51	52.27	44.03	ICE	SWE	SWE
1845	73.86	54.59	45.99	DK	SWE	SWE
1846	77.39	57.57	48.05	NOR	NOR	NOR
1847	79.27	52.87	44.77	ICE	NOR	NOR
1848	75.09	53.40	45.13	NOR	NOR	SWE
1849	76.01	56.48	48.05	NOR	NOR	NOR
1850	77.16	58.67	49.53	NOR	NOR	NOR
1851	77.74	59.30	49.74	NOR	NOR	NOR
1852	78.71	57.36	48.46	NOR	NOR	NOR
1853	76.55	59.00	48.60	NOR	ICE	ICE
1854	79.13	61.03	51.65	ICE	NOR	NOR
1855	77.32	60.13	50.44	NOR	NOR	NOR
1856	77.43	60.30	50.37	NOR	NOR	NOR
1857	75.51	59.87	50.22	DK	NOR	NOR
1858	75.21	61.27	51.59	NOR	NOR	NOR
1859	76.11	59.43	49.93	NOR	NOR	NOR
1860	77.23	59.86	50.00	NOR	NOR	NOR
1861	79.29	57.32	47.65	NOR	DK	DK
1862	79.41	57.41	47.62	NOR	DK	DK
1863	79.59	57.41	47.58	NOR	DK	DK
1864	78.05	58.97	48.78	ICE	NOR	NOR
1865	76.38	60.88	50.42	SWE	NOR	NOR
1866	77.60	59.19	49.92	DK	NOR	NOR
1867	79.46	57.01	47.87	ICE	NOR	NOR
1868	73.78	56.11	47.16	EW	NOR	NOR
1869	78.70	58.74	49.25	NOR	NOR	NOR
1870	79.09	60.41	50.86	NOR	NOR	NOR
1871	79.33	59.31	49.69	NOR	NOR	NOR
1872	79.57	60.60	50.08	NOR	SWE	SWE
1873	79.57	59.67	49.67	NOR	NOR	NOR
1874	79.79	56.72	47.77	NOR	NOR	NOR
1875	74.78	56.40	47.64	NETH	NOR	NOR
1876	79.34	61.01	53.28	ICE	NZ	NZ
1877	79.75	62.99	55.55	NOR	NZ	NZ
1878	79.45	63.33	55.73	DK	NZ	NZ
1879	80.15	63.78	53.18	NOR	NOR	NOR
1880	79.72	62.56	54.56	NOR	NZ	NZ
1881	78.14	63.46	55.36	NZ	NZ	NZ
1882	79.86	63.41	54.52	NOR	NZ	NZ

1883	79.43	63.07	54.17	NZ	NZ	NZ
1884	80.68	64.19	55.70	ICE	NZ	NZ
1885	80.16	63.83	55.14	NOR	NZ	NZ
1886	80.12	64.77	55.55	NOR	NZ	NZ
1887	79.99	64.66	55.88	NOR	NZ	NZ
1888	79.96	66.03	57.51	NOR	NZ	NZ
1889	77.87	65.95	57.85	SWE	NZ	NZ
1890	79.24	65.66	57.34	NOR	NZ	NZ
1891	79.76	65.10	56.16	NOR	NZ	NZ
1892	79.04	66.15	56.76	NZ	NZ	NZ
1893	80.34	65.77	56.43	NOR	NZ	NZ
1894	80.01	65.38	56.71	NOR	NZ	NZ
1895	82.76	66.48	57.43	NOR	NZ	NZ
1896	79.36	67.98	59.35	ITA	NZ	NZ
1897	79.21	68.12	59.38	ICE	NZ	NZ
1898	80.35	67.11	58.34	SWE	NZ	NZ
1899	79.29	66.96	57.49	ICE	NZ	NZ
1900	80.09	68.25	59.67	NOR	NZ	NZ
1901	79.37	67.83	59.41	SWE	NZ	NZ
1902	80.40	67.19	57.80	NOR	NZ	NZ
1903	80.88	67.24	58.13	ICE	NZ	NZ
1904	80.55	68.66	60.33	ICE	NZ	NZ
1905	80.49	69.95	61.27	NOR	NZ	NZ
1906	80.00	69.20	61.25	ICE	NZ	NZ
1907	79.54	67.63	57.79	ICE	NZ	NZ
1908	79.46	69.35	60.78	ICE	NZ	NZ
1909	80.31	69.62	61.60	SWE	NZ	NZ
1910	81.22	69.62	61.10	SWE	NZ	NZ
1911	80.68	69.23	61.71	ICE	NZ	NZ
1912	79.54	70.27	62.92	NOR	NZ	NZ
1913	82.59	69.38	61.63	NOR	NZ	NZ
1914	80.22	69.64	62.25	NOR	NZ	NZ
1915	79.18	70.34	62.88	NOR	NZ	NZ
1916	78.84	70.08	61.91	ICE	NZ	NZ
1917	79.57	70.19	62.67	SWE	NZ	NZ
1918	80.21	66.34	56.25	DK	DK	DK
1919	79.49	70.46	63.18	NOR	NZ	NZ
1920	79.08	69.35	61.20	NOR	NZ	NZ
1921	80.50	71.21	63.85	NOR	NZ	NZ
1922	79.22	71.59	64.13	SWE	NZ	NZ
1923	80.38	71.89	63.64	DK	SWE	NZ
1924	79.74	71.72	64.97	NOR	NZ	NZ
1925	82.65	72.15	65.06	NOR	NZ	NZ
1926	79.49	71.69	64.62	ICE	NOR	NZ
1927	80.35	72.05	65.41	ITA	NZ	NZ
1928	80.38	72.22	65.38	NOR	NZ	NZ
1929	79.96	71.73	65.26	NOR	NZ	NZ

1930	81.05	72.39	65.74	NOR	NOR	NZ
1931	81.00	72.66	66.31	ICE	NZ	NZ
1932	80.75	73.25	67.28	ICE	NZ	NZ
1933	79.93	73.54	67.56	NOR	NOR	NZ
1934	79.73	73.62	67.07	ICE	NOR	NZ
1935	81.02	73.57	67.75	NOR	NZ	NZ
1936	79.40	73.43	67.15	ICE	NOR	NZ
1937	79.65	73.51	67.05	NOR	NOR	NZ
1938	80.69	74.15	67.40	ICE	NOR	NETH
1939	80.73	74.24	67.73	ICE	NOR	NETH
1940	80.13	73.56	67.87	SWE	ICE	NZ
1941	81.32	73.83	67.43	NOR	NOR	NZ
1942	80.18	75.00	68.97	SWE	SWE	SWE
1943	81.89	74.95	68.72	SWE	SWE	SWE
1944	81.91	74.74	68.09	NOR	ICE	NZ
1945	84.11	75.93	68.46	NOR	NOR	AUS
1946	82.68	76.36	69.51	ICE	NOR	NOR
1947	81.72	76.30	70.01	ICE	NOR	NOR
1948	83.21	76.90	71.13	NOR	NOR	NOR
1949	81.76	76.78	71.53	DK	NOR	NOR
1950	80.63	76.89	71.60	ICE	NOR	NOR
1951	83.27	77.64	72.54	NOR	NOR	NOR
1952	81.83	77.53	72.67	NOR	ICE	NOR
1953	81.42	77.77	73.15	NETH	NOR	NOR
1954	82.18	77.78	73.36	NOR	ICE	ICE
1955	82.33	78.37	73.44	DK	ICE	NOR
1956	82.13	77.78	73.49	NOR	NOR	NOR
1957	80.89	77.84	73.47	SWE	ICE	ICE
1958	82.20	78.13	73.43	ICE	ICE	ICE
1959	82.38	77.77	73.56	LAT	NOR	NOR
1960	82.28	78.73	74.09	BUL	ICE	ICE
1961	82.45	78.23	73.59	SWI	ICE	NOR
1962	82.50	78.39	73.68	USA	ICE	ICE
1963	82.32	77.39	73.56	SWE	ICE	SWE
1964	83.68	78.21	73.73	LAT	ICE	NETH
1965	83.55	78.65	73.88	ICE	ICE	SWE
1966	83.44	77.71	74.13	CAN	NOR	SWE
1967	82.40	77.97	74.16	NOR	ICE	SWE
1968	82.74	78.82	74.03	CAN	ICE	SWE
1969	83.23	78.05	74.15	ICE	ICE	SWE
1970	84.13	78.19	74.70	DK	SWE	SWE
1971	84.64	78.10	74.62	ICE	SWE	SWE
1972	84.51	78.48	74.72	LIT	ICE	SWE
1973	83.53	78.41	74.88	CAN	ICE	SWE
1974	84.14	78.82	74.99	FRA	ICE	SWE
1975	84.46	79.74	75.35	SWI	ICE	ICE
1976	86.45	80.03	76.71	ICE	ICE	ICE

1977	85.01	80.29	76.11	DK	ICE	ICE
1978	83.30	80.51	76.42	FRA	ICE	ICE
1979	85.44	80.65	76.63	ICE	ICE	ICE
1980	84.13	79.87	76.66	CAN	ICE	ICE
1981	84.64	79.89	76.60	SPA	JAP	JAP
1982	86.54	80.36	77.11	ICE	JAP	JAP
1983	85.21	80.46	77.14	NETH	JAP	JAP
1984	84.81	80.84	77.54	SWE	JAP	JAP
1985	85.46	81.07	77.84	NZ	JAP	JAP
1986	86.34	81.49	78.26	SWI	JAP	JAP
1987	86.34	81.87	78.67	USA	JAP	JAP
1988	85.38	81.79	78.58	FRA	JAP	JAP
1989	86.21	82.22	79.02	JAP	JAP	JAP
1990	86.31	82.26	79.04	FRA	JAP	JAP
1991	86.18	82.52	79.32	NETH	JAP	JAP
1992	86.70	82.60	79.37	FRA	JAP	JAP
1993	86.57	82.70	79.51	SWI	JAP	JAP
1994	87.30	83.13	79.92	JAP	JAP	JAP
1995	88.06	83.00	79.77	JAP	JAP	JAP
1996	87.78	83.63	80.47	FRA	JAP	JAP
1997	87.68	83.85	80.70	JAP	JAP	JAP
1998	87.99	83.98	80.78	JAP	JAP	JAP
1999	88.22	83.91	80.75	FRA	JAP	JAP
2000	88.65	84.48	81.35	JAP	JAP	JAP
2001	89.32	84.84	81.70	JAP	JAP	JAP
2002	88.02	85.11	82.00	NZ	JAP	JAP
2003	88.64	85.22	82.06	FRA	JAP	JAP
2004	89.06	85.50	82.36	SWI	JAP	JAP

Source: Human Mortality Database (18/4/2006)

Note: BUL = Bulgaria, CAN = Canada, DK = Denmark, EW = England and Wales, FRA = France, ICE = Iceland, ITA = Italy, JAP = Japan, LAT = Latvia, LIT = Lithuania, NETH = Netherlands, NZ = New Zealand, NOR = Norway, SPA = Spain, SWI = Switzerland, SWE = Sweden.