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# Increase of Human Longevity: Past, Present, and Future

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## Introduction

The remarkable rise of human longevity that has occurred over the past few centuries is perhaps the greatest of all human achievements. The average length of life in the early history of our species was probably in the range of 20 to 35 years. By 1900, this value had already risen to around 40 to 50 years in industrialized countries. Slightly more than a century later, the world's healthiest countries now have a life expectancy at birth of around 80 years. Thus, at least half of the historical increase in human life expectancy occurred during the twentieth century. Much of the increase in this average value has been due to the near-elimination of infant and childhood deaths.

The increase of life expectancy at birth for France (Figure1) illustrates several key aspects of that country's demographic history over the past two centuries:

- Enormous increase of average longevity
- Differential impact of the various wars on men and women
- Emergence of a larger gap in life expectancy between men and women

Except for the particular experiences of war, the trends shown here are similar in form to those of many other nations.

Thanks to the "longevity revolution", industrialized societies (including Japan) are now faced with a large and growing elderly population, which poses a significant challenge in terms of medical care and social support. To some degree, societies must merely reorient themselves toward the care of a large dependent population at the end of life rather than at the beginning. Such adjustments are not without costs, however, as the needs of children and the elderly are quite different. Therefore, careful social planning is required, based on a firm understanding of demographic trends.

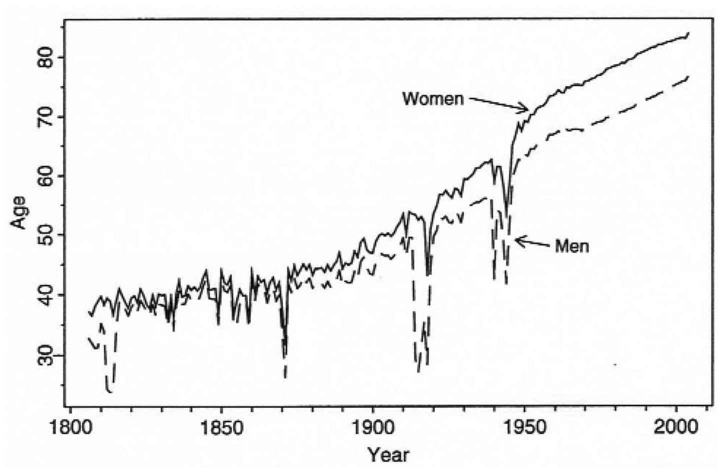
In this brief summary, I will not attempt to provide answers about how to make the needed social and economic adjustments. Rather, I will seek to explain the driving forces behind the increase of human longevity that underlie this momentous shift in population distribution from younger to older ages.

## 1. Human Longevity in the Past and Present

### 1.1 Prehistoric and Preindustrial Eras

We do not know much about how long humans lived before 1750. At that time, the first national population data were collected for Sweden and Finland. For earlier eras, we have some life tables constructed for particular groups that were probably not representative of the population at large. For the Middle Ages and earlier, mortality levels have been estimated based on data gleaned from

**Figure 1 Life Expectancy at birth and sex, France 1806-2004.**




Source: From Ref 1,2

tombstone inscriptions, genealogical records, and skeletal remains. The accuracy of such estimates has been a subject of dispute. However, most scholars agree that life expectancy at birth (or $e_0$, in the notation of demographers and actuaries) was probably in the mid-20s for early human populations, roughly a third of the values (around 75 to 80 years) found in wealthy countries today.

### 1.2 Historical rise of life expectancy

The rise in life expectancy at birth probably began before the industrial era. As noted earlier, $e_0$ was probably in the mid-20s during the Middle Ages and earlier. By 1750, Sweden (and probably other parts of northwestern Europe) had attained an $e_0$ of around 38 years, and thus the upward trend in longevity appears to have begun before the industrial era. Over the next century or more, there was a slow and irregular increase in life expectancy. After about 1870, however, the increase became stable and more rapid. During the first half of the twentieth century, life expectancy in the most advanced industrialized countries rose quite rapidly. Since 1950, the rise in life expectancy for these countries has slowed down somewhat, as illustrated in Figure 1 for France.

The cause of the earlier rapid rise in life expectancy and its subsequent deceleration is quite simple: the decline of juvenile mortality to historically low levels. By around 1950, infant mortality in wealthy countries was in the range of 2% to 3% of births, compared to perhaps 20% to 30% historically. Since then, infant mortality has continued to decline and is now less than half a percent of live births in the healthiest parts of the world. Once juvenile mortality was reduced substantially, improvements in life expectancy due to the reduction of mortality in this age range had to slow down, and further gains had to come mostly from mortality reductions at older ages.

### 1.3 Epidemiologic Transition and the Early Mortality Decline

The epidemiologic transition is the most important historical change affecting the level and pattern of human mortality. The transition refers to the decline of acute infectious disease and the rise of chronic degenerative disease. Increasingly, people survived through infancy and childhood without succumbing to infectious disease. Once past these critical early years, survival to advanced ages is much more likely, but at older ages, various degenerative diseases present mortality risks even when infection is well controlled. As mortality from infectious causes declined, heart disease, cancer, stroke, and accidents became the most common causes of death in industrialized societies.

### 1.4 Mortality Decline Among the Elderly

The most significant trend now affecting longevity in industrialized societies is the decline of death rates among the elderly. Until the late 1960s, death rates at older ages had declined slowly, if at all. Traditionally, rates of mortality decline were much higher at younger than at older ages. Since about 1970, however, the pace of mortality reduction at older ages has accelerated substantially. Thus, the decade of the 1960s marks a turning point, from an earlier era of longevity increase due primarily to the decline of acute infectious disease among juveniles to a more recent era involving the decline of chronic degenerative disease among the elderly.

### 1.5 Rectangularization or Mortality Compression

The age pattern of human mortality can be characterized in various ways. Figure 2 shows the American mortality levels in 1900 and 1995 from three perspectives. The first panel shows death rates by age. These death rates are used to construct a life table, which describes the experience of a hypothetical cohort subject throughout its life to the age-specific death rates of a given year. Thus, the middle and last panel show the distribution of deaths and the proportion of survivors at each age among members of such a hypothetic cohort.

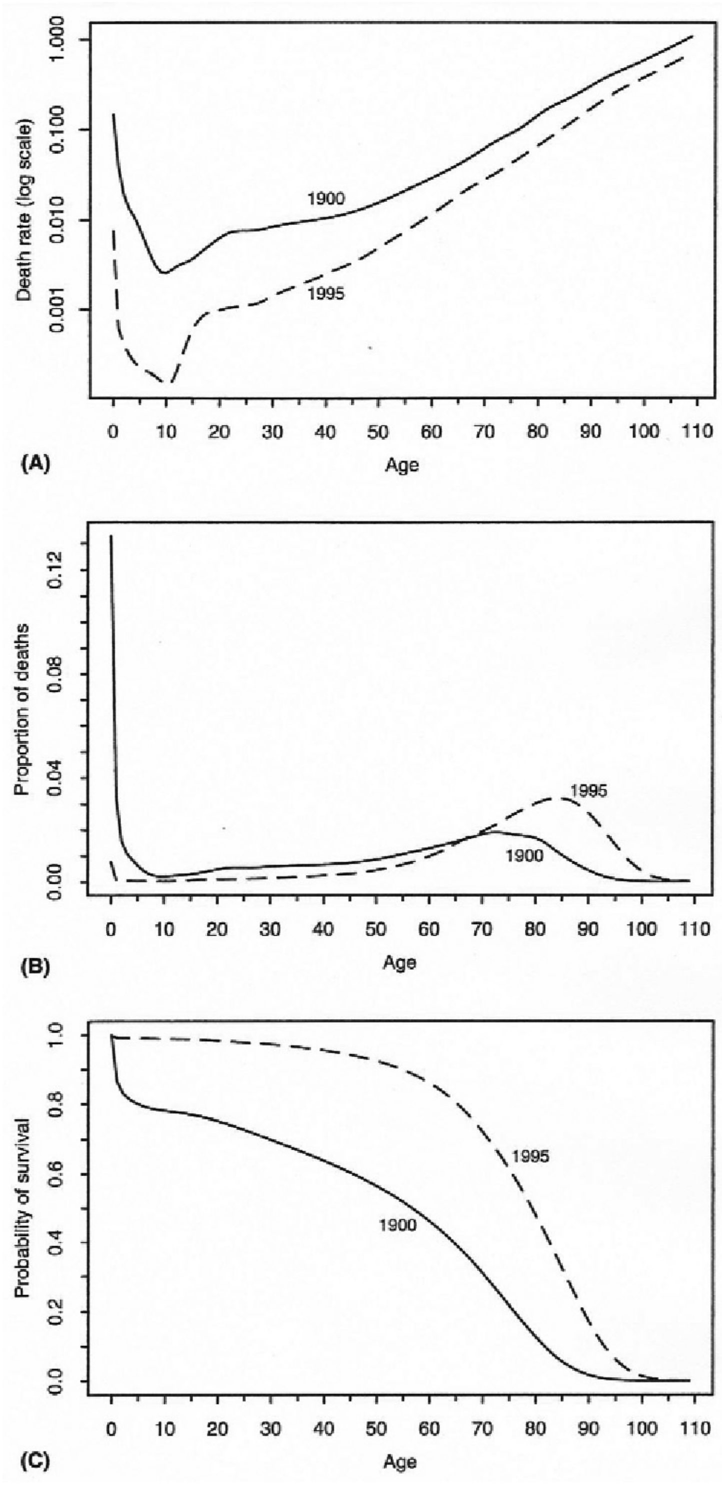
Together, these three panels illustrate some major features of the mortality decline that took place over this time interval. First, death rates fell across the age range, but they fell most sharply at younger ages. The distribution of ages at death shifted to the right and became much more compressed. At the same time, the survival curve shifted to the right and became more “rectangular” in shape. This last change is often referred as the “rectangularization” of the human survival curve.

Like the historic rise of life expectancy, this compression of mortality was due largely to the reduction of juvenile mortality. Once survival to adulthood became commonplace, a pattern emerged in which deaths are concentrated in the older age rages. As mortality falls today among the elderly, the entire distribution of ages at death is rising slowly, but its level of variability seems to have stabilized.

### 1.6 Trends in Global Life Expectancy

Life expectancy has been increasing not only in industrialized societies but also around the world. According to estimates by the United Nations(4), life expectancy at birth for the world as a whole has risen from around 46 years in 1950

**Figure 2 Age pattern of mortality from three perspectives, United States, 1900 and 1995.**




Source: From Ref 3

to approximately 68 years in 2009. During this same time interval, life expectancy at birth has increased from 65 to 77 years for the more developed regions and from 40 to 66 years for the less developed regions. Even the least developed countries have experienced a rise in life expectancy at birth over this period, from 35 to 57 years. (Given data limitations, all of these estimates should be regarded as approximations, especially for the less developed regions of the world.)

## 2. Outlooks for the Future

It is impossible to make a firm scientific statement about what will happen in the future. In truth, scientists can only present the details of well-specified scenarios, which can serve as forecasts or projections of the future. Limits that may affect the increase of human longevity are the first topic of this section, followed by a discussion of extrapolative techniques of mortality projection or forecasting. Our discussion of future mortality concludes with a comparison of "optimistic" and "pessimistic" points of view on this topic.

### 2.1 Maximum Average Life Span

There are two ways to define limits to the human life span: maximum average life span and maximum individual life span. Let us consider whether there might be an upper limit to the average life span first. This question can be posed as follows: Can death rates keep falling forever or will they hit some fixed lower bound? If a nonzero lower limit for death rates exists, we could compute the maximum achievable life expectancy at birth. In this way, we would know the upper limit of the average human life span.

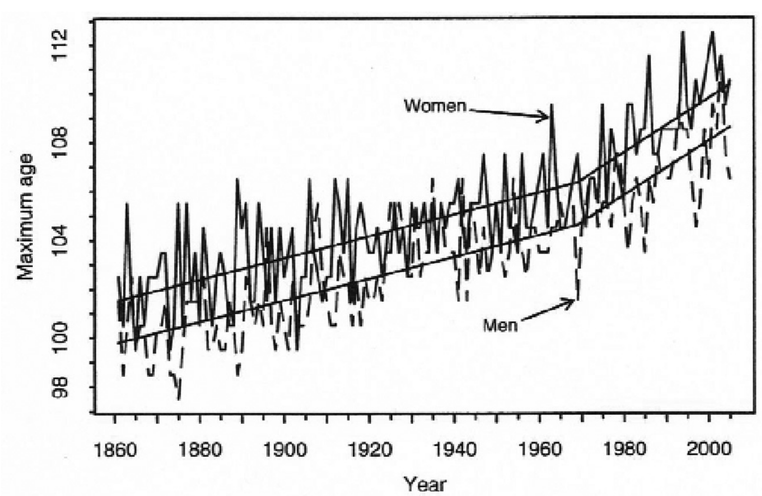
In fact, there is little empirical support for the belief that an upper limit to life expectancy exists. An argument frequently put forward is that the rise in life expectancy at birth slowed down in the second half of the twentieth century. However, this deceleration resulted merely from a shift in the main source of the historical mortality decline from younger to older ages. Furthermore, if death rates are approaching their lower limit, one might expect a positive correlation between the current level of mortality in a given country and the speed of mortality decline. In fact, no such correlation exists for death rates at older ages.

As I discuss later, current forecasts suggest that life expectancy at birth may not rise by more than a few years above current levels over the next half century. Nevertheless, there is simply no demographic evidence that life expectancy is approaching a fixed upper limit. Certainly, such a limit may exist, but it is nowhere in sight at the present time.

### 2.2 Maximum Individual Life Span

Next, let us consider the upper limit to an individual life span. This concept is much easier to understand than the notion of an upper limit to life expectancy. Nevertheless, identifying the world's oldest person is difficult even today, because of the widespread practice of what demographers politely call "age misstatement". Putting it less

**Figure 3 Maximum reported age at death. Sweden 1861-2005.**




Source: From Ref 1,5

politely, some people lie about their age. Others, if asked, give the wrong age because they do not remember, because they are not numerate, or because they have never paid attention to such matters.

In terms of a scientific discussion about longevity, experts agree that it is best to ignore undocumented cases of extreme longevity. Thus, when we make statements about who is the oldest person alive today or in the past, we limit ourselves to cases where solid evidence exists. The historical record is still held by a Frenchwoman, Jeanne Calment, who died at age 122 in August 1997. The oldest man whose age was thoroughly verified was Christian Mortensen, who died in 1998 at the age of 115. A Japanese man named Shigechiyo Izumi was reportedly 120 years old when he died in 1986. However, this case has now been rejected by almost all experts who are familiar with it, and the common belief is that Izumi was in fact "only" 105 years old at the time of death(6).

Although these world records are intrinsically interesting, we must turn to other forms of evidence if we want to know about trends in extreme longevity. Figure 3 shows the trend in the maximum age at death for men and women in Sweden during 1861 to 2005. The trend is clearly upward over this time period, and it accelerates beginning around 1969. The rise of this trend is estimated to be 0.44 years (of age) per decade prior to 1969, and 1.1 years per decade after that date. These Swedish data provide the best available evidence for the gradual extension of the maximum human life span that has occurred over this time period.

### 2.3 Extrapolation of Mortality Trends

Demographers claim some expertise in predicting future population characteristics, and their method of choice is usually a mere extrapolation of past trends. This approach is particularly compelling in the case of mortality:

*First,* mortality decline is driven by a widespread, perhaps universal desire for a longer, healthier life.

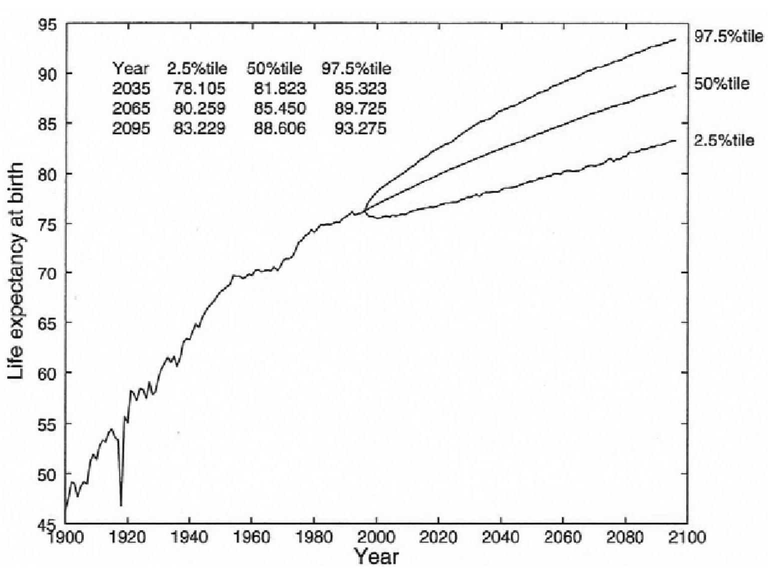
*Second,* historical evidence demonstrates that mortality has been falling steadily, and life span has been increasing for more than 100 years in economically advanced societies.

*Third,* these gains in longevity are the result of a complex array of changes (improved standards of living, public health, personal hygiene, and medical care), with different factors playing major or minor roles in different time periods.

*Fourth,* much of this decline can be attributed to the directed actions of individuals and institutions, whose conscious efforts to improve health and reduce mortality will continue in the future.

The life expectancy forecasts of Lee and Tuljapurkar(7) are reproduced here as Figure 4. These projections are based on a clever extrapolative technique pioneered by Lee and Carter(8), which has been very influential in the world of mortality forecasting over the last 15 years. The method yields a range of estimates for each calendar year during the forecast period. The inherent uncertainty of future trends is represented in the graph

**Figure 4 Life expectancy at birth, United States, 1900-1996 (actual) and 1997-2096 (forecast).**




Source: : From Ref 7

by plotting not only the median forecast, which may be considered the "best estimate", but also by showing two extreme forecasts.

It is important to remember that these projections are mere extrapolations of the historical experience of one country during a particular time period. The implicit assumption is that future trends will resemble past ones. This assumption is plausible given the fairly steady pace of mortality decline over the past century. Of course, extrapolation is not without its flaws. It could not, for example, have anticipated the rise of mortality in the former Soviet Union after 1990, the emergence of AIDS in certain populations during the 1980s, or the divergence of mortality trends between Eastern and Western Europe after 1960. However, such observations are less an indictment of extrapolation as a method of mortality forecasting than a demonstration that the greatest uncertainties affecting future mortality trends derive from social and political rather than technological factors.

### 2.4 Optimism vs. Pessimism

In recent years, the extrapolative approach to mortality prediction has been challenged by assertions that future changes in average human life span may come more or less quickly than in the past. The more optimistic view that life span will increase rapidly in the near future is partly a result of the acceleration in rates of mortality decline among the elderly in developed countries during the past few decades. From a historical perspective, however, this change is relatively recent and should be extrapolated into the future with caution.

Another source of optimism about future mortality rates lies in the potential application of existing technologies (e.g., nutritional supplements, reductions in smoking) or the unusual longevity of certain groups such as Mormons and Seventh Day Adventists. Such discussions may be a good way to improve health behaviors, but they are not so good at informing predictions, largely because this same sort if advocacy influenced past trends as well.

From time to time, technological breakthroughs provide another source of optimism. In 1998, the manipulation of a gene that halts the shortening of telomeres during the replication of human cells in vitro was a source of great optimism in the popular media, provoking rather extraordinary claims about the possibility of surviving to unprecedented ages in the near future. Talk of cures for cancer or vaccines against AIDS promotes similar hopes. Such discussions should not be dismissed as mere wishful thinking but should also be seen in historical perspective.

As wondrous as they may be, recent scientific advances should be compared, for example, to Koch's isolation of the tubercle bacillus in 1882, which provided confirmation for the germ theory of disease and led to a great flourishing of public health initiatives around the turn of the 20th century, or to Fleming's discovery of the antibacterial properties of penicillin in 1928, an event that led to the antibiotic drug therapies introduced in the 1940s. Extrapolations of past mortality trends assume, implicitly, a continuation of social and technological advance on a par with these earlier achievements.

More pessimistic scenarios of the future course of human longevity are based on notions of biological determinism or arguments about practicality, yielding the now-familiar claim that life expectancy at birth cannot exceed 85 years. Sometimes, evolutionary arguments are invoked in support of the notion that further extension of the human life span is impossible, even though existing theories say little about whether and to what degree the level of human mortality is amenable to manipulation.

Current patterns of survival indicate that death rates in later life can be altered considerably by environmental influences, and there is little conclusive evidence that further reductions are impossible. Furthermore, as noted before, trends in death rates and maximal ages at death show no sign of approaching a finite limit. Nevertheless, although claims about fixed limits to human longevity have little scientific basis, a life expectancy at birth of 85 years is within the range of values predicted by extrapolative methods through the end of the twenty-first century for the U.S. (Figure 4). In contrast, more optimistic claims – a life expectancy at birth if 150 or 200 years or even more – are much farther afield and would require a much larger deviation from past trends.

### 2.5 Learning from History

It seems reasonable to expect that future mortality trends in wealthy nations will resemble past changes. The longevity increase of the past two centuries is fundamentally a social phenomenon in which humans have *recognized* the causes of mortality, have *reacted* by seeking means of averting or delaying such causes, and in this way have *reduced* mortality rates across the age range. This pattern of recognition/reaction/reduction is an apt characterization of the process of mortality decline in various eras and in relation to various causes of death, including infectious disease, cardiovascular disease, cancer, and motor vehicle accidents.

Thus, although the focus of our efforts will surely evolve, the net effect on death rates will probably be similar in the future. For this reason, extrapolation remains the preferred means of predicting the future of human mortality. This strategy rides the steady course of past mortality trends, whereas popular and scientific discussions of mortality often buck these historical trends, in either an optimistic or a pessimistic direction.

History teaches us to be cautious. Pessimism is not new, and earlier arguments about the imminent end to gains in human longevity have often been overturned(9). On the other hand, dubious claims about the road to immortality are probably as old as human culture itself, even though they have not influenced official mortality forecasts as much as their more pessimistic counterparts.

Although imperfect, the appeal of extrapolation lies in the long-term stability of the historical mortality decline, which can be attributed to the complex character of the underlying process. This combination of stability and complexity should discourage us from believing that singular interventions or barriers will substantially alter the course of mortality decline in the future.

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