World life expectancy and future longevity scenarios

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The increase in life expectancy that we have been observing over the last two and a half centuries is a very spectacular phenomenon. It has a significant impact on society and on the economy. Governments, actuaries and medical care providers all have a great interest in studying its reasons and all have to make assumptions on the future evolution of life expectancy.

The first part of this document provides an overview of various studies that focus on the causes of mortality improvements as well as of the observed convergence of life expectancies in the developed countries and to a smaller extent in the whole world.

The later part of the paper examines the effect of improving life expectancy on individual life durations. People live longer lives now, and more of them survive to older ages, which causes the so-called "rectangularisation" of the survival curve. The question that one may ask is: what is going to happen next? Is there is a limit to a life span? For a reinsurance company, the obvious question is: what the possible future scenarios would mean for the life insurance business?

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Life expectancy: increase and convergence

The following graph from Jim Oeppen's article [1] is a good illustration of the history of life expectancy over the past four centuries. The vertical scale for life expectancy starts at the value of 22.5 years of age, which corresponds to the approximate "lower viability limit", i.e. a population with an average life expectancy lower than this cannot survive in the long term.

The curved line shows the "best practice" life expectancy, that is, at each point in time this would be the world's highest life expectancy at that particular moment.
This means that the historical values of average life expectancies in the world must lie between the "lower viability limit" and the "best practice" line. Jim Oeppen goes on to explain that even if the scope for the divergence in world life expectancies is increasing, we observe the opposite. Life expectancies recorded in different parts of the world are more concentrated, as illustrated by the three vertical bars that show the inter-quartile range of life expectancy for countries containing half of the world's population. These bars demonstrate for example that in 1950 life expectancies for half of the world's population were between 38 and 65 years (a 27 year interval), whereas in the year 2000 life expectancies are much more concentrated: the corresponding interval is only 8-years long, from 65 to approximately 73 years of age. However, the gap between the 75th percentile and the "best practice" limit seems to be growing. This might be interpreted as evidence of a new period of divergence.

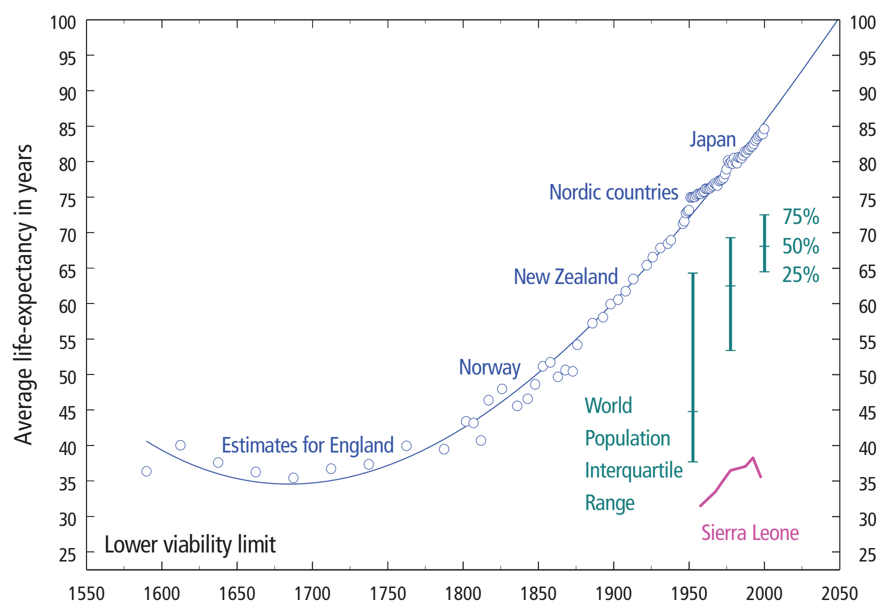


Figure 1 Limits and convergence for national average female life expectancy at birth; source: J. Oeppen, 2006.

The concept of health transition

There exists a substantial volume of literature describing and explaining past mortality improvements. One of the most complete works in our opinion is that of France Meslé and Jacques Vallin who described and enlarged the concept of Health Transition introduced by Julio Frenk [3], [4], [5], [6].
This concept combines the development of epidemiologic characteristics and the ways in which societies respond to their health status and vice versa. The idea is that any major improvement in health would first benefit a small segment of population (generally the most favoured one), and the time it would take for the improvements to spread to the rest of the population depends on the social policy and the economic conditions, e.g. improved social conditions, health policies, diet, behavioural changes, etc. The whole health transition process can be broken down into two or possibly three successive stages. Some countries pass through certain stages more slowly than others and might even pass to the next stage before entirely completing the previous one.

The typical features of historical demographic regimes were high mortality, high fertility, infectious diseases, epidemics and famines.
Then, starting in the middle of the 18th century in Europe, mortality began to decrease. During the first stage of the health transition, which saw the start of progress against infectious diseases, epidemics became less frequent and infectious diseases declined. Initially this was achieved due to better availability of quality foods and hygiene, and later the discovery of antibiotics helped to fight mortality caused by infections. The second stage of health transition is the cardio-vascular revolution. Mortality due to infectious diseases became very low, and advances in treatment and prevention of cardio-vascular diseases became the main driver of mortality decline. This type of progress is much more difficult to achieve: cardio-vascular diseases back off not because of some miraculous treatment (as was the case with antibiotics), but because of many innovative medical techniques, better public awareness resulting in better diet and healthier lifestyle.

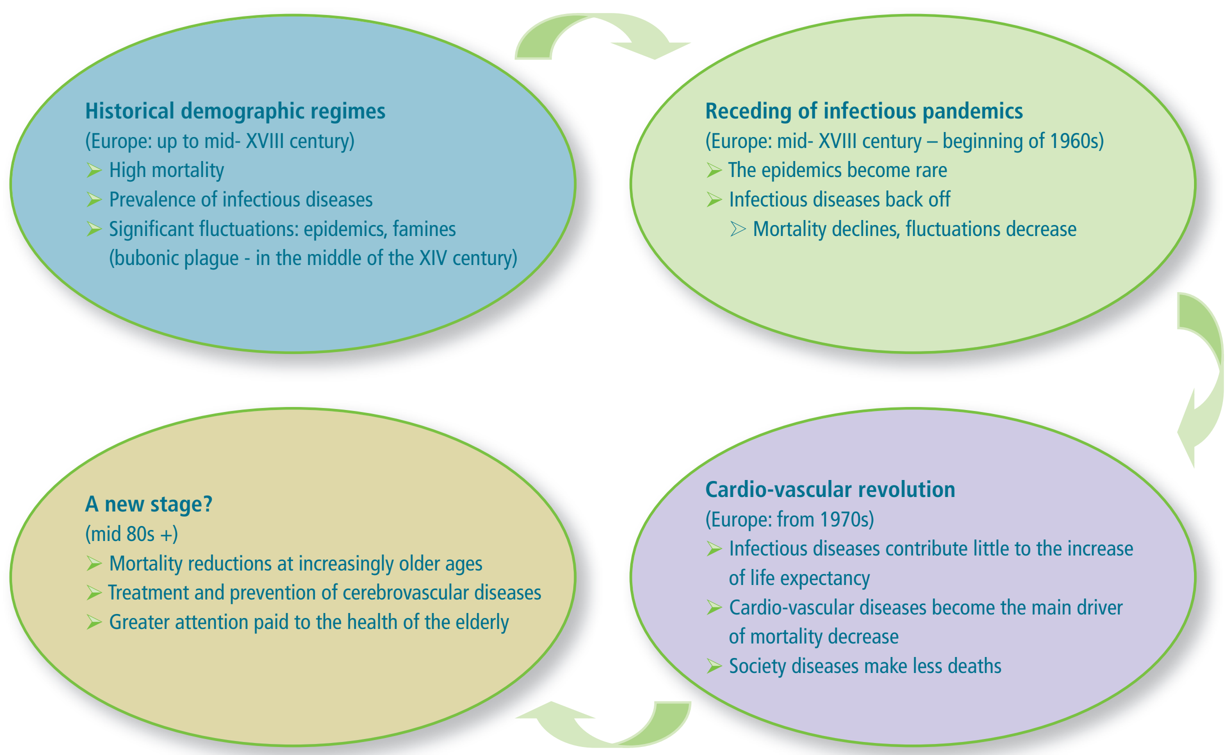


Figure 2 Stages of Health Transition, as suggested by F. Meslé and J. Vallin.

The recent divergence observed for female life expectancy between France and Japan on one hand, and some other developed countries on the other (Figure 3), gave rise to the notion of a third stage of health transition centred on the ageing process.

This stage could be characterised by mortality reductions at increasingly older ages, progress in the treatment and prevention of cerebrovascular diseases and more generally, greater attention paid to the health of the elderly. It seems that Japan and France have already engaged in this third stage [5], [6].

Social policy and the way the society is treating the elderly seem to be very important at this stage of health transition. For example, Japan has a system of care credits "Fureai Kippu" which allows people who help the elderly or disabled to earn time credits for use by themselves later in life or for someone else they choose.

The funding of long term care and support is certainly on the agenda in some countries: with the CLASS program in the USA, the Government White paper in the UK discussing the options of a voluntary insurance solution or a shared cost partnership scheme, and the debates on the "5th risk" of the social security system in France.

Trend in best practice life expectancy

The regularity of the increase in life expectancy at birth driven by the health transition process has given rise to a few interesting studies. Jim Oeppen and James Vaupel's study "Broken limits to life expectancy" [2], published in Science in 2002, demonstrated that the development of "best practice" life expectancy is best approximated by a linear trend, estimated over the past 160 years.

France Meslé and Jaques Vallin revisited the idea in 2009 [9], and argued that some data had to be excluded from the whole Oeppen and Vaupel's data set such as the data for Norway from 1826 to 1866 and for New Zealand from 1876-1930[1].

The exclusion of this data means that the historic development of record life expectancy is no longer a linear trend, but a segmented line, each segment corresponding to a specific phase of the health transition process. The slope of life expectancy increase varies depending on the age group most affected by the current mortality decrease: mechanically, the health gains obtained at the younger ages produce higher increases in life expectancy at birth[2].

To forecast future best practice life expectancy a simple extrapolation of the past linear trend would have been too easy, especially as the slope seems to change from time to time. One needs to understand the driving forces behind the mortality decrease.

Links to income and heath technology?

An interesting and related idea that explains life expectancy increase through income growth and improvements in health technology was presented by Preston in 1975 in his classic

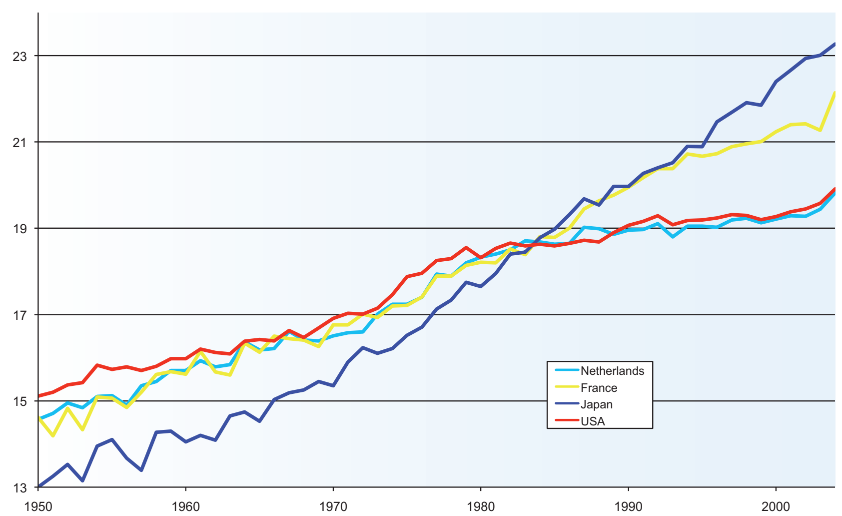


Figure 3 Female life expectancy at age 65 in France, Japan, the Netherlands and the United States, 1950-2004; source: Human Mortality Database.

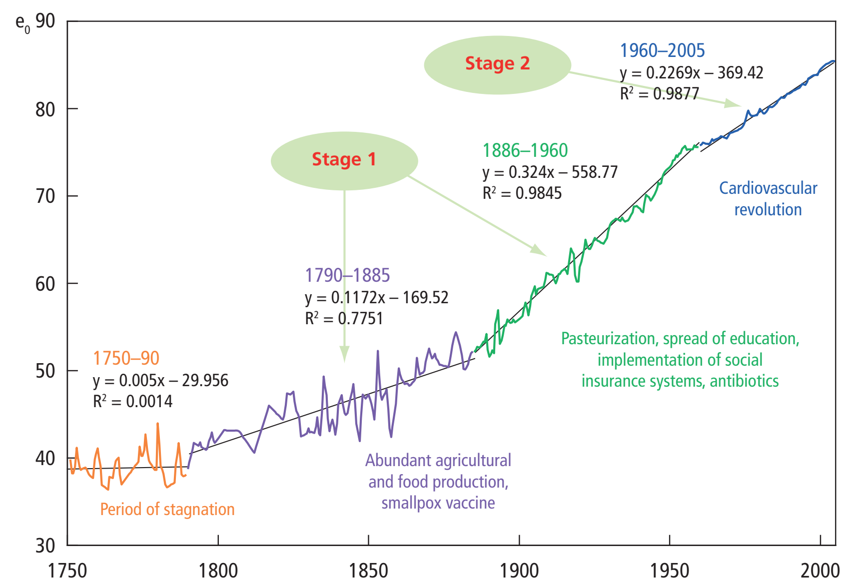


Figure 4 Maximum female life expectancy at birth after removal of Norway (until 1866) and New Zealand, 1750-2005. Meslé, Vallin [9], 2009.

(1) In Norway a centralisation of statistical publications and several reforms concerning data collection and transmission occurred in the 1860s. Moreover there are significant differences for the excluded period in the annual life expectancies given by HMD and decennial averages published in 1969 by Statistik Sentralbyra. In New Zealand the excluded data correspond to the period of large-scale immigration from Europe, which acted as a strong selection in view of the difficulties to collect the means necessary to emigrate from Europe and to survive the long trip.

(2) This can be seen from the following formula for life expectancy at birth: e0= p0+p0*p1+p0*p1*p2+…+p0*p1*..*pΩ, where pi is the probability to survive until age i+1 for a person of age i. Thus increase in p0 leads to higher increase in e0 than a similar increase in p50.

article [7], and extended by Jim Oeppen in 2006 [1]. The idea is that the link between income (GDP per capita) and life expectancy can be expressed with help of a logistic function at any given time period, and this function is subject to temporal shifts due to the improvements in health technology.
The form of the logistic curve suggests that for low GDP per capita a small increase in income would lead to high gains in health and life expectancy, but when GDP is already at high levels, further increase in income would not produce significant gains in life expectancy, and a technological shift is needed in order to pass to a different logistic curve.
Thus for example, in order to attain a life expectancy of 50, a nation requires an income level almost three times greater in the 1930s than in the 1960s.

Numerous authors have extended the analysis to include many other factors such as education, standards of living, public health initiatives, medical practice, personal health care. The effect of income inequality on life expectancy has been a subject of debate (Deaton [8], Wilkinson [10]).

Jim Oeppen proposed a multilevel model to include national effects within the overall relationship, since not all the countries undergo any stage of health transition in exactly the same manner; moreover, late-entrants would achieve high life expectancy at a "lower cost", similar to the economic growth with lower costs of imitation compared with innovation.
His analysis suggests that *"countries of Northwest European origin have translated a diminishing proportion of their gains in income into gains in health. Combined with the "catch-up" opportunities for the laggard countries, this has led to rapid convergence. Japan and the Southern European countries seem to be the exceptions to this diminishing return to log income. They seem to have emerged from the "pack" by maintaining a small long run advantage over the international position."*
This agrees with the suggestion of F. Meslé and J. Vallin that France and Japan have entered the new stage of health transition, by paying more attention to the health of the elderly and more successfully combating cerebrovascular diseases. Some authors however suggest that this divergence is simply due to the differential impact of smoking related mortality on female populations of France and Japan versus other Western countries (Staetsky, [11]), however the common view is that the end to the diverging trends is on the horizon.

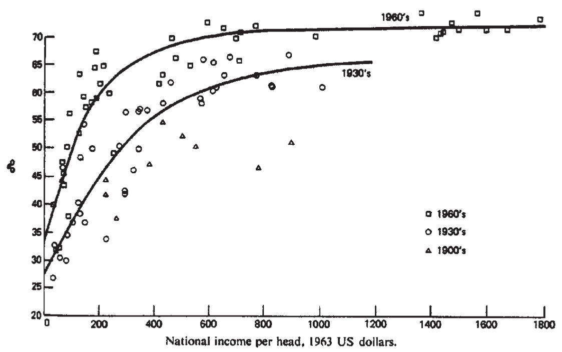


Figure 5 Preston curve, Preston [7], 1975.

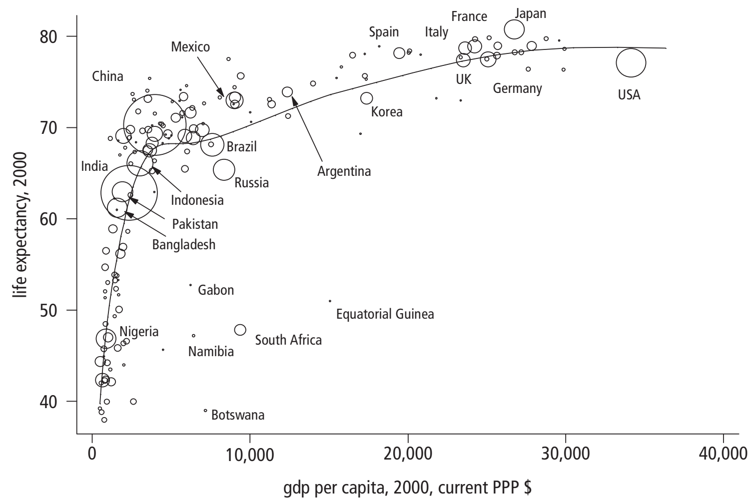


Figure 6 The Preston curve in 2000 (Deaton [8], 2003).

Rectangularisation of the survival curve and possible future longevity scenarios

Length of life and survival curve are somehow more intuitive concepts than life expectancy at birth. Demographers and epidemiologists have studied the survival curve for many years, and for a long time they believed that the survival curve is restricted by some biological limit, some sort of constant characteristic of human species corresponding to a normal longevity in the absence of diseases (Lexis [12], 1878).
The increase of life expectancy was caused by mortality reductions at increasingly older ages as populations were passing through different stages of health transition, and this caused so called "rectangularisation" of the survival curve.
A lot of research has been conducted in recent years on the mortality at the highest ages, including validations of the true ages at death for the longest-lived persons [13], 2010.

Cheung et al [14] distinguish three dimensions of the rectangularisation of the survival curve:

- the "horizontalisation" corresponding to the fall of childhood mortality: the survival curve becomes flatter;
- the "verticalisation" due to a certain concentration of ages at death for the adults, and
- the longevity extension which corresponds to a possible increase in human longevity.

The following graph from Robine [15], shows the evolution of the survival curve for women in Switzerland, in 1876-2002.

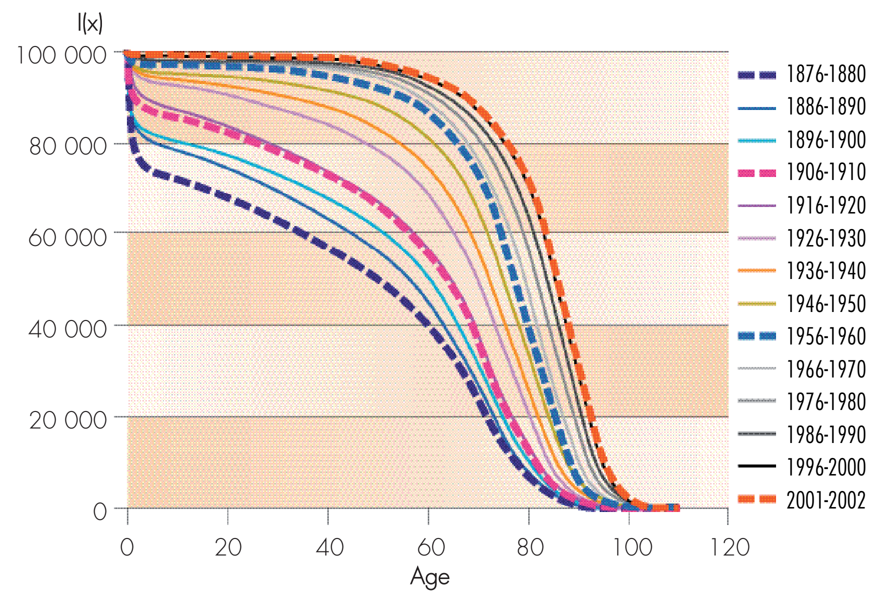


Figure 7 Female survival curve in Switzerland, 1876-2002.

The survival curve is approaching a rectangular shape, but the rectangle itself is becoming larger.
The longevity extension corresponds to the final point of the survival curve- the age, at which there are no more survivors.

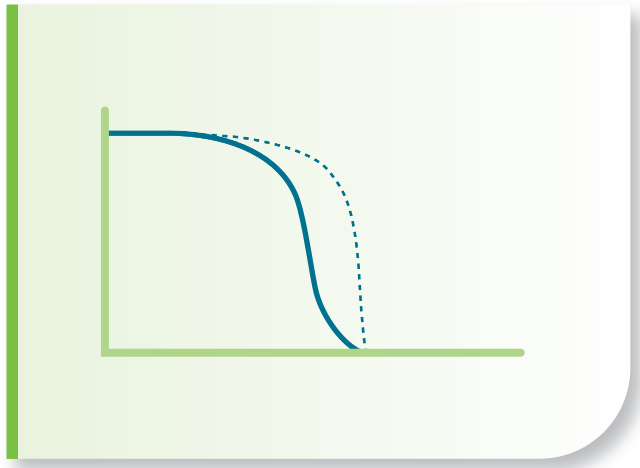
What is going to happen next with human survival curve?

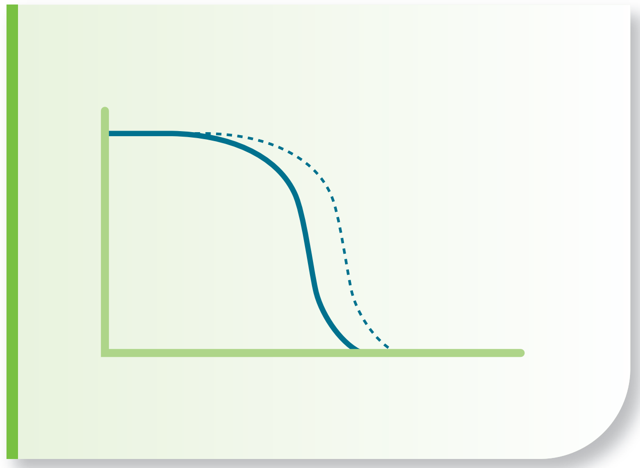
This is also an important question for the insurance industry. Indeed, three possible future scenarios can be envisaged:

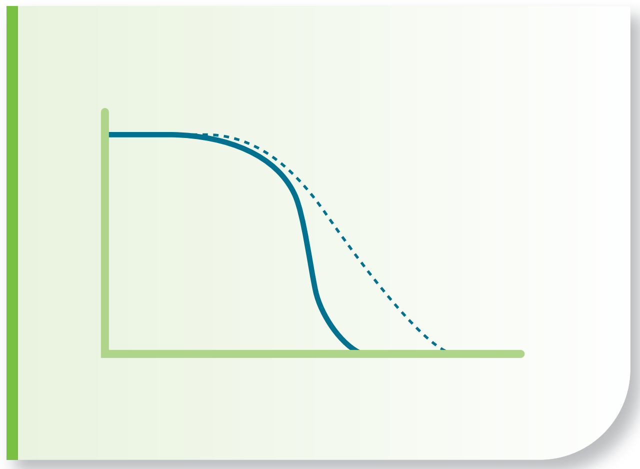
1) Complete rectangularisation and mortality compression. The survival curve becomes more and more rectangular. The probability to die becomes extremely small at ages before the limiting age. Everyone lives up to the human "ideal life duration", and then quickly dies. In this case there is nearly no uncertainty as to the duration of human life. There is no need for annuities: people have a pretty good idea about the time of their death, and thus would be losing interest in certain insurance products in favour of the pure saving products. There might still be demand for accidental death cover or for some forms of insurance protection in case the standardisation of human life durations is not accompanied by the standardisation of healthy life durations.

2) Shifting mortality scenario or delay of ageing. This is the scenario where the whole survival curve is shifted towards higher ages, terminology first proposed by Kannisto [25]. The "modal", or "most common" age at death is increasing, but without further compression of life durations, there are as many people living above this modal age at death as before. This scenario results in continuing uncertainty in the individual's life duration and continuing demand for insurance products, especially annuities and long-term care as the number of oldest-old, centenarians and persons 105 or 110 years old, would increase continuously.

3) An extension of limiting age and "de-rectangularisation". The arrival point of the survival curve is pushed further to the right, thus a number of persons surviving much longer, creating a greater heterogeneity in life durations. People would become more "unequal" in relation to their life span: either because of life style, access to healthcare, or some genetic predispositions. This would result in an increased demand for mortality products at older ages, as well as for annuities and long-term care. Of course this scenario would create a real problem to pension funds, especially the pay-as-you go schemes.







M-Project

Many researchers are trying to forecast what is going to happen next and which scenario is most plausible. An interesting project has been undertaken by an international group of scientists – demographers and mathematicians ([16], [17], [18], [19], [20]) from UK, France, China and Mexico.
It is called the M-project, and is inspired by the work of Kannisto, who proposed to study the increase in life durations by looking at the distribution of ages at death rather than at life expectancy at birth.
Indeed, the late mode M (the peak on the distribution curve) represents the most common age at death, the final point of the curve shows the maximum attained age at death, and the height of the peak together with the slope of the curve beyond the mode visually represent the degree of mortality compression. The following graph from [20] shows empirical distribution of adult life spans since the 17th century and up to the recent years. *(The distribution is scaled so that 1000 deaths represent 1% of all deaths.)*

The first distribution is almost flat, so it is impossible to determine the most common length of life. For the second one, more than half a century later in Sweden, a small mode can be distinguished. With time the peak becomes higher with the decline of infant mortality, and then it starts moving to the right, demonstrating a steady lifespan increase. The yellow curve shows the ultimate distribution proposed by James Fries in 1980, very narrow and centered at the modal length of life of 85, following from his well-known theory of the rectangularisation of the survival curve and the compression of mortality (Fries, 1980 [21]).
The last curve for Japanese women in 2000-2004 shows that they have already surpassed the ultimate value proposed by Fries in terms of modal length of life, and many more people are reaching older ages than predicted by Fries.

The M-project consists in studying the evolution of the modal age at death M and in measuring the standard deviation of the ages at death above the mode SD(M+). The increase in M would correspond to the extension of human lifespan, and the decrease in SD(M+) would suggest the compression of adult life durations.
Accordingly, it is relatively easy to interpret our three scenarios in terms of trends in M and SD(M+).
The first scenario of complete rectangularisation and mortality compression would correspond to the decrease in SD(M+) with no further increase in M.
The shifting mortality scenario means the whole distribution of the adult life durations is sliding to higher ages, but retaining the same shape and height of distribution: the modal age at death M continues to increase but the number of persons

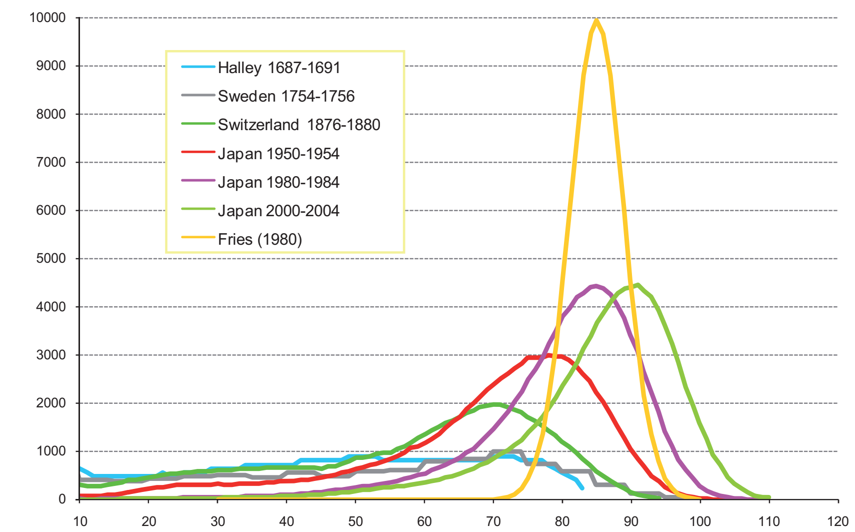


Figure 8 Distribution of adult life durations: selected empirical data 1687-2004 and the hypothetical pattern predicted by Fries; source: Robine, Cheung, 2008 [20].

dying at the modal age and the standard deviation of ages at death above the modal age SD(M+) stay the same.
The third scenario would mean an increase in SD(M+) with or without some further increase in M.

In the context of the M-project, the experience of a large number of developed countries was modelled, and its analysis confirms a strong compression of mortality since 1751, although much less pronounced than expected by Fries. Moreover, this compression occurred at higher ages than predicted by his theory, leading to a shift to higher ages of the distribution of the adult life spans.
The most interesting finding concerns Japan, as it is a leading country in terms of longevity progress. The analysis of Japan [19] shows that in this country the compression seems to have stopped in the 1980s-1990s, the modal age at death continues to increase, whereas the standard deviation SD(M+) and the number of people dying at the modal age remain unchanged. The authors suggest that Japan has probably switched to a new pattern- that of the second scenario, "the shifting mortality scenario", and that some other European countries seem to follow the Japanese trend with a few years lag. However, a different method of estimation of SD(M+) in [17] 2010, showed somewhat less pronounced stagnation in SD(M+) for Japan.

Thus overall, the compression has decelerated in the recent years. Nevertheless, decelerated compression might continue for some time yet, unless, as noted by Cheung and Robine, the medical advances have the same effect at old ages and at higher old ages and thus mortality improves at the same speed at age 70 as at age 90.

While it is an open question whether or not the period of compression is coming to an end, it seems that in terms of longevity extension the modal age at death and maximum reported age at death are increasing, and even accelerating in Japan ([22], [19]). One might conclude that there seems to be no looming limit to human longevity on the horizon yet.

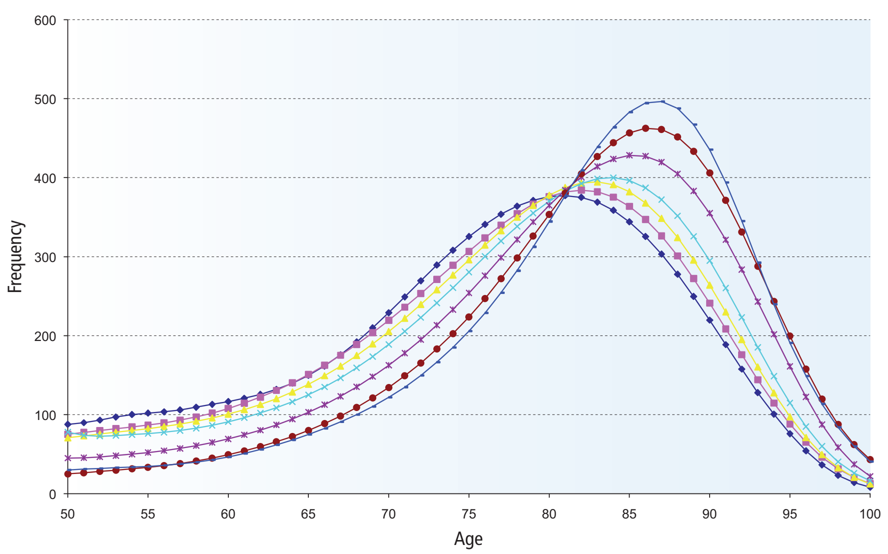


Figure 9 Distribution of ages at death for male pensioners per annual pension amount band; data source: CMI, Self-Administered Pension Scheme pensioners.

Discussion

So it seems that for the moment the near future lies in between scenario 1 and 2. This intermediate scenario can be called a relative compression of mortality. M is continuously increasing, SD(M+) has decelerated but is still decreasing slightly. Life duration continues to rise, while human lifespans become a bit more homogeneous. But even if the dispersion of the lifespans at the national level seems to be decreasing, meaning that people life durations are more "equal", there still is a huge difference in mortality levels for different social class subpopulations.

The uncertainty is always there. It is fuelled by the continuing increase in lifespan: people are living longer than their parents and grandparents, and the length of life continues to be very difficult to predict.
People are now more aware that they will most probably live longer lives than their ancestors, so the need for old age protection and pensions will stimulate the demand for private coverage, especially in the case of a government's partial disengagement.
Another important question is whether this increase in life duration will be accompanied by the increase in the healthy life duration? As the number of oldest old is continuously increasing – in France the number of centenarians has tripled in the last 10 years – the consequences for Long Term Care provision and financing are extremely important. Are the new nonagenarians and centenarians more frail and have a poorer functional health status than their elders?
There is no common view on this subject and various studies produce conflicting results. Health is difficult to measure. It seems that generally the number of years spent in self-perceived good health has increased. As for disability, it depends on its level. For most severe levels it has decreased (which is a very good news), whereas people are living longer with milder disabilities. Though again, the existing studies show differences among countries [23].
In James Vaupel's recent article published in Nature in 2010 [24], he argues that the whole process of deterioration is being postponed, not decelerated. His suggestion is that mortality is being delayed because people are reaching higher ages in better health, and not because of slowing the ageing process.
As for the future, a lot of research is on the way to get a better understanding of genetics and root causes of ageing, and of how senescence can be further delayed.

It is clear, however, that demand for long-term care coverage, disability and Critical Illness is going to increase as the number of older people is growing. This is definitely an important issue for insurance and reinsurance as it is a low frequency and high severity problem.

The recipe to forecasting the future lies in understanding the past progress and the nature of advances that may lie ahead. International comparisons, inputs from demography, biomedicine, social and biological sciences are all very valuable in understanding and forecasting mortality trends.
It has become clear that the demographic future is going to be very different to what we have seen in the past, and it will have profound implications on society. The balancing act between insurance and the state's social provision for the elderly is going to become an extremely important dynamic going forward in addressing the insurance needs of the older age population.

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