Is There a Limit to the Compression of Mortality?

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Abstract

With the fall of mortality, the frequency distribution of ages at death has been shifting to the right, but it has not retained the same shape over time. The distribution of ages at death has become more compressed around the mode, which is consistent with the prediction of mortality compression proposed by James Fries in 1980. In this paper we investigate trends in the age distribution of deaths at old ages using historical data from European countries (i.e., England and Wales, France, Italy, Sweden and Switzerland), the United States of America and Japan. The results, especially for recent decades in Japan, prompt us to reconsider the validity of the mortality compression scenario. This paper discusses the notion of limit for the compression of mortality and examines alternative hypotheses such as the shifting mortality model.

1. Introduction

Our contribution to the 2008 Symposium "Living to 100 and Beyond" has been in two parts, in which we examine whether compressions of mortality and morbidity have actually occurred, and (if so) how they proceeded. This paper discusses the compression of mortality, and the second one discusses the compression of morbidity and disability. The theory of compression of morbidity, proposed by James Fries in 1980, relied on the prediction of the rectangularization of the survival curve and on the hypothesis of normal distribution of ages at death from “natural” causes (i.e., natural deaths, or aging-related deaths): “*Thus, under ideal conditions, 66 per cent of natural deaths would occur in persons 81 to 89 years, and 95 per cent in persons 77 to 93 years*” (Fries 1980). This idea of normal distribution for adult mortality or aging-related mortality is quite old. It started with the work of Lexis, who made a clear distinction among three mortality components: the infant mortality following an inverse J curve, the aging-related mortality following a normal distribution and the premature adult mortality being in between and overlapping the other two. The history of this idea can be traced back to Lexis (1878), Pearson (1897) and Benjamin (1959). James Fries (1980) advanced a theory that through time the age distribution of aging-related deaths shifts to higher ages and becomes more concentrated. His paper is still among the most widely cited in gerontology and geriatrics.

2. The M-Project

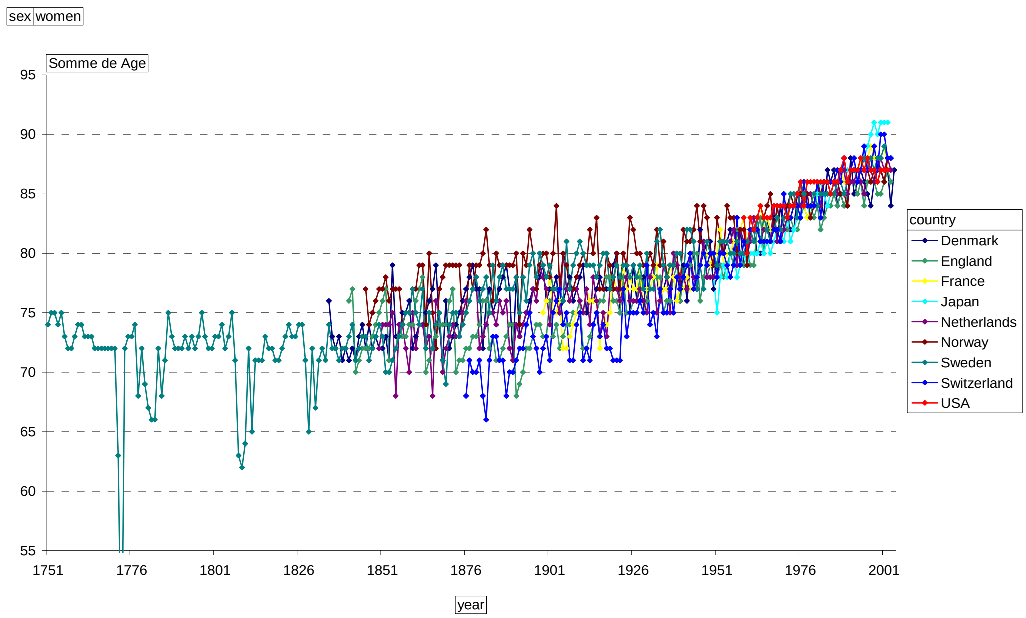
Kannisto demonstrated that Lexis' approach can be used to assess whether the increase in the modal age at death (M) is accompanied by a compression of mortality (Kannisto, 2001), resuming the previous work on the distribution of the ages at death by Lexis, Pearson and Benjamin. Kannisto proposed to measure the compression of mortality by the decrease in the standard deviation of the ages at deaths above the mode, denoted by SD(M+). Building on this work by Kannisto, our M-Project aims to understand the dynamics of the distribution of ages at death among the elderly (Cheung et al., 2005; Cheung and Robine, 2007). Does an increase in the modal age at death inevitably leads to a compression of ages at death, and, if so, why? This paper briefly describes some of the empirical findings of the M-project and raises new questions about the limits of compression of mortality.

3. The Experience of Nine Countries

The data in the Human Mortality Database (http://www.mortality.org/) allow us to investigate changes in the modal length of life (M) and SD(M+) in 26 countries, starting with Sweden in 1751, through more than 5000 life tables. (The database has recently been extended to include 33 countries in total.) For ease of reading, this first section focuses on nine selected low mortality countries only: Denmark, England, France, Japan, the Netherlands, Norway, Sweden, Switzerland and the United States of America. These countries have long and high quality series of statistics on mortality.

GRAPH 1

Increase in the Modal Length of Life (M) for Women in Selected Nine Countries since 1751

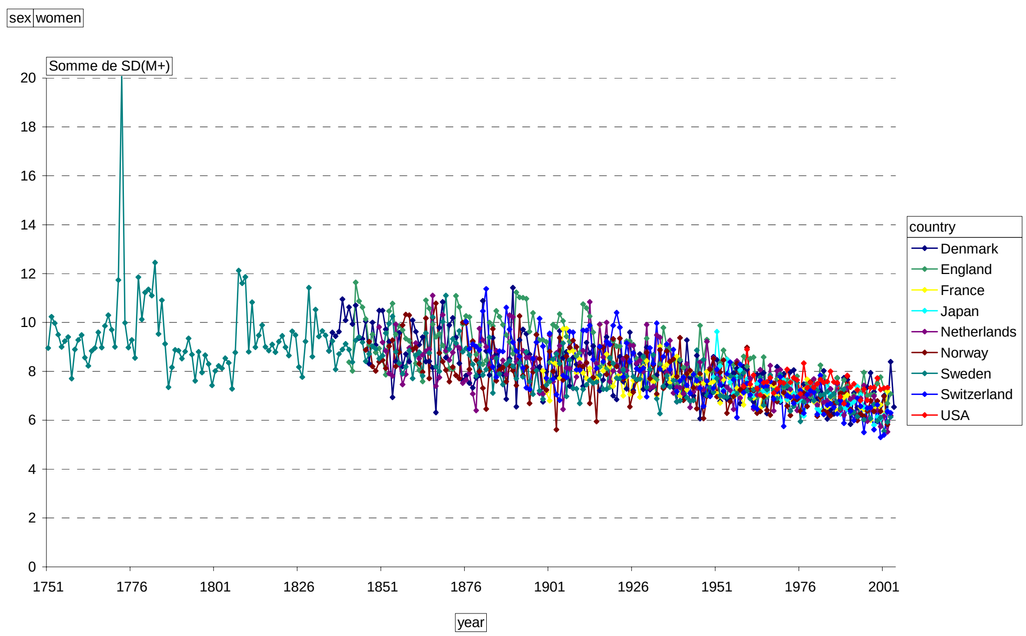


Graph 1 shows the increase in the modal length of life (M) since 1751. Looking at the changes over time, three periods can be distinguished. During the first period, from 1751 to 1851, when only Swedish data are available if we exclude the last years, the modal length of life fluctuated between 70 and 75 years. The second period, 1851 to 1951, is the time of the epidemiologic transition. Some countries entered this transition early as Sweden and Norway, and some other countries entered relatively late as Switzerland, vertically scattering the M values. But by 1950, the epidemiologic transition had been almost finished in these countries, and the modal length of life (M) was close to 80 years for all of them. Since then, a steady increase in the modal length of life has been observed, with an increase by more than two months per year on average: this is the current longevity revolution. Now, the modal length of life is above 90 years for women in some countries such as Japan, France and Switzerland.

Graph 2 shows the decrease in the standard deviation of the age at death above M (SD(M+)). SD(M+) measures the dispersion or the concentration of deaths above the modal value. The overall trend is about the same among these countries, with basically no significant change before 1950. But a clear decline after 1950 can be observed, beyond small fluctuations, if we put aside the United States, for which the value remained nearly constant.

GRAPH 2

Decrease in the Standard Deviation of the Age at Death above M (SD(M+)) for Women in Nine Selected Countries Since 1751



Thus, a significant compression of old-age mortality obviously occurred during the last 50 years in these nine most developed countries having the longest life expectancies; a substantial increase in the modal length of life has been accompanied by a significant decrease in the dispersion of individual life durations above the mode.

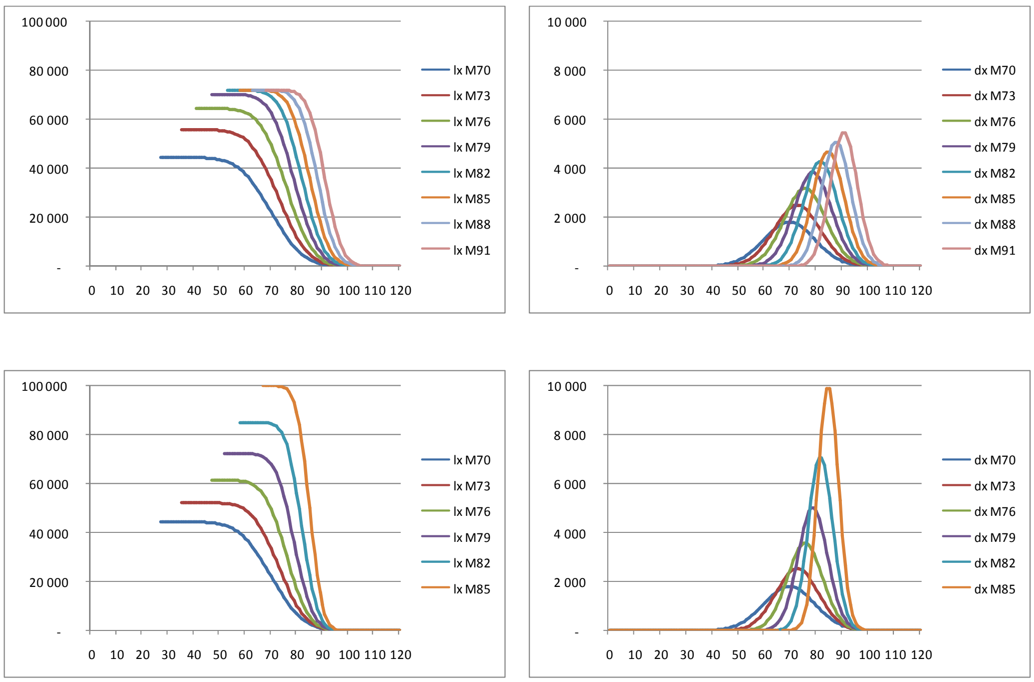
4. Modelling the Longevity Experiences in 26 Developed Countries

The upper panels of Graph 3 summarize the empirical evidence provided by 5,000 life tables for 26 developed countries in the Human Mortality Database, starting with Sweden in 1751. We constructed the age distribution of aging-related deaths based on the Lexis model, in which all deaths above the modal age are considered aging-related, and adult deaths below the modal age can be divided into aging-related deaths and premature deaths assuming that of aging-related deaths are symmetrically distributed around the modal age. Infant deaths and premature deaths, which are in an adult age range partly overlapping with aging-related deaths, are not included in these figures. Those infant and premature deaths correspond to the difference between the displayed survivors (i.e., those who will die later from aging-related causes) and the 100,000 radix of the death distribution. Starting with a mode at age 70 and a standard deviation above M of 9.8 years, the distribution of deaths moved slowly to a mode at age 91 and a standard deviation of 5.3. These ranges of M and SD(M+) correspond to observations in the past and recent periods. The life table number of survivors at M increased from 22,000 when M was at 70 years to 36,000 when M is at 91 years, implying that the aging-related deaths increased from 44,000 to 72,000. These changes indicate both a considerable decrease in infant and premature mortality over time and the significant intensity of premature mortality that still remains.

On the other hand, the lower panels of Graph 3 illustrate a smooth transition from the same initial situation [M = 70 years; SD(M+) = 9,8 years and l(M) = 22,000] to Fries' ultimate survival curve and distribution of natural deaths [M = 85 years; SD = 4 years and l(M) = 50,000] (Fries, 1980). The comparison of the upper and lower panels highlights the gaps between the expected changes (based on the prediction by Fries) and the actual changes. The modal age at death increased much more than expected, already exceeding 85, Fries' ultimate value, by 6 years. The standard deviation decreased much less, but it is still clearly larger than the expected ultimate value of 4 years, and the number of life table survivors at M never reached 50,000, which was proposed by Fries. Therefore deaths are much less concentrated around M than expected.

GRAPH 3

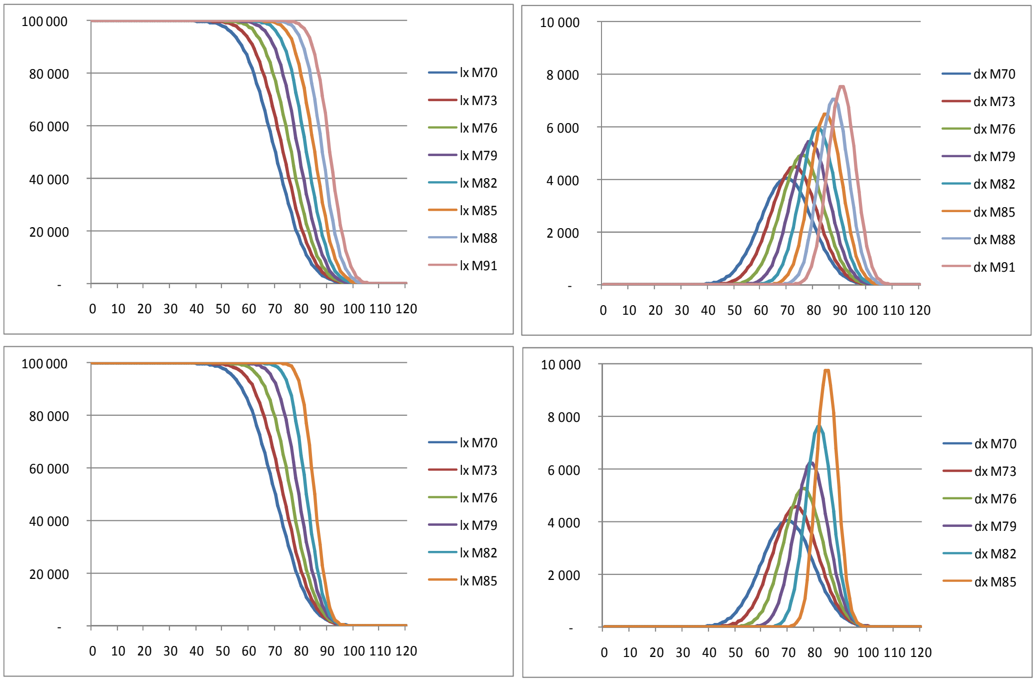
Changes in the Age Pattern of Aging-Related Mortality (Lexis Mortality): A Summary of Experiences of 5000 Life Tables (Upper Panels) Versus a Scenario Leading to Fries' Ideal Distribution (Lower Panels). (Infant and Premature Deaths Are Included in the Computations but Not Shown)



Graph 4 displays the same aging-related mortality, according to the 5000 life tables experience (upper panels) and to the scenario leading to Fries' ideal distribution (lower panel) when Lexis' infant and premature mortality are excluded. On this graph 100,000 deaths are distributed under each curve, focusing only on the changes in M, the modal length of adult life and in SD(M+), the standard deviation of the ages at deaths occurring above M. Again this graph highlights the gaps between the actual changes in the distribution of the aging-related mortality and the expected changes, focusing only on the shape of the distributions.

GRAPH 4

Changes in the Age Pattern of Aging Related Mortality (Lexis Mortality): A Summary of Experiences of 5000 Life Tables (Upper Panels) Versus a Scenario Leading to Fries' Ideal Distribution (Lower Panels) (Infant and Premature Deaths are not Included in the Computations)



This analysis confirms that a compression of mortality proceeded over time, but this compression occurred at higher ages and to lesser extents than expected by Fries' theory, leading to a shift to the right (i.e., to higher ages) of the distribution of adult life spans. The shift produced pronounced increase in the number of oldest-old, nonagenarians and centenarians during the last three decades (Robine et al., 2003; Robine and Paccaud, 2005).

5. A Summary of the Human Longevity Experience Based on Some Empirical Distributions

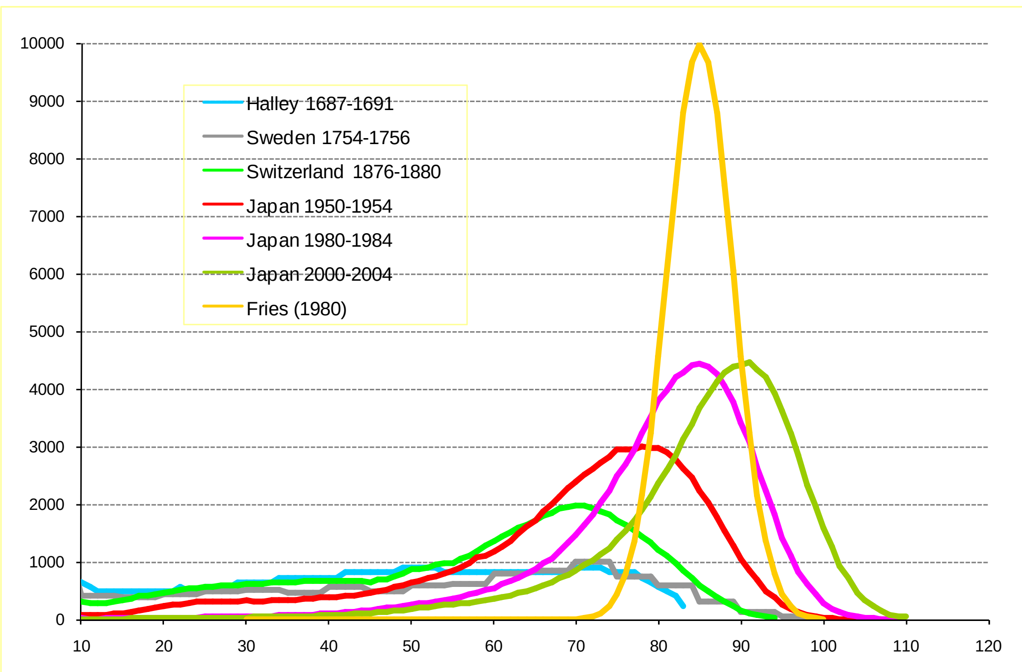
This compression of adult mortality was observed in some empirical distributions of adult life spans since the 17th century, from the first empirical data set (for the city of Breslaw, 1687-1691) published and commented by Halley in 1693 with the invention of the life table, to the most recent data for Japan (Cheung and Robine, 2007). Each of the distributions displayed on Graph 5 contains deaths in the life table with 100 000 persons at birth, meaning that 1,000 deaths represent 1 percent of all deaths.

The first distribution of adult life durations, the one commented by Halley in 1693 for the city of Breslaw, is almost flat from about the age of 40 to the age of 75, with about 1,000 deaths occurring at each single year of age, corresponding to about 1 percent of those who die between age 40 and 75. Of course, in this case it is impossible to identify a modal value and theorize the existence of a common length of life (Graph 5).

The second distribution, 65 years later, is for Sweden during 1754-1756. The age distribution is also quite flat but it is already displaying a low peak of adult life spans around the age of 70. This distribution of deaths by single age was sent by Wargentin to a French demographer, Deparcieux, who published them as an addition (1760) to his famous *Essai sur les probabilités de la durée de la vie humaine*. Wargentin published his data for Sweden, starting in 1751, but the mortality data were grouped by broad age intervals, making it impossible to distribute the deaths by single age.

GRAPH 5

Distribution of Adult Life Durations: Selected Empirical Data 1687-2004 and the Hypothetical Pattern Predicted by Fries



The third distribution, 125 years later, is for Switzerland during 1876-1880, corresponding to the first published complete life table (1876-1880). The shape and the features of the distribution of adult life spans are exactly the same as the Swedish ones, some 125 years earlier: the modes are exactly at the same age. The only difference is that there are more people around the adult modal age at death in Switzerland in the late 19th century than in Sweden in the mid-18th century. This is due to the fall of infant mortality that occurred during the 19th century, allowing more newborns to become adults. One-thousand persons (or 1 percent of the life table cohort) die at the emerging mode in 1754-1756 in Sweden, and 2,000 (or 2 percent) die at the mode in 1876-1880 in Switzerland.

The fourth age distribution of adult deaths, 70 years later, is for Japan during 1950-1951, right after World War II. It is based on the first complete life table of the modern Japanese series. As seen on Graph 1, in 1950, the epidemiologic transition was almost finished in the low mortality countries and, at that time, adult life durations in most developed countries (North America, Nordic and Western European countries and Japan) were very similar. Japan summarizes perfectly well the common situation: the female modal length of life has reached 80 years, and 3,000 persons (or 3 percent) of the life table cohort die at the mode. After WWII, these countries entered a new period of steady lifespan increase, displaying very little fluctuations in the rise of the modal length of life.

In 1980, 30 years later, James Fries proposed his well-known theory of the rectangularisation of the survival curve and the compression of mortality (Fries, 1980). He proposed an ultimate distribution for adult life durations (i.e., natural deaths), centered at the modal length of life of 85 years with a normal distribution and a standard deviation of 4 years above and under the mode. In this very narrow distribution, about 10 percent of the people should die at the modal age (within the one-year age range) and almost no one dies before the age of 70 and no one survives over the age of 100 years. The fifth death distribution on Graph 5 represents this ultimate distribution of Fries.

Of course, when Fries published his paper in the *New England Journal of Medicine*, he did not know the actual values for the 1980s, but now we do. The sixth death distribution on Graph 5 is for Japan during 1980-1984. In term of modal length of life, Japanese women have already surpassed the ultimate value proposed by Fries, i.e., the mode of 85 years (complete life table for Japanese females, 1980-1984). But the standard deviation of adult life spans is much larger than 4 years and fewer than 4,500 among the life table cohort of Japanese women (or 4.5 percent) die at the modal age. Therefore many more people are reaching oldest ages than predicted by Fries. In Fries' ultimate distribution, very few persons die at age 95 or above, whereas in the actual Japanese distribution corresponding to the mortality experience in 1980-1984, many women survive to age 95 and even age 100.

The comparison between the actual age distributions of deaths, from Switzerland in 1876-1880 to Japan in 1980-1984, all in all, indicates a strong compression of mortality as the modal length of life moved from 70 to 85 years in one century, although the compression was less pronounced than expected by James Fries in 1980.

6. Towards the End of the Mortality Compression

Twenty years later, the seventh distribution, based on the complete life table for Japan during 2000-2004, reveals a new and unexpected trend. Whereas until now, Japan was following the general pattern of mortality compression (i.e., the higher the modal length of life, the more concentrated the distribution of the individual life durations), the last distribution shows that the whole distribution of the adult life durations is sliding to the right (i.e., to higher ages), but retaining the same shape and height of distribution: Japanese women are now displaying a modal age at death above 90 years, 6 years higher than 20 years ago, but the whole distribution has almost exactly the same features: i.e., the same standard deviation and the same number of persons dying at the modal age. The changes in adult longevity are no longer following the pattern of compression of mortality. The maximum reported age at death (MRAD), an indicator of the maximum life span (MLS), has increased by the same number of years as the modal length of life (M). The compression of mortality, which has occurred in almost all low mortality countries during the whole period since World War II, seems to have ceased in Japan for the last 10 to 20 years. Japan, which is leading international trends in human longevity, is moving to a new trend pattern that we can call "the shifting mortality scenario" following the terminology proposed by Kannisto (1996) and Boongarts (2005), where the modal length of life keeps increasing but the shape of death distribution curve remains unchanged (Cheung and Robine, 2007). Changes in longevity in France, Switzerland and Italy seem to follow the Japanese pattern with a few year lag and present an intermediate situation between mortality compression and mortality shift, where a steady increase in the modal length of life is accompanied by a modest decrease in the standard deviation of the ages at death above the mode (Cheung et al., in press).

Compared to other species, longevity is extremely homogeneous in the human species (Finch and Kirkwood, 2000; Horiuchi, 2003). Impressive reduction in the standard deviation of the human adult life spans occurred through and after the epidemiologic transition. The standard deviation above the mode, SD(M+), of women's adult life spans already declined to 6.5 years or even less in countries that were most advanced in the adult longevity revolution, such as France, Italy, Japan and Switzerland. An important issue for the future is the limit or the potential of homogenization in human longevity beyond the remaining social inequalities. More than 25 years ago, Fries proposed a standard deviation of 4 years for the ultimate distribution of adult life durations. Is it realistic from social and/or biological points of view? Lack of our answer to this question makes it difficult to correctly forecast the size, the sex-ratio and the age structures of the oldest-old segments of the population.

Acknowledgments

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