Population

Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France

Jean-Marie Robine

Abstract

Robině Jean-Marie.- Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France

Of the very few theories about the evolving health status of populations, one of the best known is that of the epidemiological transition. Formulated by Omran in 1971, it describes the changes in the cause-of-death pattern associated with the reduction in mortality rates during the demographic transition. Omran argued that the second stage, "the Age of Receding Pandemics", forms a transition between the "Age of Pestilence and Famine" and the "Age of Degenerative and Man-made Diseases". In 1986, Olshansky and Ault proposed adding a fourth stage to the epidemiological transition, with the "Age of Delayed Degenerative Diseases". However, the changeovers from the second to third stages and from the third to fourth stages are hard to date. Indeed, examination of the changing dispersion in life spans casts doubt on the historical reality of the last two stages, though it does allow the move from the second to following stage to be dated, this article proposes therefore to merge Omran's third stage, "the Age of Degenerative diseases" with Olshansky and Ault's fourth stage, "the Age of Delayed Degenerative Diseases", to form a new stage, referred to as the "Age of the Conquest of the Extent of Life", characterized by the fact that the fall in mortality - which continues throughout this stage - is associated with little or no further concentration of life spans.

Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France

Jean-Marie ROBINE*

While precursors are not entirely lacking[1], it is exactly twenty years since the physician James Fries introduced the concept of the "rectangularization of the survival curve" by publishing his theory on the compression of morbidity in the *New England Journal of Medicine* (Fries, 1980). Drawing on the work of the biologist Comfort (1964), Fries observed that the historical increase in life expectancy was accompanied by a gradual "rectangularization" of the survival curve. He argued that this change was responsible for a shift to an "ideal" survival curve, highly rectangularized, corresponding to a life expectancy at birth of 85 years and with a high concentration of individual life spans around this average value: 66% of life spans would be between 81 and 89 years and 95% between 77 and 93 years. Fries justified this prediction by the existence of a fixed biological maximum limiting the human life span to roughly 100 years and the average life span to 85 years. His view received support from well known biologists such as Leonard Hayflick (Hayflick, 1981). Fries's theory of morbidity compression has been highly successful (for example, Medline currently references 526 documents containing the term "compression of morbidity", 18 of them in the title)[2] but few studies have actually tested the "rectangularization of the survival curve" hypothesis (Medline references 4 documents containing "rectangularization of the survival curve", 3 of them in the title) even though this is the key to Fries's theory (Nusselder and Mackenbach, 1996; Robine, 1997; Wilmoth and Horiuchi, 1999). It is the rectangularization of the survival curve which

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[1] For the notion of "rectangular curve" (Comfort, 1964) and that of "curve squaring" technologies (Gordon, 1980).

[2] January 2000. Medline is the on-line bibliographical database of the U.S. National Library of Medicine.

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makes possible the compression of morbidity in a shorter period of time in the latter years of life.[3] Some authors have proposed curves that are even more rectangular than that of Fries. Watkin, for example, predicts that in 100 years 95% of the population will survive "in good health" to at least 115 years and that everyone will die before 120 years (Watkin, 1987). Some even appear to envisage the scenario of a curve that is completely rectangular: "... the result would be a society whose members would live full, physically vigorous, youthful lives until death claimed them at the stroke of midnight on their one-hundredth birthday" (Hayflick, 1981). Such a rectangularization of the survival curve implies the *ipso facto* elimination of all mortality differentials, between men and women and rich and poor, or between different regions of a country. The hypothesis has an obvious social appeal, encouraging some authors to treat it as proven and accept a limit of 85 years for life expectancy. Lohman and his co-researchers, for example, affirmed in *Nature* in 1992 that "In developed countries, the average life expectancy at birth has stabilized since the 1980s" (Lohman *et al.*, 1992).

The relationship between the increase in life expectancy and the rectangularization of the survival curve is poorly understood. Robine has argued that clarification of this relationship and in particular of whether or not the increase in life expectancy is associated with a reduction in the dispersion of individual life spans, constitutes a key question for public health and gerontology today (Robine, 1997). Wilmoth and Horiuchi hold that there is no reason for thinking that life expectancy and distribution of life spans are linked, and that the change and limits in each should be studied separately. In particular, an important question concerns the change in the distribution of life spans over time and the contrasts observed between countries (Wilmoth and Horiuchi, 1999). But problems arise over the choice of an indicator for this purpose since the possibilities are multiple (see Table 1) and at present there is no consensus among experts.

Wilmoth and Horiuchi have catalogued ten indicators, of which six measure the rectangularity of the survival curve, three measure the variability in the distribution of age at death, and one measures the elasticity of increase in life expectancy to reduction in mortality rates. If the 4th and 5th indicators are excluded, the degree of correlation between each pair of indicators is above 0.9 for the American, Japanese and Swedish data. Of the eight most closely correlated indicators, Wilmoth and Horiuchi recommend using the interquartile range for reasons of convenience and ease of interpretation (Wilmoth and Horiuchi, 1999). They compare the change in

[3] Some authors have spoken of a "compression" of mortality to describe the concentration of life spans around the value of the life expectancy at birth. This term has caused some confusion with the term compression of morbidity as defined by Fries. Between a life expectancy fixed at 85 years and a postponement, thanks to prevention, of the age of onset of chronic illnesses, the time lived in poor health is necessarily compressed. This is the idea behind the theory of the compression of morbidity. For this reason we avoid reference to "compression" of mortality in the present article.

the size of this range up to the present day for Sweden since 1751-5, for the United States since 1901-5, and for Japan since 1951-5.

TABLE 1.– LIST OF MAIN INDICATORS PROPOSED FOR MEASURING THE DISPERSION OF LIFE SPANS AND THE RECTANGULARITY OF THE SURVIVAL CURVE

Number[a]	Name or short description of indicators proposed
	1. Indicators listed by Wilmoth and Horiuchi (1999)
1st indicator	The proportion occupied by the surface below the survival curve (SC) of a fixed rectangle
2nd indicator	The proportion occupied by the surface below the SC of a moving rectangle
3rd indicator	The largest absolute decline in the SC between ages
4th indicator	The greatest acceleration of the decline in the SC between ages
5th indicator	The greatest deceleration of the decline in the SC between ages
6th indicator	The "prolate" indicator (Eakin and Witten, 1995), equal to the slope of the CS between the points of inflection corresponding to the 4th and 5th indicators, after standardization of time based on the life span of each species (measure of verticality)
7th indicator	The interquartile range, equal to the age interval between the 1st and 3rd quartiles of life spans (measure of dispersion)
8th indicator	The standard deviation, equal to the square root of the variance of the life spans (measure of dispersion)
9th indicator	The Gini coefficient, an index of concentration in a distribution (in this case of life spans) which varies from 0 to 1
10th indicator	The H of Keyfitz (Keyfitz and Golini, 1975), equal to the proportional increase in life expectancy caused by a 1% reduction in mortality rates (measure of elasticity)
	2. New indicators proposed by Kannisto (1999)
11th indicator	The dispersion of life spans beyond the modal age at death[b]
12th indicator	The size of the quartiles of life spans
13th indicator	The indicator C, the smallest age interval necessary to cover 10%, 25% or 50% of deaths, C10, C25 and C50
	3. Other indicators proposed by Nusselder and Mackenbath (1996)
14th indicator	The coefficient of variation (CV = standard deviation divided by the mean)
15th indicator	The numerator of Keyfitz's H (NH = H multiplied by the life expectancy)
	4. Other indicators proposed by Manton and Stallard (1996)
16th indicator	The age corresponding to different percentiles of the distribution of life spans

[a] Order of appearance in the text.
[b] Cf. the article by Kannisto in this issue of *Population: An English Selection*.

Three new indicators to measure the dispersion of life spans were introduced by Kannisto. In the four countries studied in detail – England, Finland, The Netherlands, and Switzerland – the three indicators follow a very similar course over time. Kannisto recommends use of C50 – defined as the shortest age interval necessary for 50% of deaths to occur – on the grounds that it is the most expressive (Kannisto, 1999). He then compares the change up to the present day in C50, since 1841 for England, since 1850-60 for The Netherlands, since 1876-80 for Switzerland, and since 1881-90 for Finland.

The two indicators thus recommended – the interquartile range by Wilmoth and Horiuchi (1999) and the C50 by Kannisto (1999) – possess strong similarities though they are substantively different. Both measure an age interval that covers 50% of the life spans, but while the interquartile range has a fixed position in the distribution of the life spans – between the 25th and 75th percentiles – the position of the C50 is not fixed in advance: it occupies the smallest age interval necessary to cover 50% of the life spans. The first part of this study thus takes the form of a comparison of these two indicators using data for France, a country absent from previous studies.

Levy had earlier listed several indicators identical or similar to those listed by Wilmoth and Horiuchi, and not presented here. His conclusion seems to be that the standard deviation is the best indicator to characterize the rectangularization of the survival curve (Levy, 1996). In fact, historically, Fries defined his ideal survival curve as the ultimate rectangularization, itself defined by a standard deviation of 4 years around the average life span – 66% of deaths occurring between 81 and 89 years, 95% between 77 and 93 years, and the upper limit life span of 100 years being at 4 standard deviations from the average – (Fries, 1980). Thus it is logical that rectangularization of the survival curve be measured first using the standard deviation, so as to confirm or refute Fries's hypothesis. This is done in the second part of this article where particular attention is given to demonstrating the effect of truncation of the shortest life spans. The same indicator is also used by Myers and Manton to refute the hypothesis of a concentration of ages at death, at least as regards the United States between 1962 and 1979. They calculate the average age at death for all deaths above age 60 and the corresponding standard deviation. Their conclusion is that the increase in the average age at death is not negatively correlated to the value of the standard deviation, rather the reverse. Only when all deaths (i.e. the deaths before age 60) are considered is a negative relationship observed between the increase in the expectation of life (i.e. at birth) and the standard deviation (Myers and Manton, 1984a). Fries rightly criticises these authors for their arbitary exclusion of deaths before age 60, which represent different proportions of deaths in 1962 and in 1979. He argues that truncation should be on proportion of deaths and not on particular ages (Fries, 1984). Reworking their calculations on this basis, Myers and Manton acknowledge that the standard deviation is approximately constant from 1962 to 1979 from the 75th, 66th, 50th, 33.3rd and 25th percentiles of the longest life spans (i.e. corresponding to the highest ages at death) (Myers and Manton, 1984b). Applying this approach more systematically to consider deaths from the 1st, 5th, 10th, 25th, 50th, 75th, 90th, 95th, 99th percentiles and from the 999th thousandth and extending the period of study from 1962 to 1984, Rothenberg *et al.* conclude that in the United States the increase in the average age at death has been accompanied by an increase in the standard deviations, a process they label the "expansion of mortality" (Rothenberg *et al.*, 1991).[4]

[4] Other authors have used the standard deviation of the life spans to compare the mortality of different population groups, as for example Go and his co-researchers (1995) to compare the ethnic groups in California between 1970 and 1980.

Some authors have suggested replacing the standard deviation by the quantity H developed by Keyfitz for measuring the percentage increase in life expectancy that corresponds to a one percent reduction in the mortality rate. The larger the proportion of survivors at older ages, the less the reduction in mortality rates – in proportion – increases life expectancy. Nagmur has shown that the value of Keyfitz's H fell in Canada between 1921 and 1981 with the increase in life expectancy, which he interprets as a clear demonstration of the rectangularization of the survival curve (Nagmur, 1986). Drawing on his work, Nusselder and Mackenbach select two series of indicators to measure the dispersion of life spans, namely the standard deviation (SD) and the related coefficient of variation (CV), as well as Keyfitz's H and its numerator (NH). NH is obtained by multiplying Keyfitz's H by the life expectancy at the starting age. According to the authors, a decline in the value of the standard deviation or of NH signifies absolute rectangularization of the survival curve, corresponding to a concentration of deaths in a smaller age range, whereas a decrease in the value of CV or H indicates merely relative rectangularization, corresponding to a concentration of deaths in a smaller proportion of the life expectancy. Nusselder and Mackenbach consider that H and NH present numerous advantages because they can be decomposed by age and cause of death (Nusselder and Mackenbach, 1996 and 1997). Their four indicators (H, NH, SD, and CV) are calculated for four different ages (at birth, age 10, age 30 and age 60) for The Netherlands between 1950-4 and 1990-2. The four indicators show a clear decline when calculated from birth, but from ages 10 and 30 the results are increasingly less clear, and from age 60 they indicate rather a "de-rectangularization" of the survival curve. However, according to the authors, since 1980-4 the indicators show an absolute rectangularization above age 60 except for the standard deviation for women. Nusselder and Mackenbach's work is valuable, first, for showing that results can vary considerably depending on the starting age used – which echoes Fries's remark about the arbitrary nature of this choice (Fries, 1984) – and, second, for having introduced the distinction between absolute and relative rectangularization. It is also worth noting that Nusselder and Mackenbach use deaths from period life tables, whereas the previous authors work directly with the deaths observed each year, without controlling for differences in cohort size.[5] However, Hill points out that changes in life expectancy and in Keyfitz's H are not independent since the life expectancy is used in calculation of H. In this way, any increase in life expectancy is necessarily reflected in a decrease in the value of Keyfitz's H. Hill has compared the change in life expectancy at age 30 (E or e_{30}), the H of Keyfitz (H_k) and its numerator (N_k or NH), the ages of the stable population associated with the law of mortality (H_s), the entropy of the ages at death (H_f), as well as the change in the variability of the life spans (V or V_{30}) and the mortality rate at the age corresponding to the life expectancy

[5] Dutch readers may wish to consult Nusselder W.J., Mackenbach J.P. (1996) "Langer leven in goede gezondheid of een ouderdom met gebreken", *Demos*, 12 (7): 49-52.

($m(e_{30})$), using data for cohorts born between 1776 and 1901 in France, England and Wales, United States and Canada. From this it emerges that while the H of Keyfitz falls sharply with the rise in life expectancy at age 30, the other indicators H_s, H_k, $m(e_{30})$, and V_{30}, vary hardly at all during the period studied. In particular, the variance of the ages at death above 30 has barely changed in England and Wales from the 1841 generations to the 1901 generations, whereas over the same time life expectancy at age 30 has increased by more than 7 years within the cohorts. Hill estimates that three-fifths of the fall in Keyfitz's H between the 1776 and 1901 cohorts for men, and four-fifths for women, is directly attributable to the increase in the life expectancy of the cohorts (Hill, 1993).

In an article published in 1996 Manton and Stallard examine change in the distribution of deaths above age 65 in the United States between 1960 and 1990, using a different indicator, the age corresponding to different percentiles of the distribution of life spans. They observe that the ages corresponding to the 25th, 50th, 75th, 95th, 99th, 99.5th, 99.9th and 99.99th percentiles of the deaths above age 65 follow a parallel course of change, the age corresponding to each having increased by roughly 3 years over the period. Thus, the age corresponding to the 75th percentile had increased by 3.3 years and the age corresponding to the 99.9th percentile by 3.0 years (Manton and Stallard, 1996). Although this result is in theory evidence of a concentration of life spans, it does not really argue for a reduction in the dispersion of age at death above 65 years. The same method was used in 1998 by Paccaud and co-researchers to examine whether the survival curve had become more rectangular above age 50 in Switzerland from 1969 to 1994. Comparing for this period the change in the modal age, the median age and the ages corresponding to the 75th, 90th and 95th percentiles of life spans, they observe visually a slight convergence of the curves which is confirmed by calculation of the slopes – the higher the percentiles considered, the gentler the slopes (Paccaud *et al.*, 1998).

Other authors, finally, have continued to measure mortality change over time chiefly in terms of average life span, relying simply on visual inspection of the survival curves to conclude in favour of an "obvious" rectangularization in Quebec between 1831 and 1991 (Pelletier *et al.*, 1997).

The first part of this article presents the application of the data for France to the main indicators proposed for measuring the dispersion of life spans and the rectangularity of the survival curve, and then compares the interquartile range and the C50 in France and other countries. The second part is concerned with the standard deviation of the life spans, and in particular aims to demonstrate the effect of truncation of the shortest life spans.

I. Change in the Distribution of Life Spans in France in the 20th Century

Before comparing the change in the interquartile range and the C50 during the 20th century in France and setting it against the results obtained for the countries already studied, the situation in France will be described using indicators of the degree of rectangularization and the degree of verticalization. Only an indicator of rectangularization can provide a direct measurement of the "rectangularization of the survival curve". Although the second indicator (moving rectangle) seems better than the first (fixed rectangle), both indicators are given so as to show the effect of "fixedness".[6] Rectangularization has often been judged "visually". Yet the "horizontalization" of the survival curve concomitant on the fall in infant mortality and the elimination of major mortality risks in the first 50 years of life, combined with a fixed right boundary, is responsible for creating an impression of rectangularization. Consequently it is especially important to measure any possible "verticalization" of the survival curve, which is the object of the 3rd indicator – the value of the largest decline in the survival curve – corresponding to the modal life span. This indicator is simple, effective and easy to interpret.

Figure 1 summarizes the transitions that have occurred in the 20th century by contrasting the extreme situations of 1890-4 and of 1990-4. Over this one hundred year period, survival probabilities have increased considerably. Mortality under age 30 has practically disappeared, resulting in a "horizontalization" of the survival curve during the early years of life.

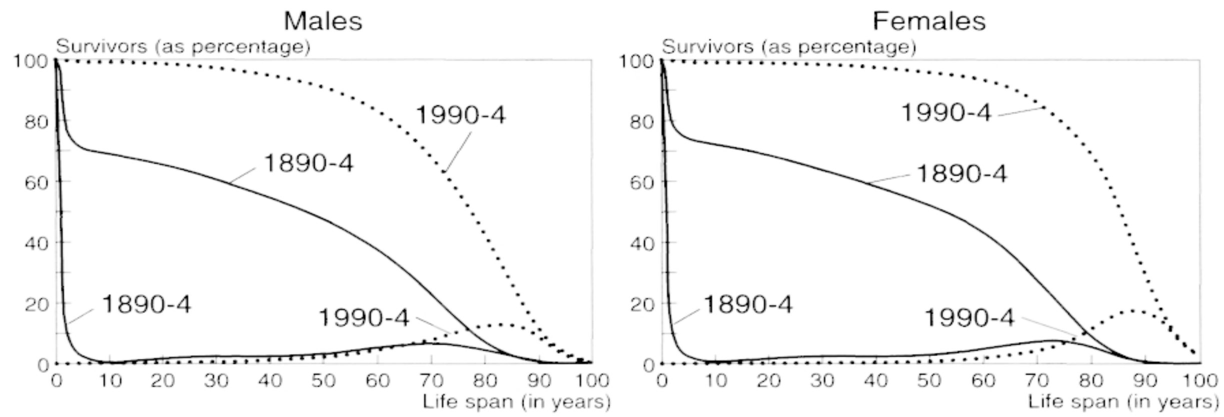

Figure 1.– Survival curves and distribution of individual life spans France 1890-4 to 1990-4, by sex

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE..

[6] In particular, the indicator based on a moving rectangle does not set any particular limit to the length of life. It adjusts to the distribution being studied in the sense that it gives the smallest rectangle into which some proportion of the lengths of life, 99% or 99.9%, for example, will fit.

Next, deaths have been postponed to higher ages, as evidenced by the increase of 12 years in the modal age at death for men, from 71 to 83 years, and of 14 years for women, from 73 to 87 years. The diagram shows that more lives end at the modal age at death for both sexes, but it also makes clear that many more individuals survive past age 95. In the conditions of 1890-4, less than 1% of men or women survive to age 89, whereas in the conditions of 1990-4, more than 1% of men survive to age 98 and nearly 2% of women to age 100. How, in the light of these observations, can it be concluded that the increase in life expectancy has been accompanied by a reduction in the dispersion of life spans?

With Figure 2 it is possible to identify on the survival curves of women for 1890-4 and 1990-4 the points where the acceleration or deceleration in the curve's decline is greatest between ages (4th and 5th indicators). To simplify, Eakin and Witten's "prolate" index (6th indicator) can be said to measure the steepness of the line that connects these points. The diagram shows, first, that all these points have moved to higher ages, and second, that the difference between them has decreased from 20 to 13 years.

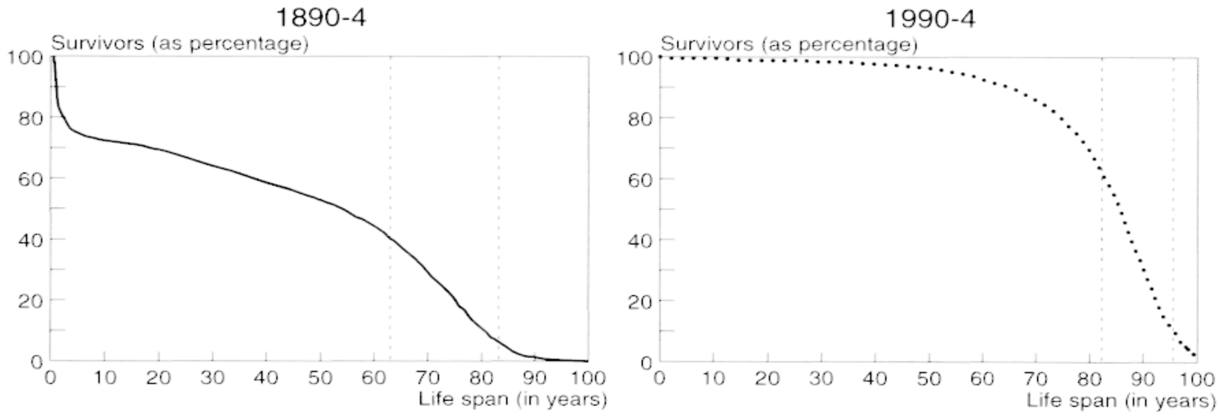

Figure 2.– Survival curves and points of inflection corresponding to the 4th and 5th indicators, France 1890-4 to 1990-4, females

The points for which the acceleration or deceleration of the decrease in the SC is the largest between ages indicate respectively ages 63 and 73 in 1890-4 and ages 82 and 95 in 1990-4.

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

Figure 3 shows that life expectancy at the median life span falls sharply over the period for men and women, indicating a reduction in the dispersion of life spans above the median. The decrease in life expectancy at the 3rd quartile, though clear is appreciably smaller.

Figure 4 uses the first set of indicators to show that the survival curve is indeed increasingly "rectangular" in the original meaning of the term – that is, the surface below the survival curve occupies an increasingly large proportion of the fixed rectangle formed by the vertical at age 100 on the abscissa and the horizontal from the initial 100,000 survivors

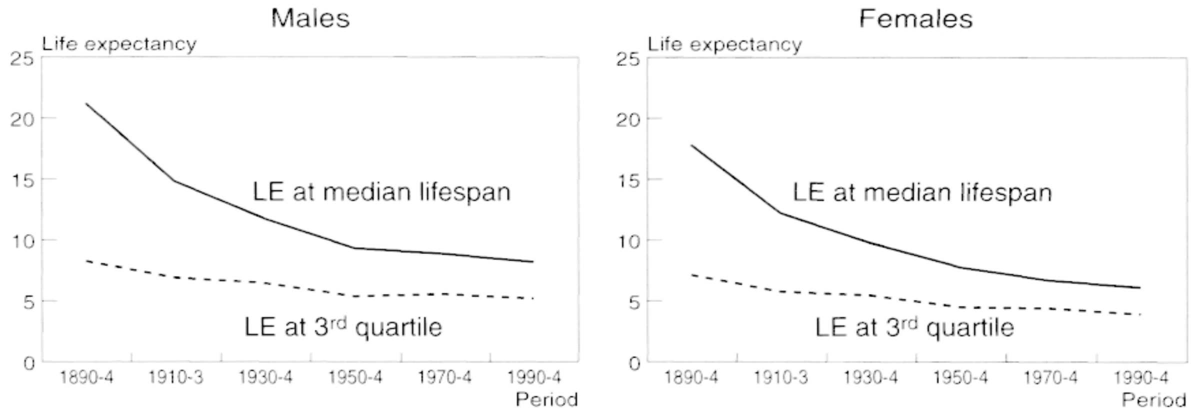

Figure 3.– Life expectancy at the median life span and at the 3rd quartile, France 1890-4 to 1990-4, by sex

During this period, life expectancy at the median life span goes, respectively, from 21.2 to 8.7 years for men and from 18.3 to 6.2 years for women. The life expectancy at the 3rd quartile goes from 8.2 to 5.3 years for men and from 7.1 to 3.9 years for women.

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

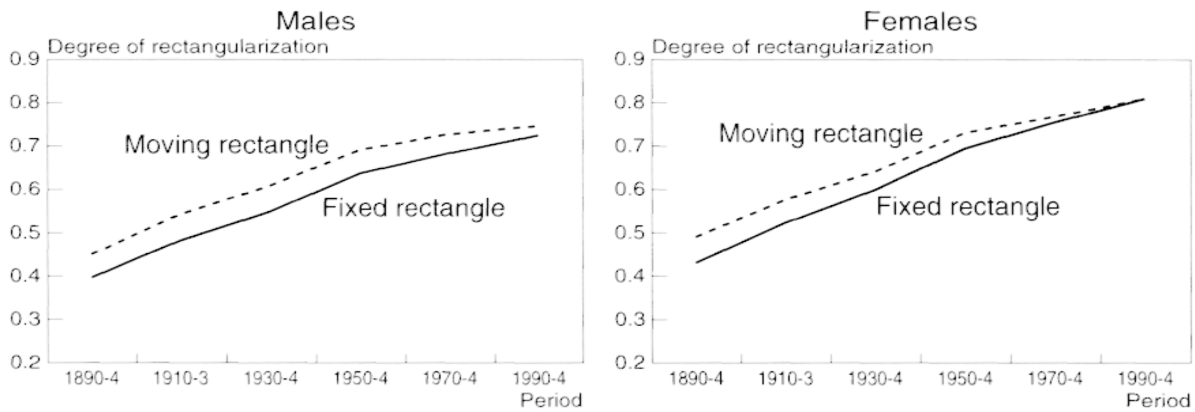

Figure 4.– Degree of rectangularization of the survival curve, France 1890-4 to 1990-4, by sex

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

(1st indicator), and of the moving rectangle formed by the same line with the vertical from the abscissa that cuts the survivor curve at the point where only 1% of survivors remain (2nd indicator). During the period, the degree of rectangularization for the fixed rectangle increases from 0.40 to 0.73 for men and from 0.43 to 0.81 for women, and for the moving rectangle the change is from 0.46 to 0.75 for men and from 0.49 to 0.81 for women. Applying a fixed right boundary of 100 years merely exaggerates the "rectangularization" observed by minimizing the rectangularity of the earlier curves. In both cases and for both sexes, a discontinuity is noted in 1950-4, with the trend to "rectangularization" being stronger before than after.

Using a second series of indicators, Figure 5 shows that the survival curve is increasingly vertical around the modal life span. The degree of "verticalization", measured by the percentage of deaths concentrated at the modal life span, increases over the period from 1.7 to 3.3% for men and from 1.9 to 4.5 for women (3rd indicator). Here too a sharp discontinuity is noted in 1950-4, with the trend to "verticalization" being stronger before than after. Conversely, this discontinuity is not observed in the progression of the modal age over the same period.

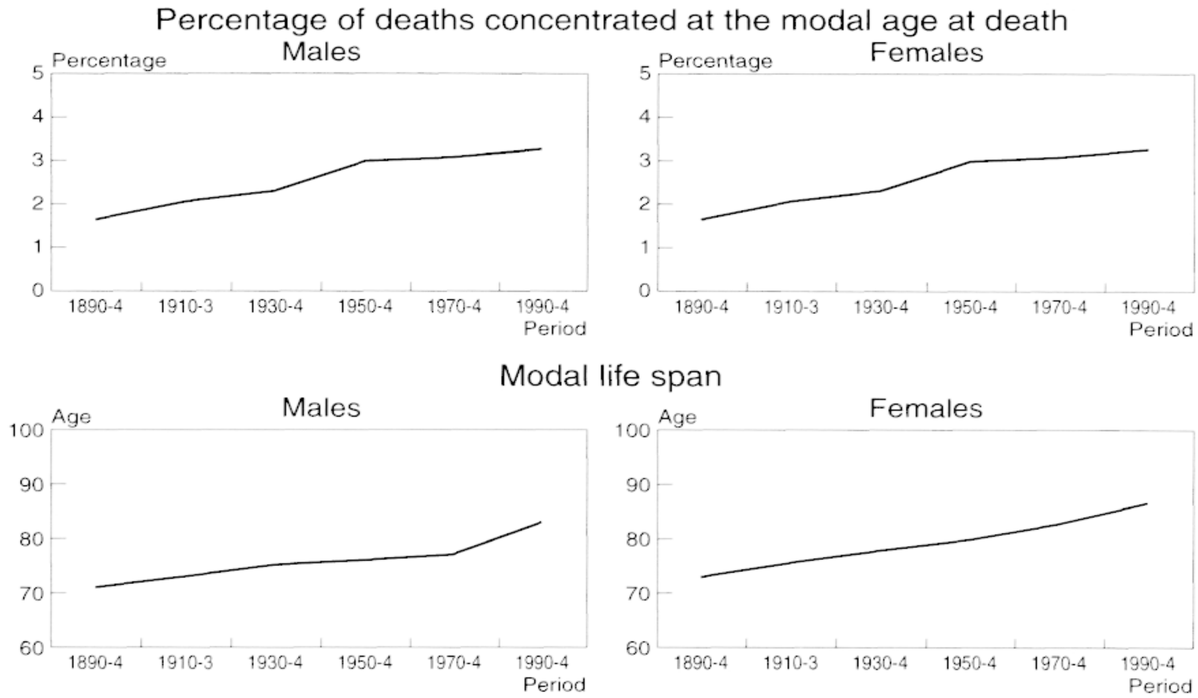

Figure 5.– Percentage of deaths concentrated at the modal age at death, and change in the modal life span, France 1890-4 to 1990-4, by sex
Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

Figure 6 displays, first, the change in the interquartile range in the distribution of the life spans between 1890-4 and 1990-4 (7th indicator). It is very clear that this interval contracts considerably at the same time as it moves to the higher ages. At the end of the period, however, there is no further reduction for men and hardly any more for women, although the range continues to move towards the higher ages.

The diagrams then display the change in Kannisto's C50 in the distribution of the life spans over the same period (13th indicator). In this case too the contraction of the interval over time is very clear, although prior to 1970 only the interval's lower limit moves towards higher ages. While the interval is still contracting at the end of the period, since the 1950s the reduction has been very small for both sexes. So much so that at the end of the period it is the interval as a whole which moves towards the higher ages.[7]

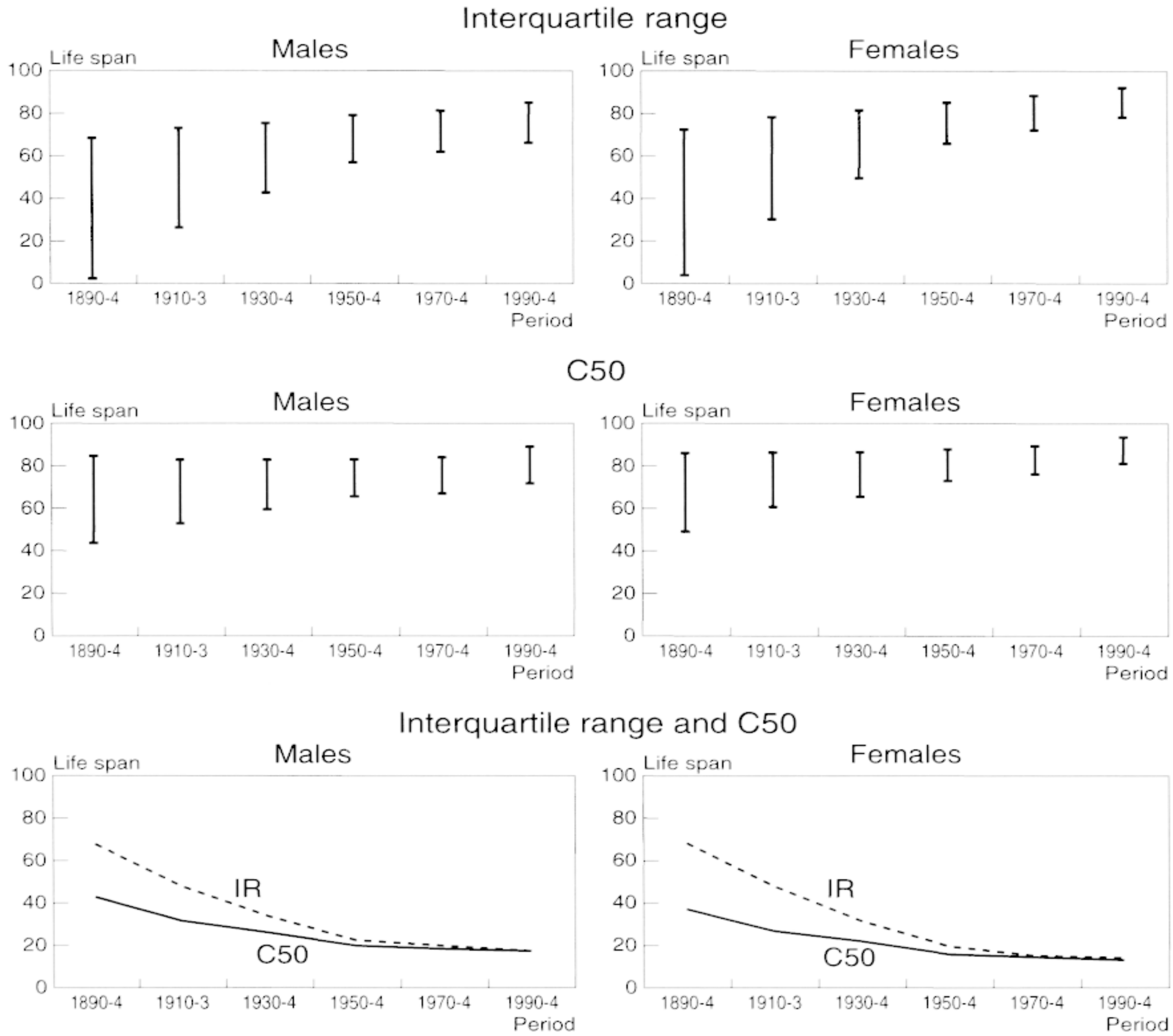

Figure 6.– Change in the interquartile range and in Kannisto's C50, France 1890-4 to 1990-4, by sex

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

A comparison of the two indicators between 1890-4 and 1990-4 shows that C50 was in the past smaller than the interquartile range. The differential reduction in the intervals over time has brought about a considerable convergence and since 1970-4 their respective sizes are almost indistinguishable. However, the C50 is still smaller than the interquartile range. A major discontinuity is again noted in the pattern of change before and after 1950-4. Up to 1950-4, there is a sharp contraction in the intervals and they become similar in size. After this date, the reduction in the inter-

[7] Following Kannisto's recommendations, only the fraction of the last year of age necessary to cover 50% of deaths is used. So for the period 1990-4, of 100,000 female deaths, 51,486 occur between ages 81 and 93, that is, in 13 years. The last year that is necessary – in this case 93 years which contains slightly fewer deaths than 81 years adds an extra 3,221 deaths whereas only 1,735 were needed to reach 50,000. Only the fraction of the year that corresponds to these deaths is taken into account, which gives a value for C50 of 12.54.

vals stops completely (interquartile ranges) or nearly (C50) for men, while it continues for women, although at a much reduced pace, for both indicators.

Comparison of the two indicators shows, in this case too, that in relation to a moving indicator, the C50, that is free to fit the distribution being studied, use of a "fixed" indicator, the interquartile range, exaggerates the concentration of life spans around the mode which has taken place during the 20th century. The C50 shows that the life spans were much more concentrated around the mode at the start of the period than is suggested by the interquartile range, the zone of maximum concentration being simply displaced in relation to this interval towards higher ages. At the end of the period, even though the differences have become negligible, the C50 is still smaller than the interquartile range. For example, for the period 1990-4, the C50 for women is 12.5 years as against 13.9 for the interquartile range. It can therefore be considered that the C50, though harder to calculate, is a better measure of changes in the concentration of life spans. In addition, it gives a direct indication of the age group in which the concentration is greatest, which in the present example is between 81 and 92.5 years for women during the period 1990-4, while the corresponding interquartile range increases from 76.7 to 90.6 years and thus does not coincide completely with the zone of greatest concentration.

International comparisons

It was decided to keep both indicators for the purpose of international comparisons, however, so as to have more countries to compare with France. Figure 7 shows that the change in the interquartile range of life

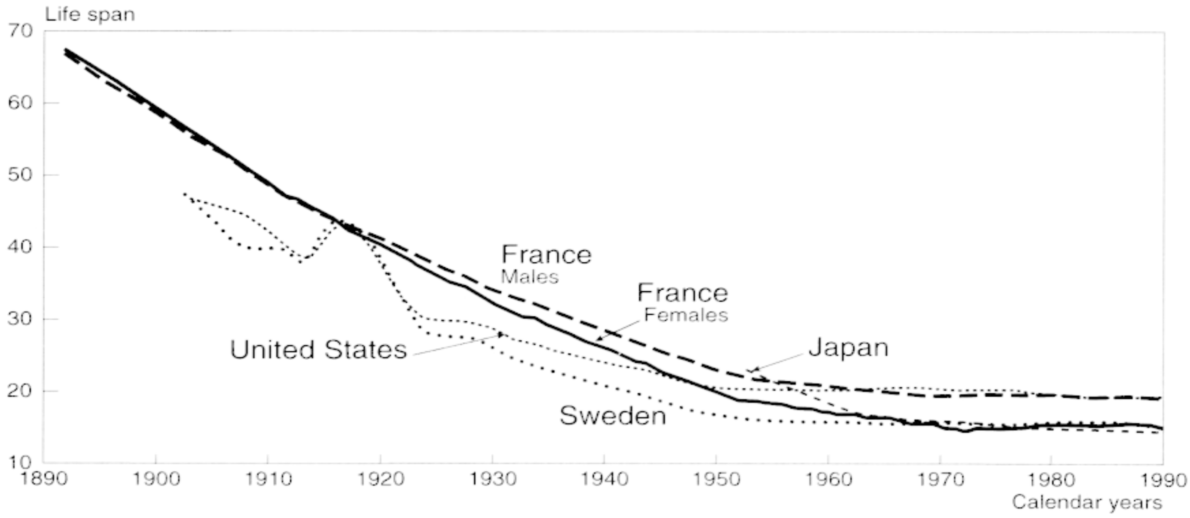

Figure 7.– Comparison of change in the interquartile range of life span in France, Sweden, United States, and Japan

Source: Wilmoth and Horiuchi (1999) and INSEE.

spans for France is similar to the changes observed by Wilmoth and Horiuchi (1999) for Sweden, the United States and Japan. In all four countries the same discontinuity is observed in the historical trend, in the 1950s for both sexes in Sweden and the United States and for men in France, and in the 1960s for both sexes in Japan and for women in France. At the end of the period, the size of the interquartile range is identical for the Japanese and Swedes and for French women (14 years), and for the Americans and French men (19 years). Overall since 1970, the reduction in the interquartile range has stopped.

Figure 8 shows that the change in Kannisto's C50 for France is practically identical to that observed by Kannisto (1999) for England, The Netherlands, Switzerland and Finland. These countries all present the same discontinuity in the historical trend observed in the 1950s for females. At the end of the period, the size of the C50 differs little between the countries. For females it varies from 13.1 years for The Netherlands in 1990-5 to 12.4 years for Switzerland in 1988-93. England alone stands out with a slightly higher figure of 14.8 years in 1990-2. With the exception of this country, for which the C50 seems to stagnate at the end of the period, the indicator shows that the concentration of life spans continues even though the reduction of the differences between periods is very small.

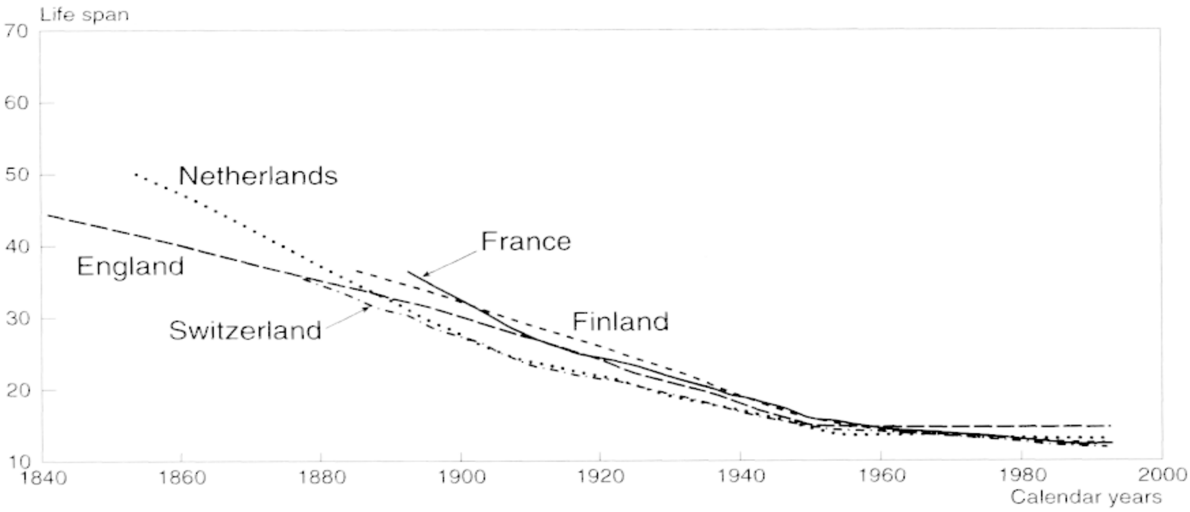

Figure 8.– Comparison of change in Kannisto's C50 in France, England, The Netherlands, Switzerland and Finland, females

Sources: Kannisto (1999) and INSEE.

The two comparisons, that of the interquartile range used by Wilmoth and Horiuchi and that of the C50 developed by Kannisto, produce very similar conclusions. After a period of sharp decrease, the dispersion of the life spans – as measured by the interquartile range or by Kannisto's C50 – has fallen only slightly since the 1950s in the countries with a low level of mortality. If England is excluded, the change in the C50 is still in the sense of a decrease – albeit small – whereas the change in the inter-quartile range points rather to a stagnation at the end of the period. Be that as it may, both indicators show the same discontinuity in the historical trends in the 1950s.

In France, even if the changes have slowed significantly compared with those observed in the first part of the 20th century, the survival curve continues to be "rectangularized" (in the sense of occupying an increasing area of the various rectangles that can be drawn around it) and continues to be "verticalized" around the mode of the life spans. However, since the 1950s, the interquartile range and Kannisto's C50, which have moved much closer, have both been decreasing only slightly. A stagnation is even observed in the interquartile range for men between 1970-4 and 1990-4. It is as if the increasing concentration of life spans that end at the modal age at death is largely compensated by an increase in the length of life spans that end after this age. Moreover, the most striking result for France is that since 1970-4 for both sexes the interquartile range and Kannisto's C50 have gone on being displaced towards higher ages whereas they show almost no further decrease. The reduction in life expectancy at the median life span gets smaller and smaller at the end of the period, and for life expectancy at the 3rd quartile of the life spans the reduction is smaller still (cf. Figure 3). This result is clearly reminiscent of those obtained by Eakin and Witten showing that rats subjected to a restricted calory diet and which lived much longer than rats nourished *ab libidum*, had a much less rectangular survival curve than their controls as measured by the "prolate" indicator (Eakin and Witten, 1995).

II. Standard Deviation and Truncation of the Shortest Life Spans

In the second section of this article, just one indicator is used: the standard deviation of the life spans or of age at death (8th indicator). This is both the indicator that defined the ideal survival curve for Fries (1980), presented as the ultimate rectangularization (cf. introduction), and the historical indicator which provided the arguments for the polemic in the 1980s opposing Fries to Myers and Manton in the United States (Fries, 1984; Myers and Manton, 1984a and 1984b; Rothenberg *et al.*, 1991).

This polemic highlighted the effect on results of truncation that excludes life spans completed before a fixed age or a proportion of the shortest life spans. Yet this has not deterred other authors from using the same approach. Hill excludes life spans below 30 (Hill, 1993), Manton and Stallard those below 65 (Manton and Stallard, 1996) and Paccaud and coauthors those below 50 (Paccaud *et al.*, 1998). Thirty, fifty, sixty-five years! It is hard to see what logic lies behind these choices other than a preference for round numbers. Even Eakin and Witten, who attach such importance to "investigator" bias, nonetheless exclude life spans below 13 years (Eakin and Witten, 1995).

Publication of the studies on The Netherlands by Nusselder and Mackenbach and which produced results that differed appreciably depending on the starting age used for the calculations – at birth, at age 10, age 30 or age 60 – ought to have drawn attention to this problem (Nusselder and Mackenbach, 1996). As far as we are aware, however, no systematic study has ever been carried out into the effect of the choice of starting age for the indicators of "rectangularization" of the survival curve or for the measures of the dispersion of life spans.

Figures 9 and 10 present the results of such a study that we have done for both sexes using French data for the period 1890-4 to 1990-4. The results are truly astonishing! Tell me what you want to find and I will tell you which starting age to use for your calculations. Say you want to show that the standard deviation of life spans has not changed with the increase in life expectancy, take age 50 for females and age 40 for men; age 45 would be a good compromise and allows an interesting discussion of the slight differences between the sexes. You might also decide to study only life spans over 95 years; a somewhat limited but extremely neat option. You want to show that the increase in life expectancy is accompanied by a large reduction in the dispersion of life spans – which implies the existence of a limit to the increase in life expectancy – take birth or a value close to birth. And you can repeat the calculation with several starting ages between 0 and 20 years. But should you want to demonstrate the opposite, namely that the increase in life expectancy is associated with an increase in the dispersion of life spans – which strongly suggests that there is no limit to the increase in life expectancy – the ideal age is around 62 years for males and 75 years for females. In any case, to confirm your results, simply repeat the calculations with different starting ages between 60 and 80 years.

Over and above these slightly tongue-in-cheek remarks, it is clear from the diagrams that only a calculation which includes all life spans or deaths is beyond criticism, and this refers us back to the analysis in the first part of this article. The change in each of the specific life spans considered, that contains either more or, on the contrary, fewer cases over the period, contributes to reducing or increasing the standard deviation of the life spans. The further from birth we fix the age below which the shortest life spans are omitted from the calculation, the more weight is apparently given to the life spans which contribute to increasing the standard deviation. A first equilibrium seems to be reached around age 40 for males and age 50 for females. Beyond this point, the standard deviation increases. But after a maximum, attained around 62 years for men and 75 for women, moving further away from birth would seem to give more weight to the life spans which contribute to reducing the standard deviation. A second point of equilibrium can be identified around 95 years for both sexes.

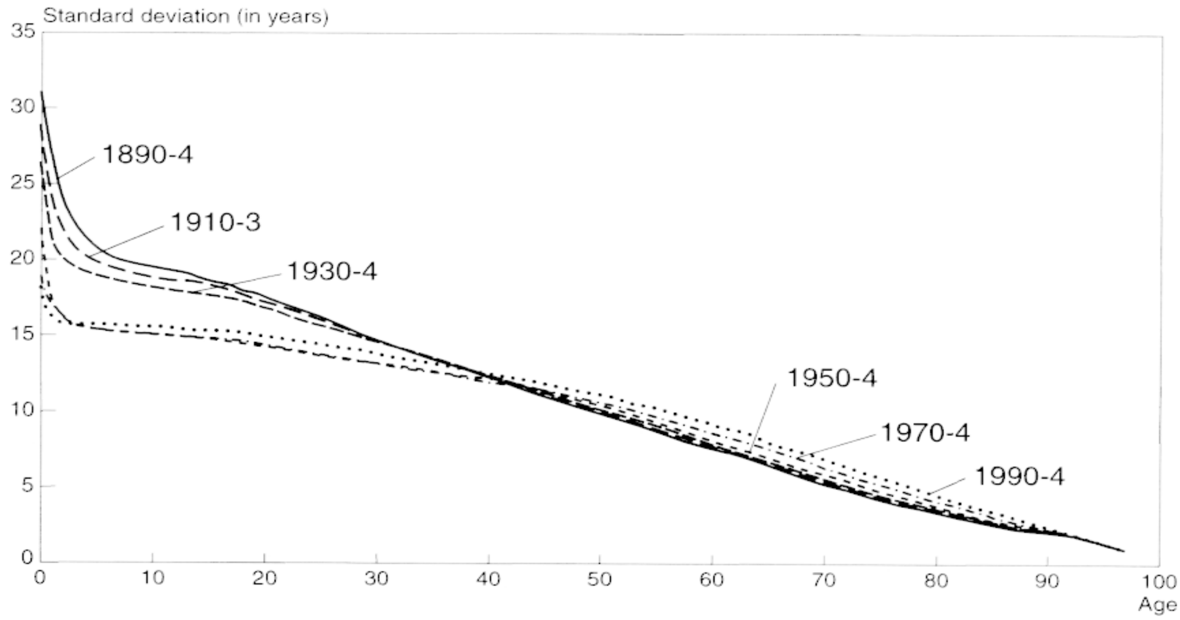

Figure 9.– Change in the standard deviation of life span in France, from 1890-4 to 1990-4, by the age below which life spans are omitted (truncation), males

Source: based on the quinquennial life tables constructed by Q.C. Dinh, INSEE.

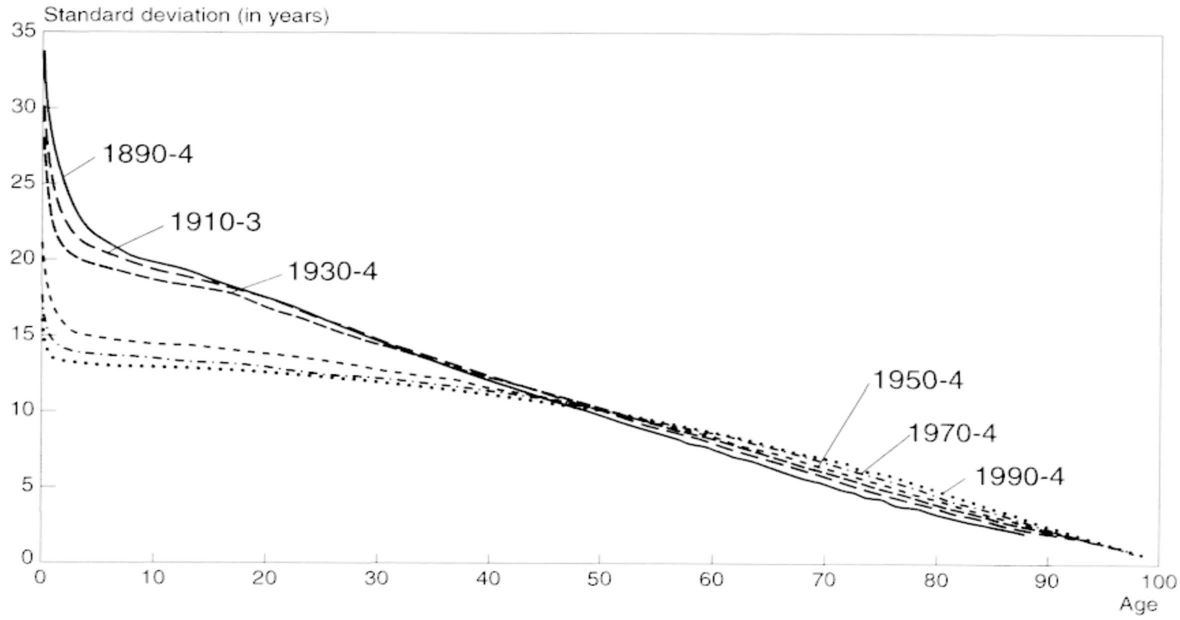

Figure 10.– Change in the standard deviation of life span in France, from 1890-4 to 1990-4, by the age below which life spans are omitted (truncation), females

Source: based on the quinquennial life tables established by Q.C. Dinh, INSEE.

We have also examined the effect of the choice of starting age for several of the indicators used in the first part, such as the indicators of the degree of rectangularization (1st and 2nd indicators) or used by other authors, such as Keyfitz's H (10th indicator). Figure 11 shows, with the example of the 2nd indicator, that the results are similar to those obtained with the standard deviation.

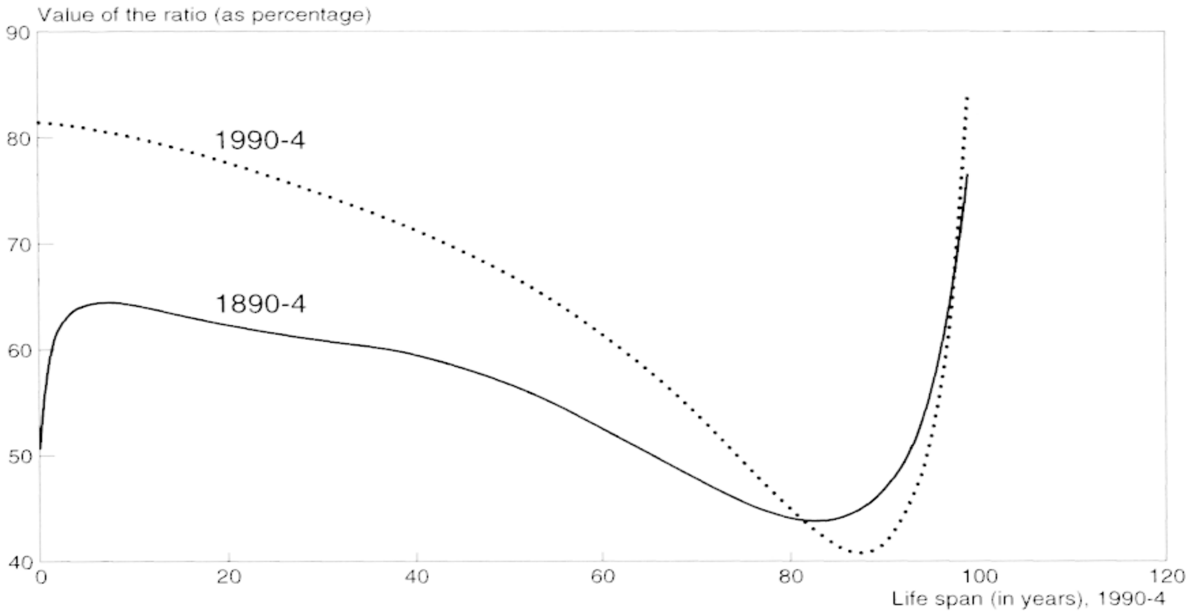

Figure 11.– Change in the degree of rectangularization of the survival curve in France, from 1890-4 to 1990-4, by the age below which life spans are omitted (truncation), females

Note: the degree of rectangularization is measured by the ratio of the partial life expectancy between age *x* and the age attained by 1% of the population, and the years of potential life between these two ages. The diagram has been constructed to show the curves for 1890-4 and 1990-4 at birth and at the age attained by 1% of the population. The ages on the abscissa correspond to the curve for 1990-4; the ages that correspond to the curve 1890-4 are obtained by dividing these by the coefficient 1.15. Thus age 100 in 1990-4 corresponds to age 87 years in 1890-4.
Source: based on the quinquennial life tables established by Q.C. Dinh, INSEE.

III. Discussion

All the authors agree on the existence of a long-term trend towards a reduction in the dispersion of life spans when the analysis is based on all life spans, including the shortest. But the conclusions diverge as soon as some life spans are excluded. The problem appears not to originate entirely in the choice of indicators, although Eakin and Witten insist that practically all these studies suffer from an "investigator" bias due to the choice of indicators used (Eaken and Witten, 1995). The second part of the present study suggests that these differences arise rather from the choice of the starting age for calculation and from the various truncations that omit the shortest life spans. The international comparisons presented at the end of part one show a high degree of convergence between the studies when the totality of life spans are considered.

According to Hill's study of the overall change in the dispersion of life spans over 30, based on data for France, England and Wales, United States and Canada for the cohorts 1776-1901, the increase in life expectancy has made little change to the dispersion of life spans but has merely pushed them back to higher values (Hill, 1993). It must be noted that Hill is the only author to have studied the changing dispersion of life spans in successive cohorts. The other authors have all produced period studies. The choice of period studies is entirely justified in view of the question restated at the beginning of this article, namely whether or not the increase in life expectancy – in a period of time – is associated with a reduction in the dispersion of individual life spans – in these populations. By contrast, use of the period perspective can be a source of difficulties if these observations are intended to produce measures of ageing and of the variability of life spans in the human species.

For the United States, Rothenberg and coauthors analysed the change in standard deviation of the life spans – from different percentiles – during the period 1962-84, and concluded that the increase in average age at death was accompanied by an increase in standard deviations – they labelled this the "expansion of mortality", by analogy with Fries's concept of the "compression of morbidity" (Rothenberg *et al.*, 1991). From their study of the change in the ages corresponding to different percentiles of the distribution of life spans between 1960 and 1990, Manton and Stallard conclude that the different ages evolve on parallel courses – a result that argues against a reduction in the dispersion of ages at death over age 65 (Manton and Stallard, 1996). It should be noted, however, that the age corresponding to the 75th percentile has increased by 3.3 years whereas the age corresponding to the 99.9th percentile has increased by only 3.0 years. For Eakin and Witten, who have studied the period 1900-1980 in the United States, and who distinguish the time intrinsic to each species (relative or not) from time measured in days and years and introduce their "prolate" indicator, the general trend towards greater rectangularization – observed since the start of the century – is interrupted around 1960 and gives way to a trend tending asymptotically to a "prolate" index of less than 1, "indicating that there may be no absolute deterministic maximum life span" (Eakin and Witten, 1995). It can be noted that the tables of Eakin and Witten start at age 13, a choice presumably not free of the "investigator" bias they criticize. For Switzerland, Paccaud and co-researchers used the same method as Manton and Stallard for the period 1969-1994, but unlike them concluded that their findings pointed to a reduction in the dispersion of ages at death after age 50, that is, the opposite of the "expansion of mortality" (Paccaud *et al.*, 1998).

For Canada, Nagmur studied the period 1921-81 using Keyfitz's H instead of the confidence interval and asserts that his results clearly illustrate the rectangularization of the survival curve (Nagmur, 1986). For The Netherlands, Nusselder and Mackenbach, who studied the period 1950-92 by establishing a distinction between the notion of absolute rectangularization, defined as a concentration of deaths in a smaller age range, and that of relative rectangularization, defined as a concentration of deaths in a smaller proportion of the life expectancy, consider that their results show a relative and absolute rectangularization of the survival curve over the entire period studied if a few years are excluded for males (Nusselder and Mackenbach, 1996). It can be noted that the rectangularization of the survival curve in The Netherlands at high ages, observed by Nusselder and Mackenbach in men from 1980-4, is due mainly to the increase in mortality of the oldest old. Rectangularization of the survival curve is thus associated with a decrease in life expectancy for the oldest old.

The "Age of the Conquest of the Extent of Life"

Situated in a more general context, all these results can be used to discuss the phases of the epidemiological transition that parallels the demographic transition. Formulated by Omran in 1971, the epidemiological transition describes the changing cause-of-death pattern associated with the historical decline in mortality. Omran's original formulation postulated three stages modelled on the stages of the demographic transition, namely "The Age of Pestilence and Famine", "The Age of Receding Pandemics" and "The Age of Degenerative and Man-Made Diseases", but in 1986 Olshansky and Ault proposed adding a fourth stage which they labelled "The Age of Delayed Degenerative Diseases". To simplify, during the first stage, exemplified by conditions in the Middle Ages, mortality vacillated at high levels, with infectious disease as the main cause of death plus a large proportion due to wars and famines. In the second stage, when mortality declined under the influence of the general progress initiated by the industrial revolution, a modification occurred in the pattern of the causes of death. Children and women were the main beneficiaries of the uneven but massive decline in malnutrition and infectious diseases. Omran's third stage marked the end of the epidemiological transition, with a halt in the mortality decline. Henceforth, the causes of death were essentially degenerative – cardiovascular diseases and cancers – and originated in behavioural and lifestyle factors, most notably the over-eating that accompanies affluence, and workplace conditions, stress, pollution, lack of exercise, smoking, plus of course road traffic accidents. Omran saw this stage as having begun in the 1960s in the developed capitalist countries. Shortly afterwards, however, it was discovered that mortality had in fact continued to decline throughout the 1970s in these countries and that for women this decline had never completely stopped. In the light of this, Olshansky and Ault proposed a fourth stage for the epidemiological transition in which mortality fell because the onset of chronic diseases was delayed to older ages. The cause-of-death pattern continues to be modified during this stage, since this delay varies, sometimes greatly, between different causes of death. The change from the first to second stages can in theory be identified by the study of mortality rates and the cause-of-death pattern, but these are of little practical help for dating the change from the second to third stages and even less that from the third to the fourth stage. In particular, the cause-of-death pattern is subject to a more or less continuous modification over time.

The results brought together in the first part of this article, relating to the study of change in the dispersion of all life spans, provide support for the existence of only three stages: (1) the mythical reference era that precedes the fall in mortality, Omran's "Age of Pestilence and Famine", which is not represented on the diagrams in this article and came to an end between the 18th and 19th centuries depending on the country; (2) a first stage of transition, when the level of mortality fell and tended to stabilize as a consequence of the decline in infectious diseases, in particular those affecting women and children, resulting in a very large reduction in the disparities of life spans. This "Age of Receding Pandemics" came to an end in the 1950s in the countries which had gone furthest in the transition, such as northern and western Europe, North America and Japan; (3) these countries have since entered a new transition in which the mortality decline at adult ages, including among the very old, becomes relatively larger than at young ages and where the increase in life expectancy is no longer associated with a reduction in the dispersion of life spans – or with only a very small reduction. This new age corresponds less to Omran's third stage – which today appears to have little basis in reality – and more to the fourth stage proposed by Olshansky and Ault and could be labelled the "Age of the Conquest of the Extent of Life". This may be the age when man having been finally liberated from the great epidemics is able to explore the full extent of his life. No doubt this stage will come to an end one day with the start of a new stage. Whether this will be the "Age of Limits" or something else we do not know. But at present, completely absorbed in exploring his potential longevity, man is making unexpected discoveries such as that it is possible to live for between 110 and 120 years.

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