Sex-specific variability in adult life span over time: have male ages at death always been more disperse?

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Sarah Zureick
University of California, Berkeley
sarahz@demog.berkeley.edu

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Presently, females enjoy an advantage over males with regards to life expectancy in most areas of the world. Much research has focused on the emergence of the gap in life expectancy between the sexes and trends in the gap over time [10, 11, 6]. In addition to experiencing greater longevity, it has been documented in developed countries that females also experience greater certainty about timing of death as the female death distribution is less disperse than the male distribution [13, 4, 6]. In this paper, we ask whether women have always experienced lower variability of age at death in comparison to males, and finding that this relationship does not hold historically, we investigate why females have recently gained an advantage.

It is important to consider trends in sex-specific variability of age at death when comparing trends in life expectancy between the sexes. As Glei and Horiuchi demonstrate in their work, the recent narrowing of the gap in life expectancy between males and females is due in part to lower variance in the death distribution for females [6]. Measures of variability have a broader importance beyond their effect on life expectancy, however. These measures give an indication of certainty in the timing of death. Noting that research has shown that the variability of age at death has remained relatively stable over the past half century in developed countries, and that women experience lower variability, we are then compelled to ask why women hold both an advantage in longevity and certainty in timing of death [13, 4, 2, 3].

Through decomposition analysis, we seek to identify the changes in age-specific mortality rates that have led to females experiencing lower dispersion in life span compared to males. We expect that the results of our decomposition of trends in variability of age at death into the contributions of changes in age-specific mortality rates will not mirror results of similar decompositions of trends in life expectancy for two reasons. First, measures of variability of age at death are more sensitive to changes at the tails of the death distribution in comparison to the measure of the mean of the distribution, life expectancy, especially in situations of low infant mortality. Also, as Edwards and Tuljapurkar find in their work, trends in the variability of adult life span, as measured by the standard deviation of ages at death above age 10 (S_{10}), do not necessarily follow the same path as trends in life expectancy [4].

The relatively recent emergence of a gap in the variability of life span between the sexes suggests that the gap is the product of the modern epidemiological environment. We will utilize the results of previous studies, which have examined changes in age-specific mortality rates by sex and cause, to

speculate on the contribution of specific causes to the emergence of the gender gap in variability of age at death [5, 10, 11]. Again, we don't expect the major causes of the emergence of the gap in life expectancy to necessarily overlap with the causes of greater certainty in timing of death for females in comparison to males. We do expect that an examination of sex-specific trends in variability of age at death will provide a different perspective on the development of the female mortality advantage.

1 Data and Methods

We want to assess sex-specific trends in variability of age at death. We are first interested in finding out whether female ages at death have ever been more disperse than male ages at death. Finding that the levels of variability were more equal in the past, we then ask why females have recently gained a substantial advantage over males.

To assess variability in ages at death, we use the measure S_{10}, the standard deviation of ages at death above age 10, proposed by Edwards and Tuljapurkar [4]. The standard deviation in ages at death is highly correlated with other measures that have been used to study trends in mortality compression such as the interquartile range (see Wilmoth and Horiuchi for a detailed overview of these methods [13]). Trends in measures of variability which include all age groups tend to be dominated by trends in infant mortality. We use S_{10} rather than a measure which takes into account infant and childhood deaths because we are interested in sex differences in mortality at adult ages.

The data needed for analysis of trends in S_{10} over time is drawn from the Human Mortality Database (HMD) and the World Health Organization's (WHO) collection of 1,802 life tables [1, 8]. Using data from the Human Mortality Database, we are able to explore the historical patterns of 33 countries using single year life tables with single year age groups that extend up to age 110. The period of observation varies by country, but extends as far back as 1751 in the case of Sweden. Sex-specific trends in S_{10} are quite consistent across the countries included in the HMD.

More countries from developing regions are included in the WHO life table collection. Data from this collection is used to assess whether the historical patterns in sex-specific S_{10} differ for countries from developing regions in comparison to developed. These life tables originally included five-year age

groups up through age 85. The life tables were extended to age 110 using the Kannisto model in order to make a more accurate estimate of S_{10}[1].

In order to understand why women have gained an advantage in terms of lower variability in the recent past, we decompose trends in S_{10} by age using a method proposed by Horiuchi et al [7]. We look specifically at the contributions of changes in age-specific mortality rates, m_x, to overall changes in S_{10} over time. We carry out the decompositions for ten countries in the HMD with sufficiently long historical records: Belgium, Denmark, England and Wales, Finland, France, Italy, Netherlands, Norway, Sweden, and Switzerland. We examine change over time across single years and carry out the decomposition using life tables with single year age groups. For ease of interpretation, we report total changes in S_{10} for three periods. The beginning of the first period is determined based on data availability and extends to 1930. Generally, this is a period of slow decline in S_{10}. More rapid decline in S_{10} occurs over the second period, 1930-1960. It is during this period that females gain an advantage over males with regards to S_{10} (see Figure 1). The final period from 1960 to the present day has largely been characterized by stagnation in S_{10} with females experiencing lower levels of variability in comparison to male. Trends in sex-specific S_{10} are described in more depth in the next section.

2 Patterns in S_{10} over time in developed regions

Interesting patterns in sex-specific S_{10} emerge across the different countries included in the Human Mortality Database. Most notably, males have not always experienced greater variability of age at death than females although since 1958 male S_{10} has been higher than female S_{10} in every HMD country included in the analysis as shown in Figure 1. In contrast, prior to 1936, in the majority of HMD countries, there was a tendency for higher female S_{10} in comparison to male.

In the year 2003, the country specific gap between male and female S_{10} ranged from .235 years in the Netherlands to 2.812 years in Lithuania. In general, the gap between female and male S_{10} is especially pronounced in the

[1]The extension of the life tables was performed by John Wilmoth. More information about the methodology can be found in [12].

former Soviet countries as illustrated in Figure 2. Unfortunately, the data series for most of the former Soviet countries is not long enough to investigate whether female S_{10} might have been higher than male S_{10} in periods prior to the midpoint of the twentieth century.

The western European countries included in the Human Mortality Database tend to have the longest historical records, and these records provide evidence that female adult life span was once more variable than male. In Belgium, France, Finland, and Spain prior to roughly the World War II period, there is a noticeable gap between male and female S_{10} with males experiencing lower variability in life span (see Figure 3). In other European countries, such as England, Norway, Sweden, and the Netherlands, during this same period, males and females have similar S_{10} values (see Figure 4).

Across the European and non-European countries alike (see Figure 5), it is clear that around World War II and in the period immediately following the war females gained a significant advantage over males in terms of lower variability of age at death. Declines in S_{10} in the first half of the twentieth century seem to have benefited females more. As Edwards and Tuljapurkar observe in their work and as can be seen in Figures 2, 3, 4, and 5, S_{10} levels have largely stabilized since the 1960s within industrialized countries [4]. Thus, for the past 50 years, females have continued to experience lower variability in S_{10} in comparison to male.

3 Patterns in S_{10} over time in developing regions

Using data from the WHO collection of 1,802 life tables, we are able to examine the sex-specific trends in S_{10} for a number of countries in developing regions. Similar to countries included in the Human Mortality Database, a recent gap between male and female S_{10} is evident in the trends of Argentina, Chile, Costa Rica, and Mexico (see Figure 6). The trends in S_{10} among the Latin American countries indicate more recent declines in S_{10} than what is observed among the European countries included in the Human Mortality Database, where there appears to be relatively stability in S_{10} in recent times.

The data from this historical life table collection provides evidence for greater variability of age at death for females within countries in developing regions. For Chile, where the period of observation extends back to 1909,

there is evidence that female dispersion in life span was higher than male up to the middle of the twentieth century. Life tables from Taiwan constructed based on data from the 1920s and 1930s offer evidence of higher female S_{10} during this period. In life tables from Sri Lanka corresponding to the years 1946 and 1953, female S_{10} is higher than male. Evidence from South Africa indicates higher S_{10} for females in 1941 and 1951 with levels in S_{10} converging in 1960.

Evidence from other countries suggests that the female advantage in variability may have been gained at a later point in time in countries in developing regions compared to developed. A long historical series from Singapore indicates slightly higher female S_{10} into the 1960s with male S_{10} higher than female in more recent years. Single year observations from India, Iran, MATLAB, Peru, and the Republic of Korea from the 1970s offer evidence of higher female S_{10} in comparison to male during this time period. Unfortunately, more recent data is not available for these five countries in the WHO collection. It would be useful to confirm a transition to higher male S_{10} in recent times within these countries.

The more rapid gains by females in the period around World War II that led to the emergence of the gender gap in S_{10} in developed countries did not necessarily take place during the same time period across all countries in developing regions. Still, the trend towards an eventual female advantage in S_{10} across countries with more complete records indicates that this advantage might be an end product of the epidemiological transition. We will return to this when we consider the changes in causes of death that might be instrumental in the emergence of the gender gap in S_{10}. In the next section, we examine how changes in age-specific mortality rates affect trends in sex-specific S_{10}.

4 Decomposing changes in S_{10}

In order to gain a better understanding of why females gained an advantage over males in terms of lower variability in life span, we have decomposed sex-specific trends in S_{10} over time into the contribution of changes in age-specific mortality rates. We have carried out the decompositions for ten countries in the HMD. We will discuss the results for all of the countries in general terms and focus specifically on the case of France[2]. The results of these

[2]Detailed results for all countries are available from the author upon request.

decompositions allow us to identify what changes in age-specific mortality rates were especially important for females more rapid decline in S_{10}. In addition, these results offer insight into how changes in age-specific mortality rates in the most recent period are contributing to relatively stability in the S_{10} measure for both sexes.

The decompositions were carried out in such a way that the annual change in S_{10} was decomposed into contributions of changes in single year age-specific mortality rates, m_x. The changes in S_{10} were then aggregated across time for ease of interpretation as explained in the methods section. Results of the decomposition for France are given in Table 1 and shown in Figure 7. In France as well as in the rest of the countries analyzed, the pace of decline in S_{10} during the first time period, from the beginning of each country's historical record in the HMD to 1930, was much slower than during the second time period from 1930 to 1960. In the most recent period, populations still exhibit some decline in S_{10}, except for French males, but these declines are not very substantial with most less than a year-thus, the observation that S_{10} has been relatively stable in the recent period.

Looking at sex-specific trends in the first period, the total changes in S_{10} were relatively similar for males and females differing by less than a year in all countries except Denmark. In some countries, such as France, the total decline in S_{10} for males was greater than the decline for females during this first period. In contrast, during the period of rapid decline in S_{10} from 1930-1960, the decline in S_{10} for females was greater than the decline for males in all countries. In Finland, S_{10} for females declined 2.76 years more than did S_{10} for males during this second period. Females had the greatest absolute gain over men in Finland, and the smallest absolute gain in England, where female S_{10} only declined .84 years more than male during this period. Females gained a significant advantage in terms of lower variability of age at death during the second period, and changes in age-specific mortality rates in the third period have not acted to close this gap.

An illustration of the decomposition of changes in S_{10} over the three periods into the contributions of changes in mortality rates for single year age groups is provided for France in Figure 7. For France as well as the other countries included in the analysis, the advantage gained by females during the period 1930 to 1960 seems to be the result of greater gains in mortality in the younger adult age groups, with the peak contribution to the decline in S_{10} coming from mortality improvements around age twenty. In Table 1, which shows the decomposition results for France over the three periods aggregated

over broader age groups, it is clear that during the second period most of the decline in S_{10} is due to mortality improvements in the peak reproductive years of 15-34 for both males and females. In France, for females, 4.29 years of the total 5.49 year decline in S_{10} over this period were attributable to mortality declines in the 15-34 year old age group. Within this age group, the declines in S_{10} over the 1930-1960 period are always greater for females compared to males across all of the countries examined. In France, mortality improvements in the 15-34 year age group led to a 4.29 year decline in S_{10} for females while for males improvements in this same age group contributed 3.25 years to a total decline of 3.73 years. When we begin to ponder the possible changes in cause specific mortality that could have led to a female advantage in S_{10}, we want to especially consider changes in mortality in these young adult ages.

The advantage in mortality that females gained over males during the period 1930-1960 is evident in the graph representing the age-specific contributions to changes in S_{10} during the third period from 1960-present (see Figure 7). Female advantage in life expectancy in the third period is evidenced by the much later crossover point for age-specific contributions to declines or increases in S_{10}. For women, progress against mortality into the late sixties/early seventies contributes to a narrowing of the variability in the death distribution while for males in this same age group it contributes to the widening. In the two earlier periods, the crossover points occurred at similar ages as life expectancy was more similar between the two sexes.

The results of these decompositions presented in Figure 7 also offer some insight into the stagnation of S_{10} in the most recent period (1960-present). The continuing yet relatively smaller mortality improvements in the younger age groups, which contribute to a declining S_{10}, have largely been balanced by improvements in mortality in the older age groups, which cause S_{10} to increase.

5 Changes in mortality by cause

In this section, we want to draw upon prior research examining sex-specific differences in mortality over time in order to speculate about the possible changes in mortality by cause that could have led to females gaining an advantage over males in terms of lower variability of age at death. Noting that during the period of rapid decline in S_{10} from 1930-1960 the decline in

S_{10} was the result of mortality improvements in the young adult ages (again see Figure 7), we want to focus specifically on changes in mortality by cause in these age groups.

To begin, we observe that over time the ratio of male to female age-specific mortality rates, m_x, in the younger age groups has risen quite steadily. While females have always had a mortality advantage in the older adult ages, recently a bimodal pattern in the ratio of male m_x to female m_x has developed as women also gain an advantage in the younger adult ages. The development of a bimodal pattern in the ratio of male m_x to female m_x over time is illustrated in the case of France in Figure 8 (a similar figure appears in [11]). Notice that the first mode occurs around age 20, the same age where the peak contributions are made to declining S_{10} during the period 1930-1960 as shown in Figure 7.

Given that the age group in which women make greater gains against mortality in comparison to men overlaps with the peak reproductive ages, one immediately considers the possible contribution of declines in maternal mortality. Indeed, during the period of rapid decline in S_{10}, female mortality rates were declining in part due to improvements in maternal care. Maternal mortality risk decreased due to improvements in treatment for hemorrhages and the discovery of sulfonamides used to treat puerperal infections [10].

Decreased maternal mortality risk, however, was not the sole factor driving female mortality advantage in the younger adult ages. In a study published in 1961, Enterline examines what particular causes of death were responsible for the major increase in the sex ratio of mortality rates in the 15-24 age group between 1929 and 1958 within the United States. In addition to the decrease in maternal related mortality, Enterline finds that the decline of tuberculosis (which affected young women more than men) and the greater increase for men in motor vehicle accidents were other major factors leading to a female advantage in this age group. Greater decline in rheumatic fever for women in the 15-24 age group compared to men also played a role [5].

In comparing trends in male and female mortality in France between the periods 1925-1929 and 1974-1978, Vallin also recognizes the importance of the erosion of the female disadvantage with regards to infectious diseases in younger age groups. Vallin attributes this historical female disadvantage to the low status of women. Thus, progress against infectious disease along with the general improvement in younger women's status have allowed females to gain an advantage over males in the younger adult ages [11].

Vallin shows that changes in infectious disease are not particularly impor-

tant for the emergence of the gender gap in life expectancy between the two periods he is examining. The female advantage in life expectancy is heavily influenced by differences in degenerative diseases and neoplasms [11]. While changes in infectious disease mortality are not an important component of the emergence of the gap in life expectancy between women and men, it is likely that they are important in explaining the emergence of the gap in S_{10} since progress against infectious disease is one of the chief explanations for females gaining an advantage in mortality in these younger age groups. Later progress against infectious disease may explain differences in the timing of females gaining advantage over males in terms of S_{10} in developing regions in comparison to developed.

6 Conclusion and future directions

Females have not always experienced lower variability of age at death in comparison to males. In fact, historical data shows that this female advantage developed within the last century. This finding suggests that this advantage is the product of the current epidemiological environment. Given that the results of decomposition of trends in S_{10} by age show that changes in mortality at the younger adult ages was the primary force driving the female advantage in S_{10}, it is likely progress against infectious disease and improvements in maternal care are the major explanations for the emergence of the gender gap in S_{10}.

Through this analysis, which relies on sex-specific decompositions of changes in S_{10} over time, we have discovered that declines in mortality in the younger adult ages led to more rapid gains in terms of lower variability of age at death for females in comparison to males. We have not decomposed differences in S_{10} between males and females at fixed points in time into the contributions of differences in age-specific mortality rates. Vallin uses this approach to analyze sex-specific differences in life expectancy and the emergence of the gender gap in life expectancy in France [11]. Using the results of decompositions of differences in S_{10} between the sexes at two points in time, before and after the emergence of the gap, we will be able to quantify directly what differences in age-specific mortality rates between the sexes were most important in the creation of the gender gap in variability of age at death.

It will also be useful to decompose differences in S_{10} between the sexes by cause as well as age like Vallin does for life expectancy in France [11]. It

will be interesting to compare what causes of death contribute to the current gender gap in S_{10} to what causes were important in prior periods. Decompositions by cause are necessary confirm our intuitions about the importance of improvements in maternal health and progress against infectious disease to the emergence of the gender gap in S_{10}. Cause specific decompositions will lend insight into why females continue to hold an advantage in terms of lower variability of age at death.

Additionally, future research in this area should focus on the inter-relationship between "inequality" in the death distribution and socioeconomic inequality in mortality. Specifically, how can our finding that females experience lower variability of age at adult death in comparison to males provide insight into why females generally experience lower absolute inequality across socioeconomic groups with regards to mortality [9]?

The results of this analysis show that examining the gender gap in variability of age at death using S_{10} yields different insights than an examination of the gender gap in life expectancy, e_0. Improvements in mortality above age 40 drive the sex differential in life expectancy [6]. With regard to cause specific mortality, differences in degenerative diseases and neoplasms are responsible for the gender gap in life expectancy [11]. In contrast, female advantage in mortality at younger adult ages led to the emergence of the gender gap in S_{10}. Having gained an advantage in S_{10} during a period of rapid improvement in young adult mortality, women have continued to enjoy greater certainty in timing of death for the past half century. In this paper, we have combined our own analysis with findings from prior research in hopes of better understanding the reasons for the current female advantage in certainty in timing of death.

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Table 1: Contributions of changes in age-specific mortality rates, m_x, to changes in S_{10} over time, France, 1899-2005.

		1899-1930	1930-1960	1960-2005
Male	Total ΔS_{10}	−1.19	−3.73	0.11
	0-9 $\Delta m_x \rightarrow \Delta S_{10}$	0.00	0.00	0.00
	10-14	−0.37	−0.52	−0.16
	15-34	−1.79	−3.25	−0.93
	35-49	0.49	−0.77	−0.71
	50-69	0.23	0.35	−0.13
	70+	0.28	0.46	2.00
Female	Total ΔS_{10}	−1.11	−5.49	−0.83
	0-9 $\Delta m_x \rightarrow \Delta S_{10}$	0.00	0.00	0.00
	10-14	−0.49	−0.74	−0.15
	15-34	−1.37	−4.29	−0.96
	35-49	−0.28	−1.20	−0.89
	50-69	0.37	−0.09	−0.94
	70+	0.66	0.79	2.05

Note on figures: The figures included at the end of the paper show the actual values of S_{10} by sex and country for each year where data is available. The graphs also include smoothed trend lines. The age distributions of death were obtained from the Human Mortality Database and the WHO collection of 1,802 life tables. Calculations of S_{10} were made by the author.

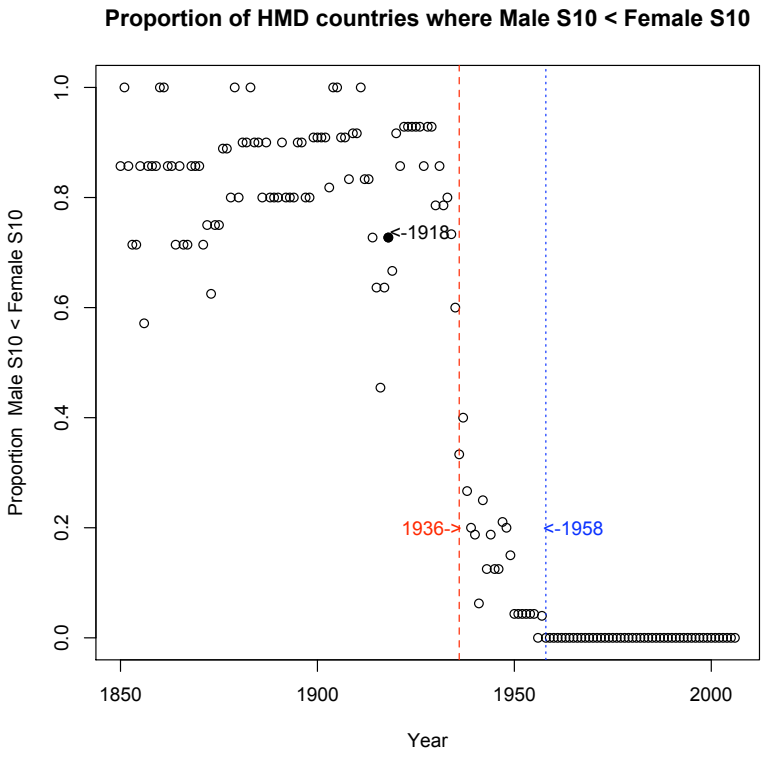

Figure 1: Proportion of HMD countries where male S_{10} < female S_{10}. Data source: Human Mortality Database

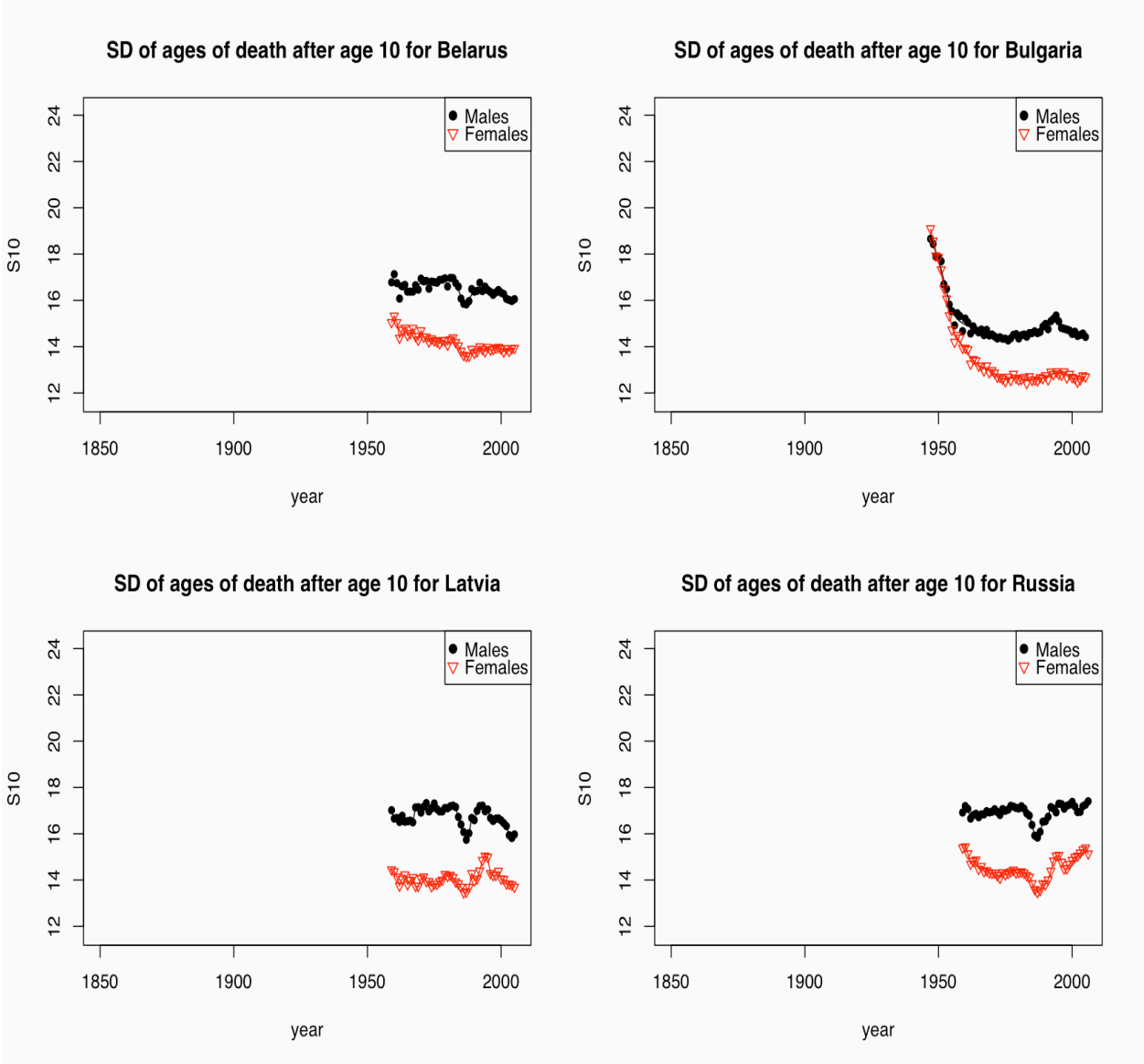

Figure 2: Trends in sex-specific S_{10} among the former Soviet countries. Data source: Human Mortality Database

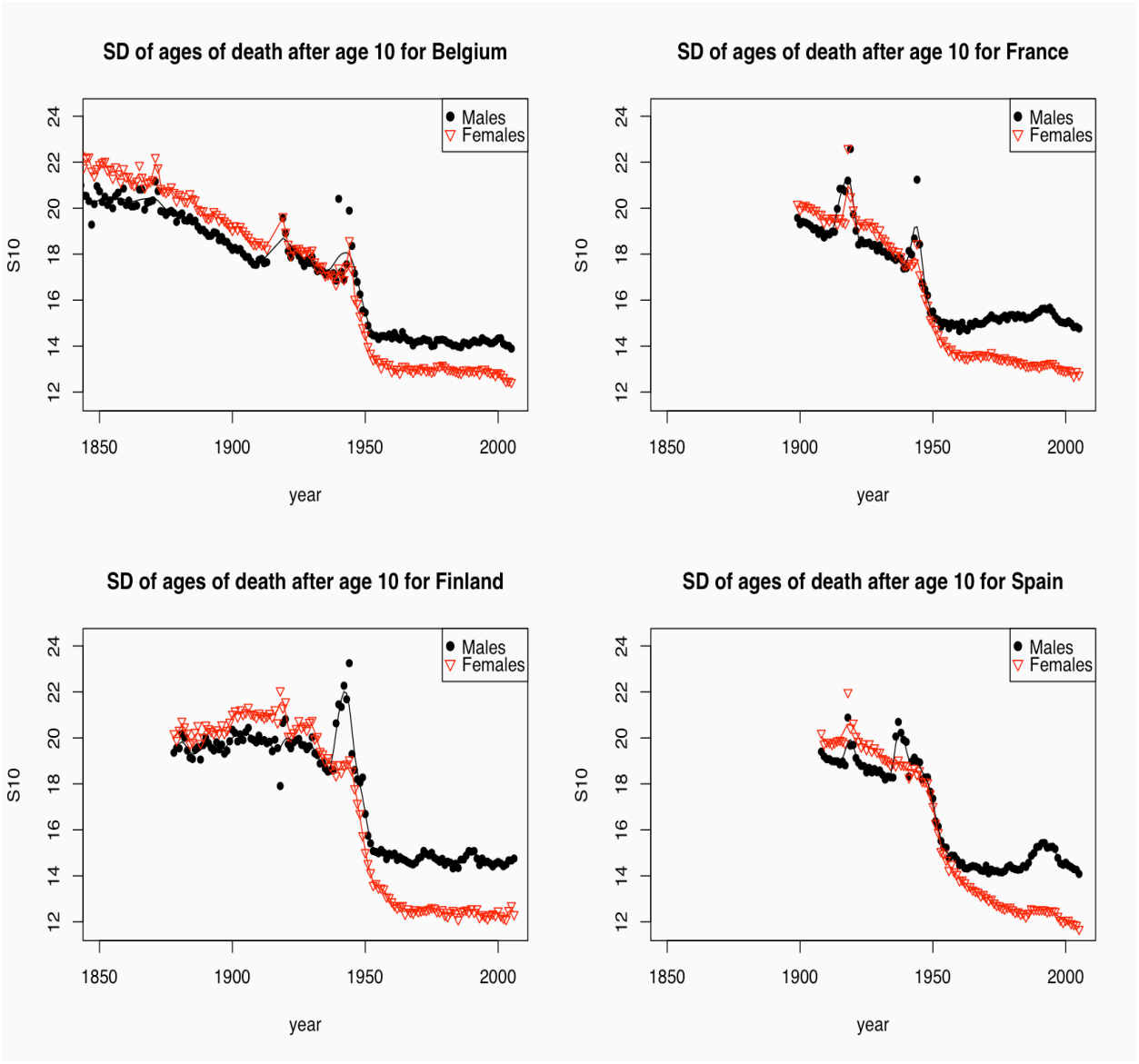

Figure 3: Trends in sex-specific S_{10} among European countries. In these graphs, there is a noticeable gap between male and female S_{10} in the period prior to World War II. Data source: Human Mortality Database

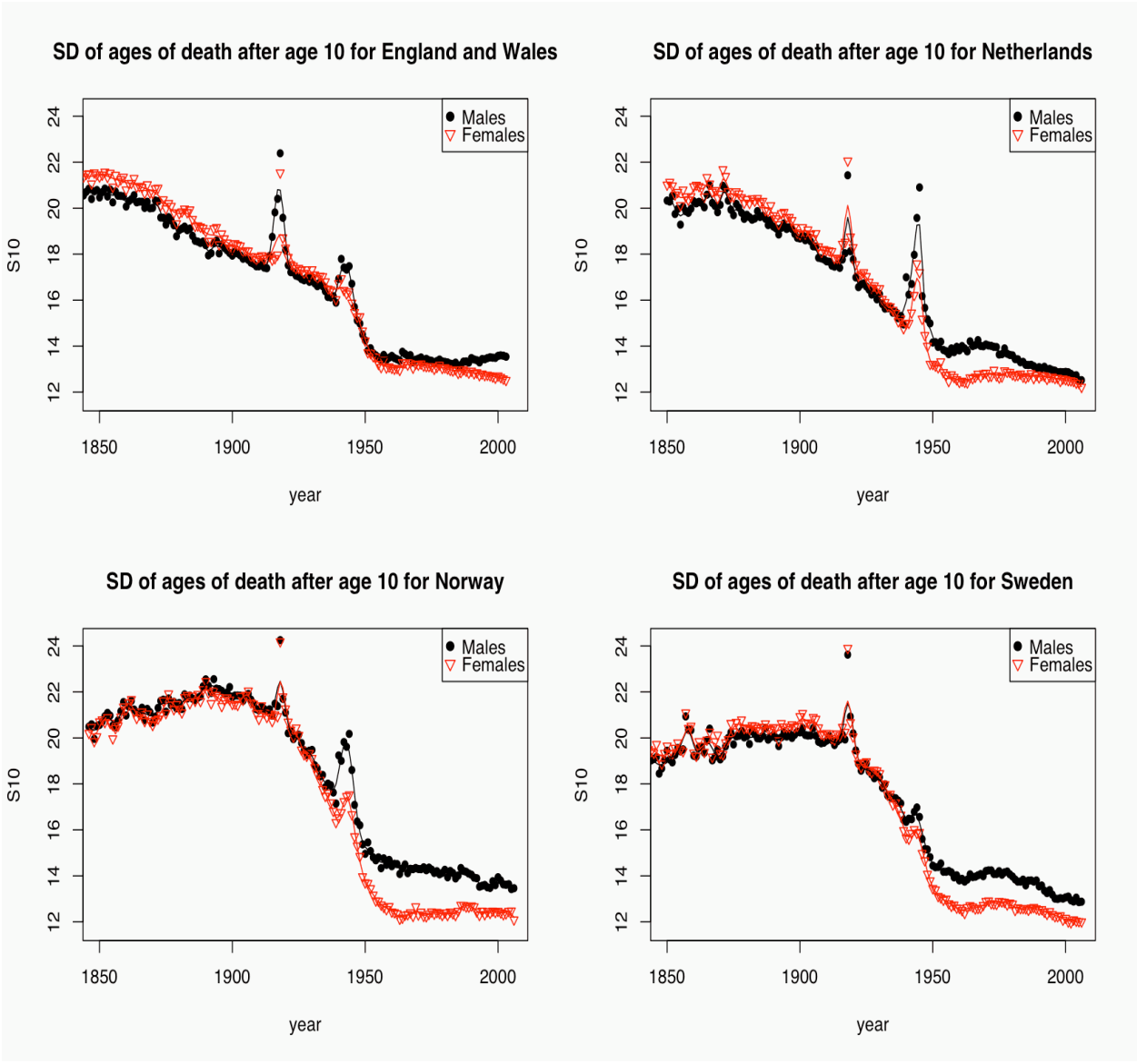

Figure 4: Trends in sex-specific S_{10} among European countries. In these graphs, male and female S_{10} values appear relatively close in the period prior to World War II. Data source: Human Mortality Database

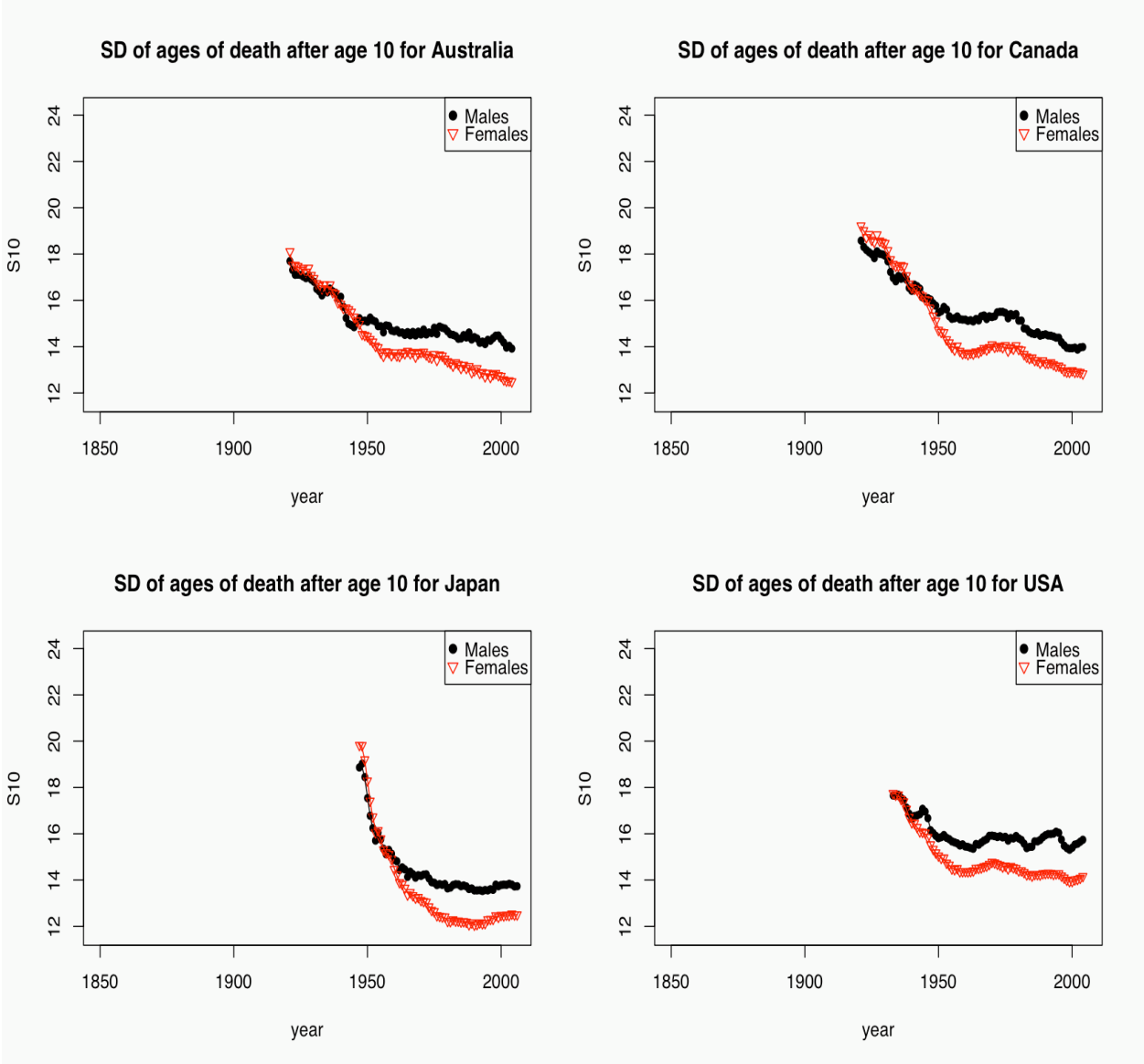

Figure 5: Trends in sex-specific S_{10} among non-European countries. Data source: Human Mortality Database

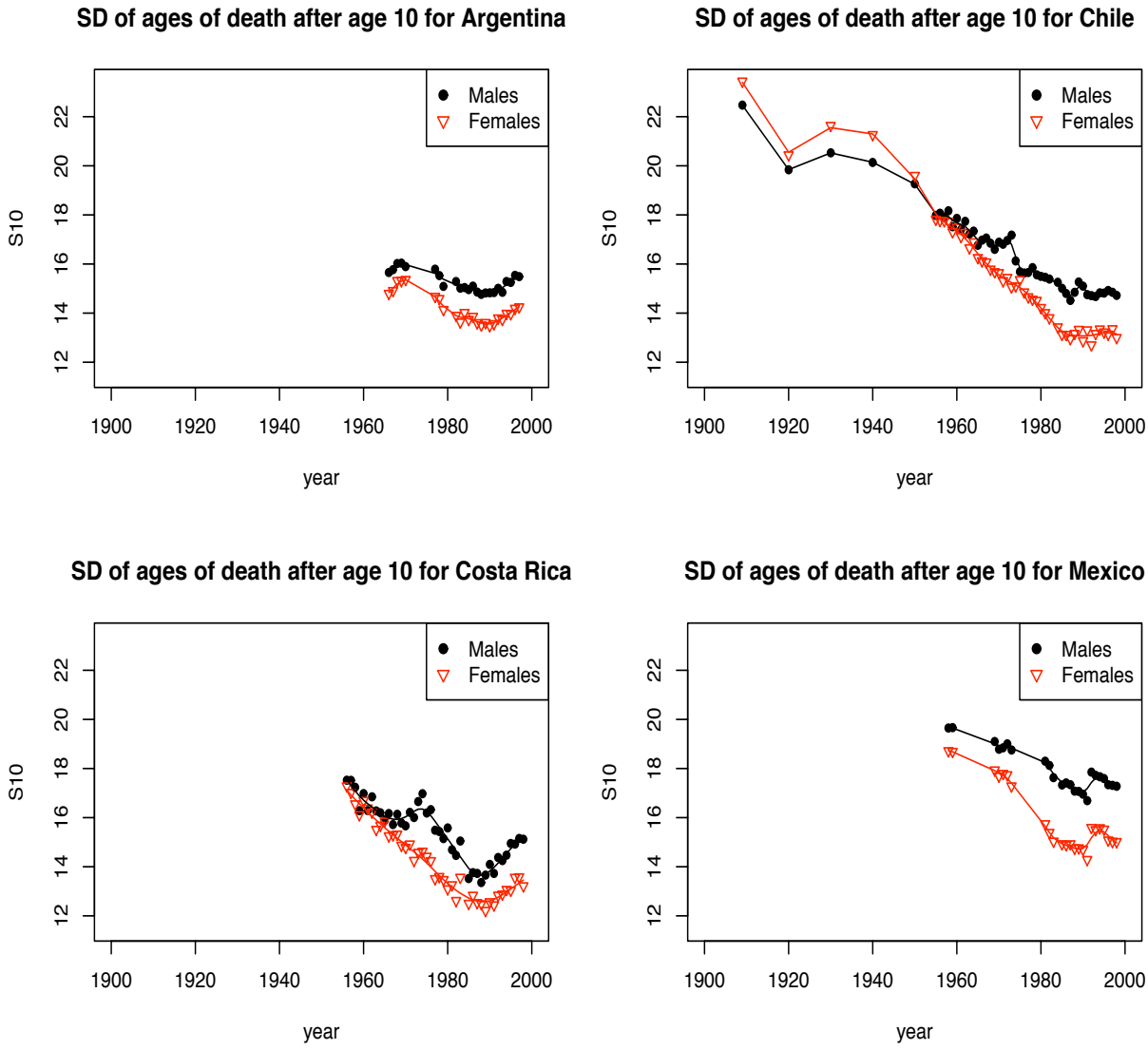

Figure 6: Trends in sex-specific S_{10} among Latin American countries. Data source: WHO collection of 1,802 life tables

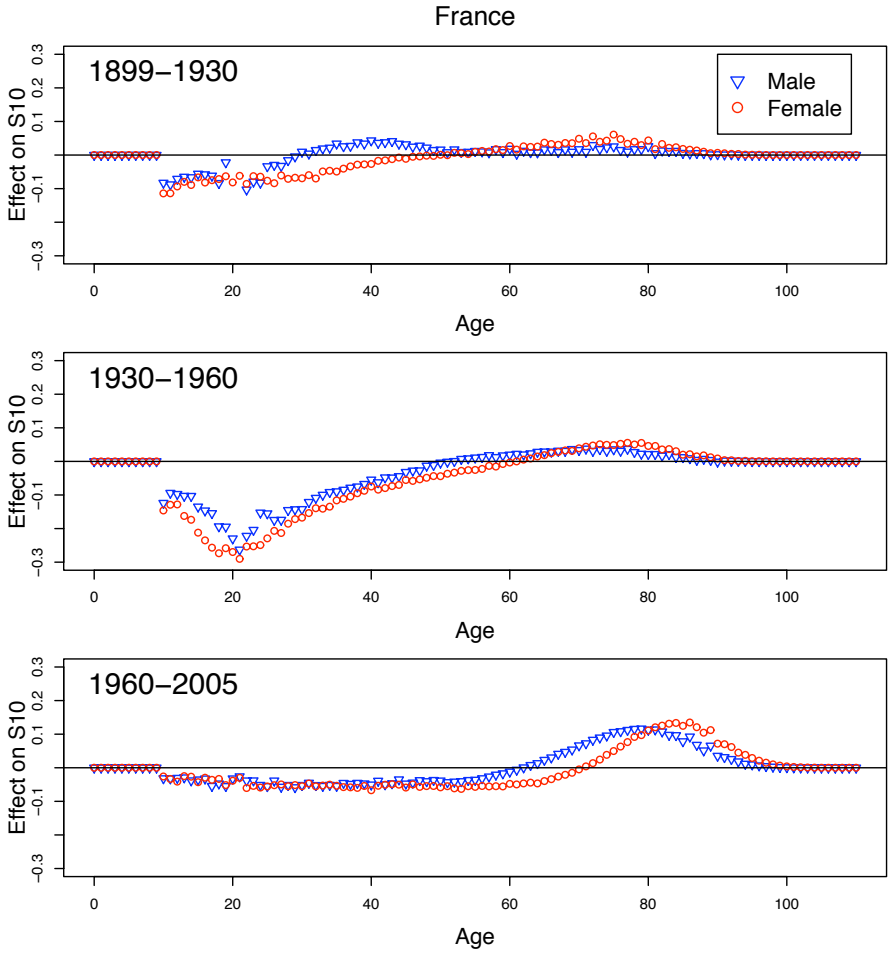

Figure 7: Contributions of changes in age-specific mortality rates to changes in S_{10} by sex over time, France.

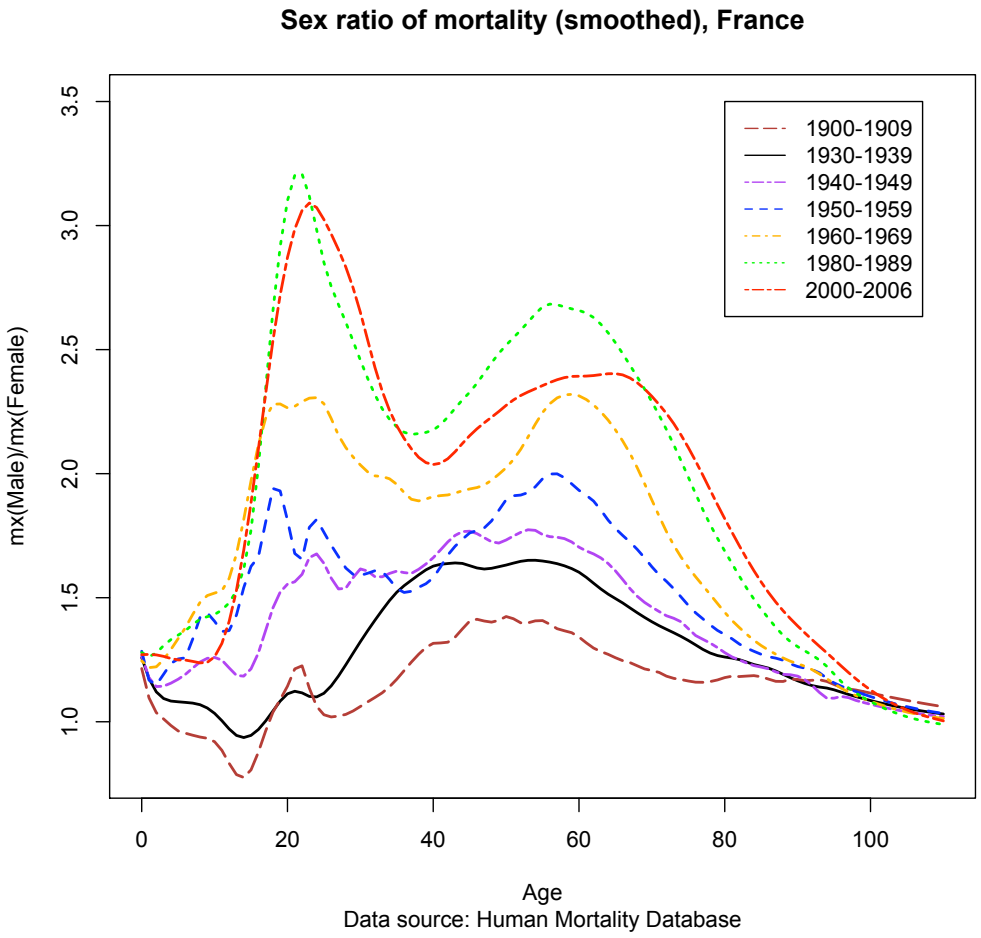

Figure 8: Ratio of male m_x to female m_x, France. Data source: Human Mortality Database