Maximum Potential Life Expectancy Based on Minimum Death Rates.

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Abstract

The maximum life expectancy observed in a given year across countries in the world, or record life expectancy, represents the highest current longevity that all populations in the world can achieve. However, an even higher life expectancy can be calculated based on the minimum age-specific death rates observed in a given year. We investigate the relations between the life expectancy of a synthetic cohort based on minimum death rates, and the actual record life expectancy attained that year. Our results show that on average in less than 5 years the life expectancy levels derived from the minimum death rates are achieved by a record life expectancy country. Record holder countries have on average less than 50% of the observed minimum death rates. However, the ages where the two coincide, i.e. minimum age-specific death rates in the record life expectancy country, are ages where the gain in life expectancy is the greatest.

Introduction

The maximum recorded life expectancy in every year, coined as “record life expectancy” or “best practice” by Oeppen and Vaupel (2002), shows an uninterrupted increase over time (Shkolnikov et al. 2011; Vallin and Mesle 2009). Although there is no question about this remarkable achievement in human life, the debate on future trends for life expectancy, even for the highest achiever longevity populations is still challenged (Olshansky at al. 2005; Olshansky at al. 2001).

Supporters of the prolongation of life argue in two directions: developed countries have achieved remarkable high levels of life expectancies thanks to the compression of mortality, with deaths concentrated now mainly at older ages (Vaupel et al. 2011; Engelman et al. 2010); and a remarkable shifting process of deaths to even older ages (Bergeron-Boucher et al. 2015; Canudas-Romo 2008; Bongaards 2005). Against that line of thinking are those that argue on favor of the imminent longevity wall that is ahead of us (Oshansky et al. 2005; Fries 1980). The latter group mentions as some of their main rationales for this thinking the possibility for calculating extreme scenarios of low probabilities of deaths by causes of death (Oshansky et al 2001), and the obesity epidemic, particularly in the USA (Oshansky et al. 2005).

Life expectancy at birth is a measure constructed from a series of age-specific death rates. Therefore, there is a very clear inverse relation between life expectancy and overall levels of age-specific death rates (Wilmoth et al. 2012). Countries at the bottom of the life expectancy rankings are also those with some of the highest mortalities, and vice versa, the correspondence between high life expectancies is with low mortalities.

Japanese females are, since the 1980s, the population holding the highest longevity in the world; this is mainly a byproduct of their low mortality rates at old ages as compared to the rest of the countries. That high Japanese life expectancy at birth holds even when Japan seconds or goes even further down in the rank of age-specific death rates at younger ages. This apparent paradox of been the record life expectancy country holder and at the same time not having most of the minimum death rates in the world is studied here.

The idea of looking at minimum death rates can be tracked back to Pascal Whelpton (1947) and his search for a "biological minimum of mortality" by looking at states in the USA as well as comparing with other countries. That work is also highlighted in the book by Dublin, Lotka and Spiegelman (1949) on the length of life as an original method of forecasting. In a similar direction the work by Jean Bourgeois-Pichat (1952) on the "biological limit life table" inspired others to add also the cause of death component and look at both minimum age- and cause-specific death rates (Vallin and Meslé 2008; Uemura 1989; Siegel 1980; Nizard and Vallin 1970). In the present study, this tradition is followed and we construct the "potential highest life expectancy" that could be achieved in each year, if a population actually had the set of lowest death rates observed in that given year. We study the ages of concordance, in the potential and record life expectancies, by identifying the minimum death rates that belonged to the record life expectancy holder country. We hypothesize that the identified concordant ages had significant contribution for these countries to be able to become record country holders.

Data and Methods

Data on age-specific death rates (not smoothed) from the Human Mortality Database (HMD 2015) for all available countries with more than one million inhabitants, and all times were included in the analysis; although the analysis was carried independently for females and males. We excluded small populations to avoid erratic death rates values found at some ages and times.

At every time *t* and age *x* we obtained the minimum mortality rate, denoted $\underline{m}(x,t)$, from all available countries from the HMD,

$$\underline{m}(x,t) = \min_i[m(x,t,i)]\,, \tag{1}$$

where $m(x,t,i)$ is the death rate for age *x*, time *t*, and country *i*. The minimum mortalities $\underline{m}(x,t)$ were restricted to be greater than zero. Life tables were then created based on the set of minimum mortality rates.

We compare results of the maximum (or record) life expectancy for every year, $e_o^r(t)$, versus life expectancies from the minimum mortality rates for every year as in equation (1), denoted $\underline{e_o^r}(t)$, and referred to as "potential highest life expectancy". Finally, for each age and time *t* the lowest *ever* death rates over time were calculated, by taking now the minimums of $\underline{m}(x,t)$ for years earlier than *t*,

$$\underline{\underline{m}}(x,t) = \min_T\left[\underline{m}(x,T)\right] \qquad \text{for } T \leq t. \qquad (2)$$

Since our interest is to study possible achievable values of life expectancy the minimum death rates from (2) force this strictly increasing "potential-ever highest life expectancy". As above we obtained life tables and compared life expectancies between record holder country, potential and potential-ever minimum.

We also identified ages *x* where the record life expectancy country holder in year *t* is also the country having the minimum death rates, $\underline{m}(x,t)$, of that year. These concordant ages are of interest particularly in years when a new record life expectancy country holder is changed. For year *t* when a change in record life expectancy country holder we do the following comparison: we compare the record life expectancy in that year, say country holder *i* so $e_o^r(t) = e_o^i(t)$, with the life expectancy from the country that lost the top one position in rankings of life expectancy, that is the ex-country record holder from year *t-1*, say country *j*, where $e_o^r(t-1) = e_o^j(t-1)$. We apply standard age-decomposition (Preston et al. 2001) of the difference $e_o^r(t) - e_o^j(t) = e_o^i(t) - e_o^j(t)$ and assess the relevance of the concordant ages as opposed to those that are not.

Results

Figures 1A and 1B present four lines of alternative maximum life expectancies, e0, trends for females and males respectively. Each of the lines in the Figure correspond to: (1) the maximum life expectancy in year *t*, (2) the maximum until year *t*, (3) the potential life expectancy based on the minimum death rates in year *t*, and (4) the potential $e_0(t)$ based on the minimum death rates until year *t*. The trends of maximum and potential maximum e_0 until year *t*, captured by (2) and (4), by definition cannot decline since they correspond to the highest value until year *t*. Thus, Figures 1A and 1B present measures (2) and (4) always above the values of the record life expectancy and the potential maximum of lines (1) and (3) based only on the observation of that specific year. Nevertheless, in both Figures 1A and 1B, for females and males, convergence between the four lines is observed in recent years, contrasting with the disparity seen in the past.

[Figure 1A and 1B here]

Figure 2 presents the differences between the maximum and potential maximum e0 ever seen, represented in measures (2) and (4) explained above. Maximum potential life expectancy until this year minus the record life expectancy until this year shows an increasing trend reaching a peak of 4 years at the end of the 19^{th} century. Opposing that, all twentieth century has been a period of convergence of the record holding country to the maximum potential until this year, with a minimum value of one year for females and two for males. Thus, males have even further room of improvement as opposed to their females' counterparts.

[Figure 2 here]

To further study the relation between potential maximum longevity and record life expectancy, we ask about the percentage of minimum death rates that record holding countries have. Figure 3A and 3B present the percentages of minimum death rates in the record $e_o^r(t)$ country for females and males respectively in year *t*. The paradox of minimum death rates and maximum life expectancy is even more puzzling in these Figures. In the 1850s between 60 to 80% of the minimum death rates were in the country that had the highest life expectancy, but this reduced with time. By 1970s a minimum is reached for females and for males around 20%. After this time, Japanese females, with the record life expectancy, have gained more and more of the minimum death rates. But for males the record $e_o^r(t)$ country continues reducing its hold of minimum death rates to levels below 20%.

[Figure 3A and 3B here]

Two final Figures 4A and 4B, show the specific ages of concordance of minimum values in the country with the highest life expectancy for females and males respectively. Each point correspond to a year and age where a minimum death rate, $\underline{m}(x,t)$, was observed in the country with the highest life expectancy in the world, $e_o^r(t)$. In the first quarter of the twentieth century, the country with the highest life expectancy was also the one with the lowest death rates at young ages. At the other end of the Figures 4A and 4B, the record holding country, is also the one with minimum death rates at ages above 60, particularly evident for females.

[Figure 4A and 4B here]

Future Steps

It is well known that the increases observed in life expectancy were first dominated by reductions in mortality at early ages and later on in advanced ages. Now we aim to add that the countries that are the record holder countries, are also those that had the lowest age-specific death rates at the time when those ages contributed the most to the changes in life expectancy. We are particularly interested to see how countries become the new record holder countries, and the ages that favor this. To study this, we plan to calculate the correlation between the ages of minimum death rates observed in the record countries, and the age-contribution of the difference between record countries when a new country step in that position. This will add a piece in our puzzle to explain the past changes in record country holders and helps us speculate on the candidates for future record $e_o^r(t)$.

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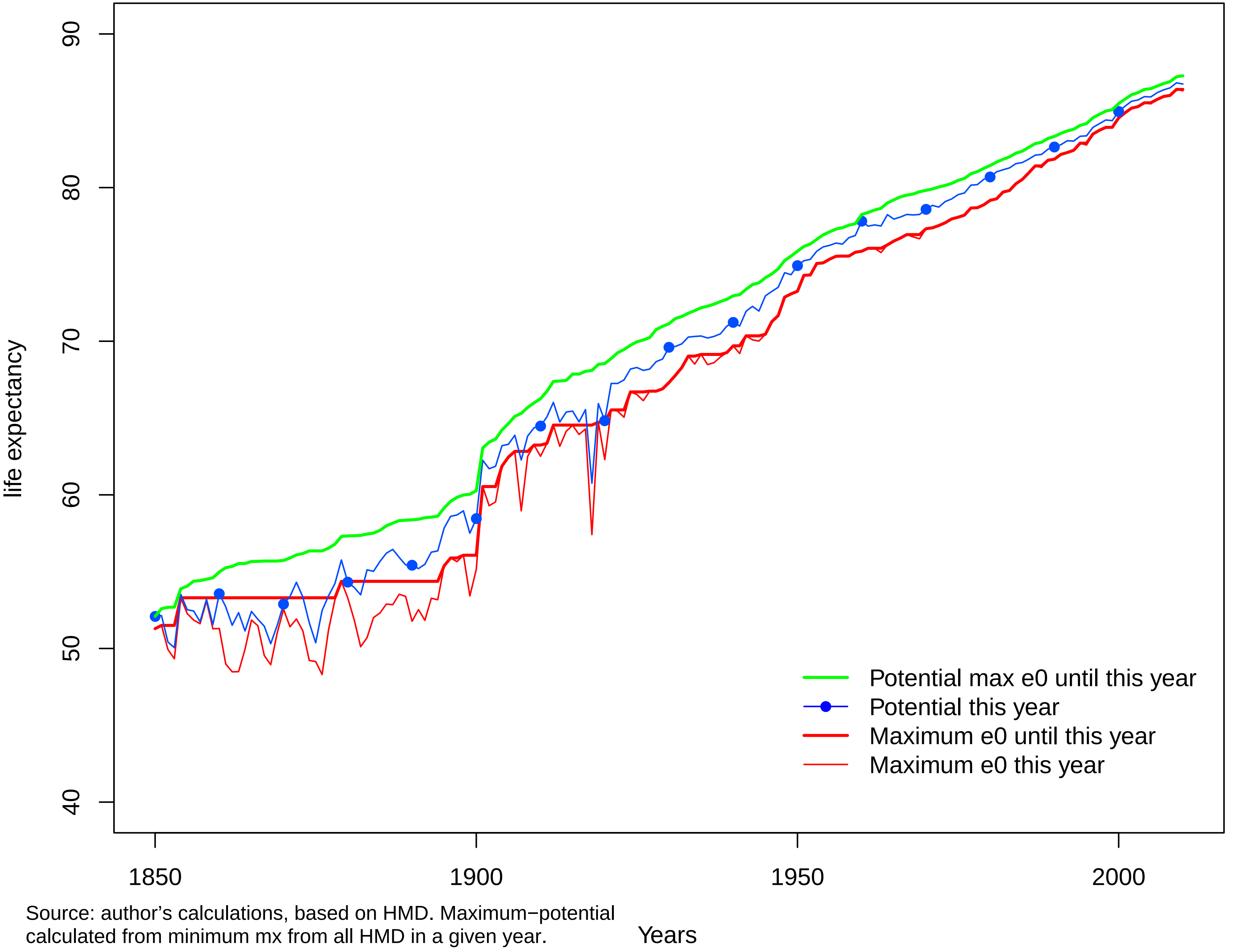
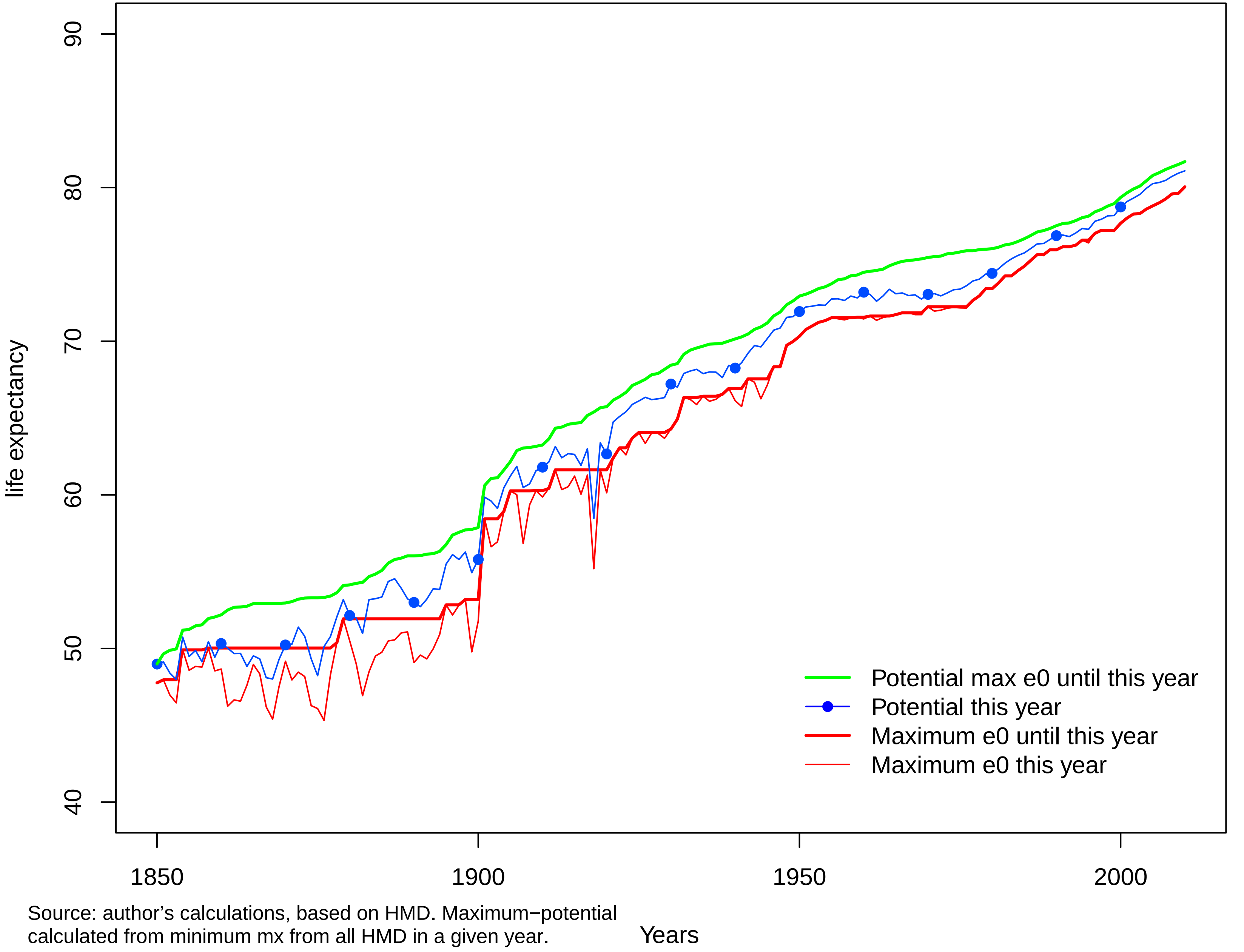
Figure 1A. Female time trends of maximum and maximum−potential life expectancy in a given year, for period life tables from HMD 1850−2010.



Source: author’s calculations, based on HMD. Maximum−potential calculated from minimum mx from all HMD in a given year.

Figure 1B. Male time trends of maximum and maximum−potential life expectancy in a given year, for period life tables from HMD 1850−2010.

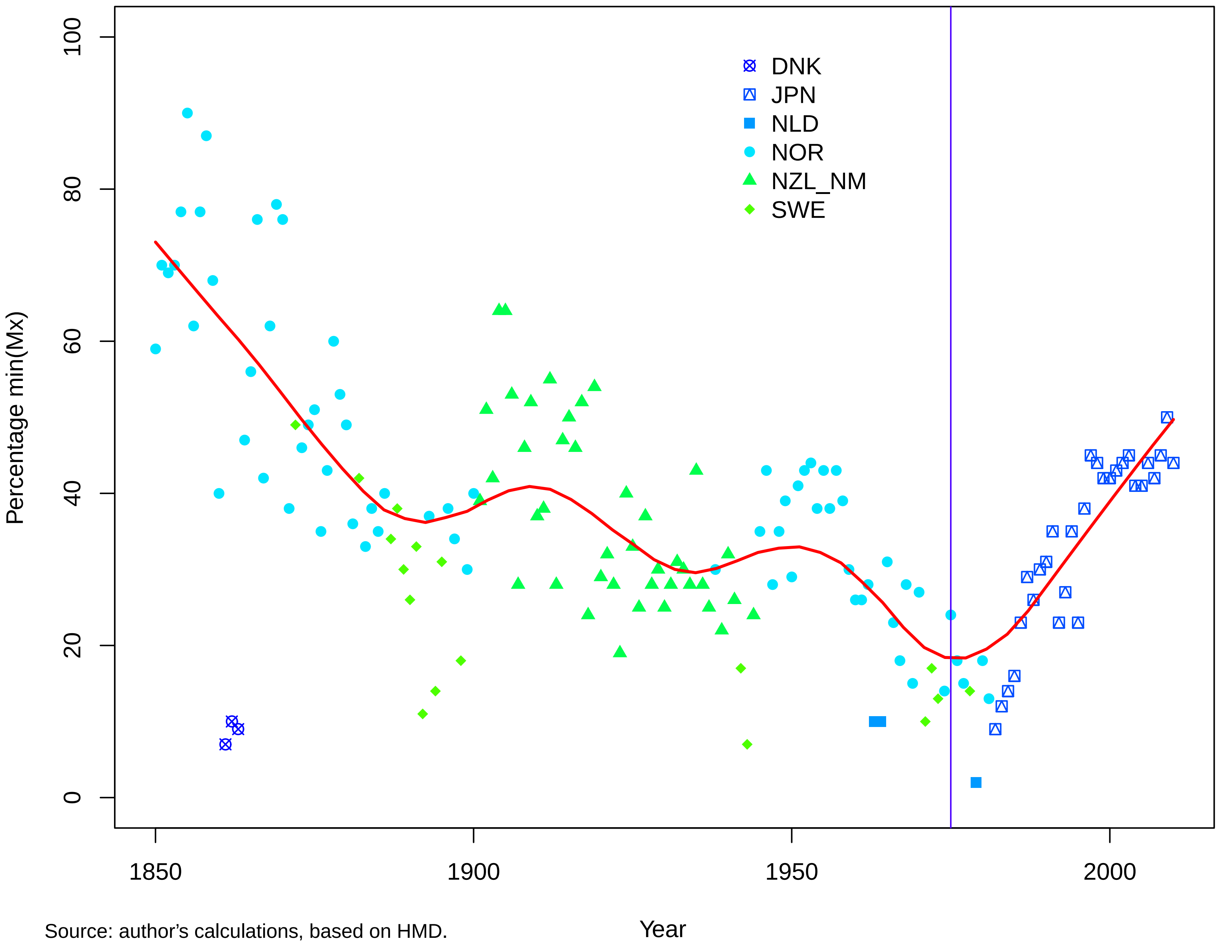


Source: author's calculations, based on HMD. Maximum−potential calculated from minimum mx from all HMD in a given year.

Figure 2. Female and male differences between maximum and maximum −potential until this year for period life tables from HMD 1850−2010.

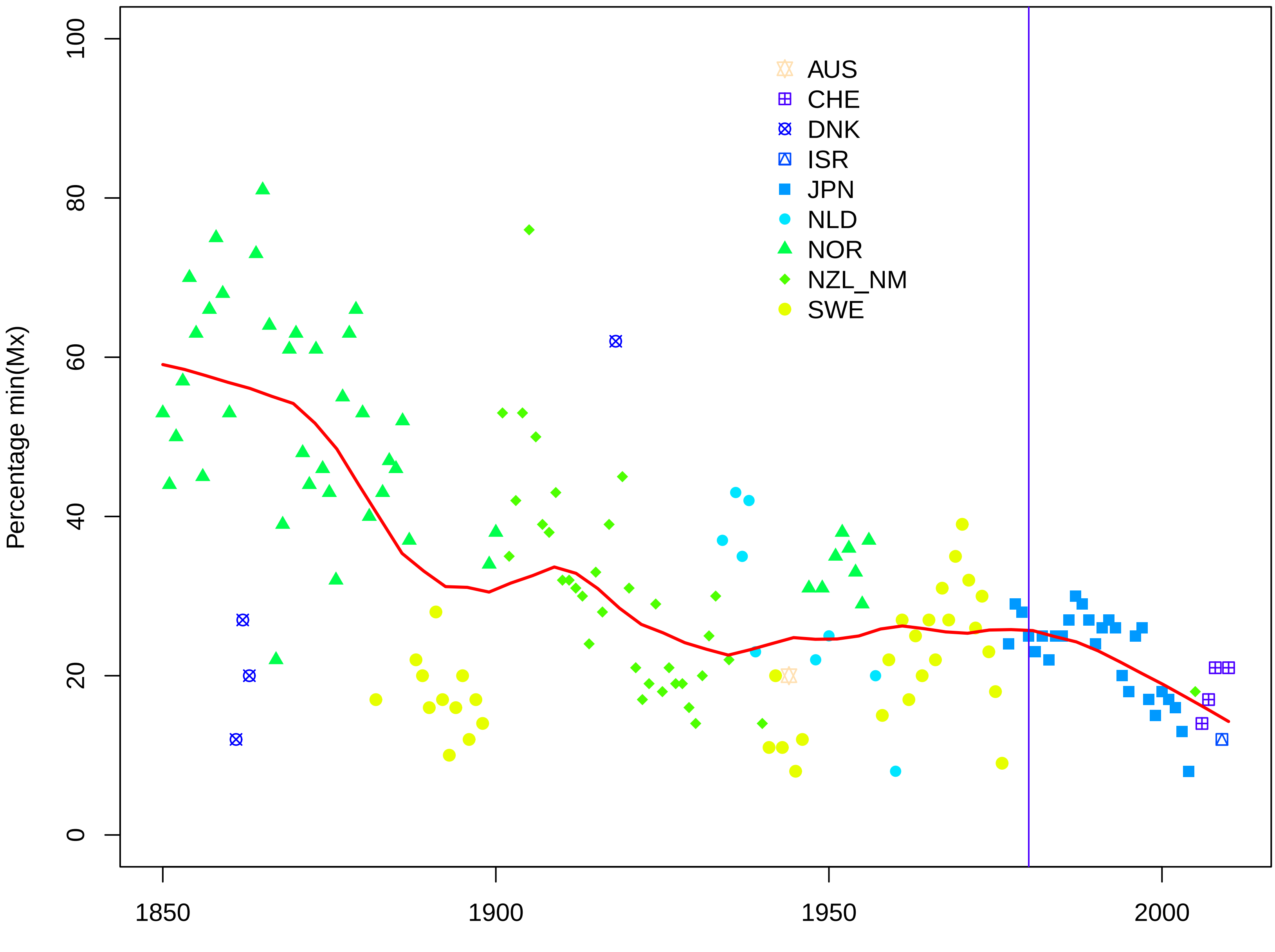
Source: author's calculations, based on HMD.

Figure 3A. Percentage of minimum Mx by the record country holder, females, 1850−2010.



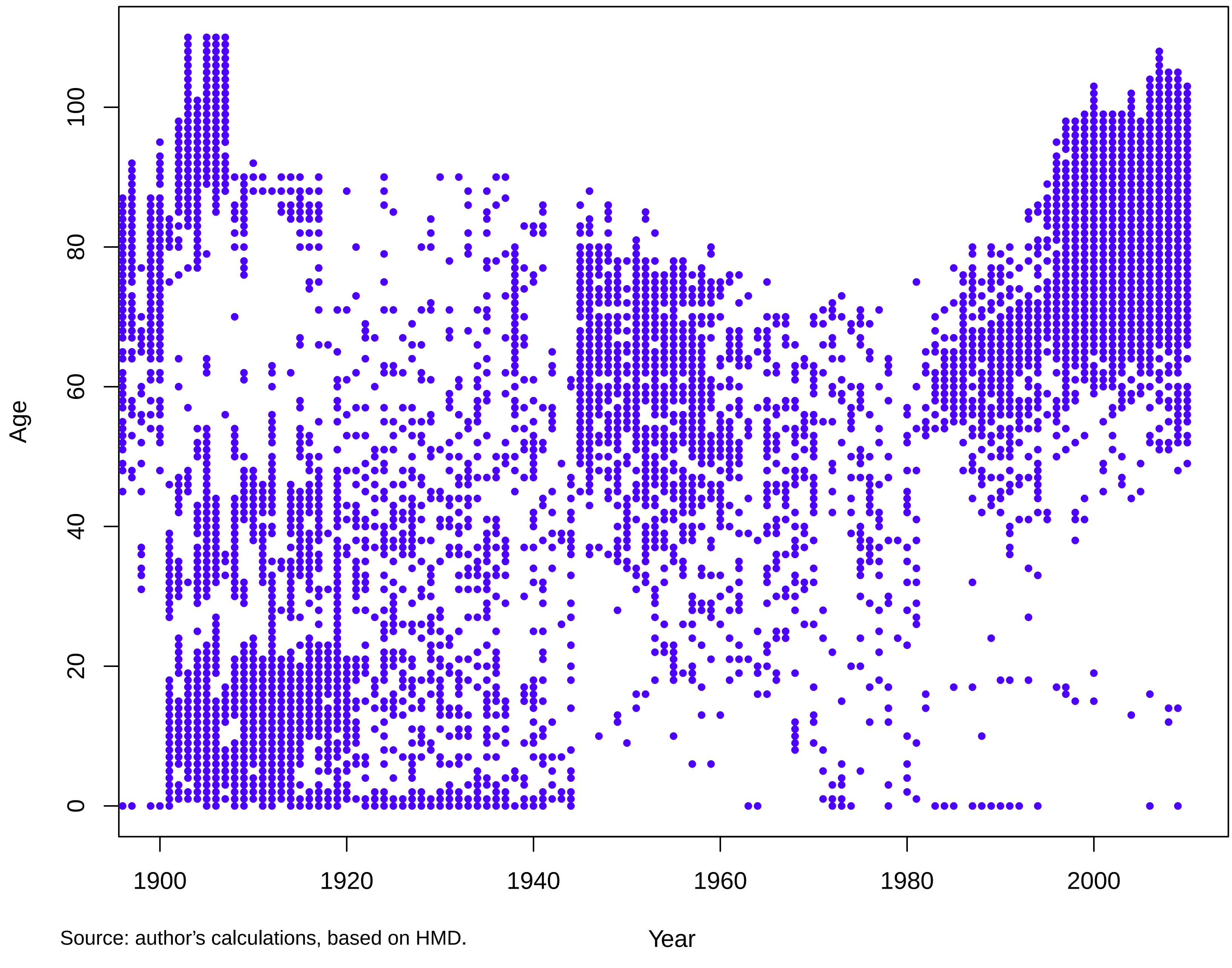
Source: author's calculations, based on HMD.

Figure 3B. Percentage of minimum Mx by the record country holder, males, 1850−2010.



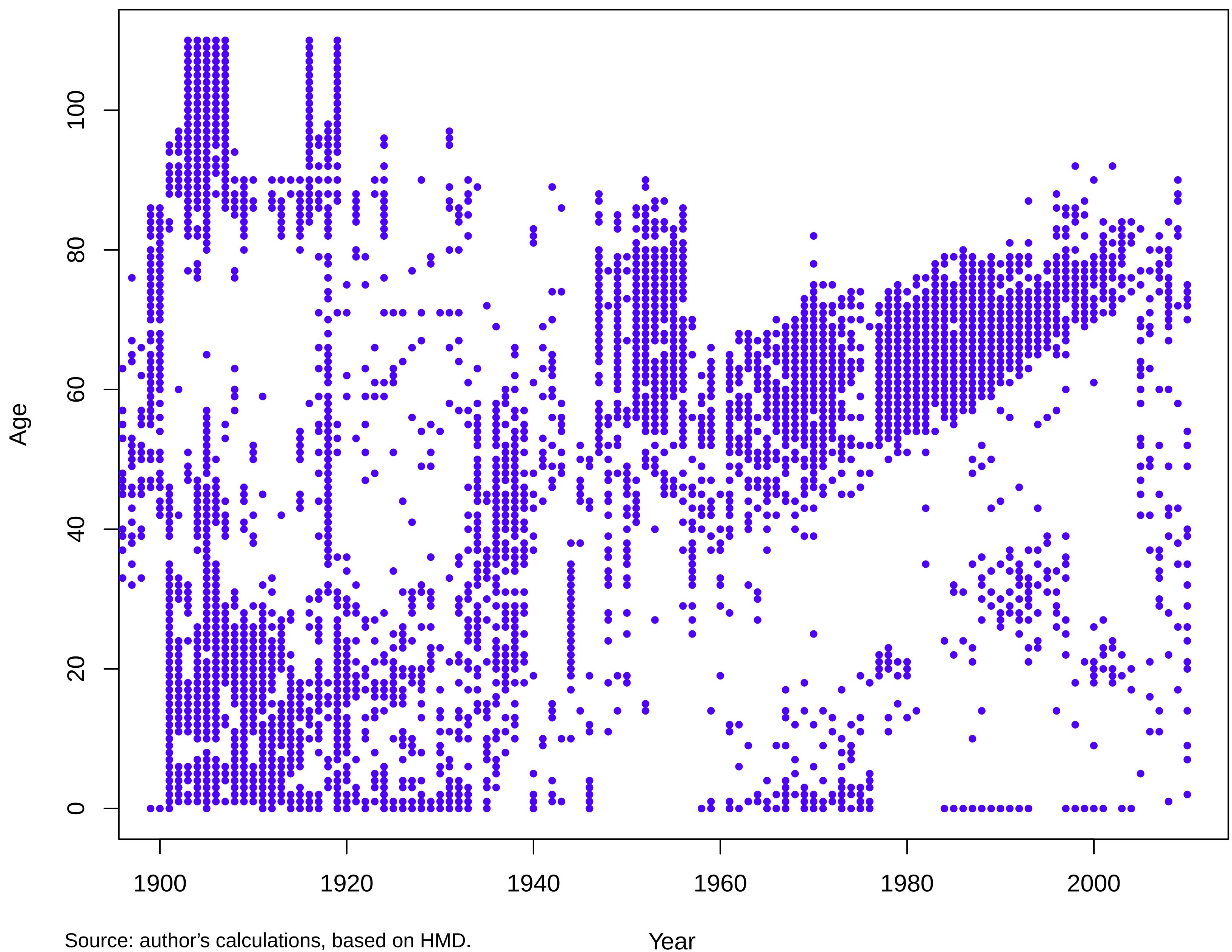
Source: author's calculations, based on HMD.

Figure 4A. Concordant ages of minimum death rates and belonging to the record country holder, females, 1900−2010.



Source: author's calculations, based on HMD.

Figure 4B. Concordant ages of minimum death rates and belonging to the record country holder, males, 1900−2010.



Source: author’s calculations, based on HMD.