Explicating the Low Life Expectancy Ranking of the United States by Studying the Mortality History of Cohorts.

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Abstract

The American period life expectancy has one of the lowest rankings among developed nations. However, these comparisons correspond to current mortality levels. Complete series of mortality that allow construction of actual life expectancies experienced by cohorts is only found in a subset of developed countries. Here, we compare countries using the truncated cross-sectional average length of life (TCAL). This measure includes historical information of all the cohorts present at a given moment and is not limited to countries with complete cohort mortality information. By calculating TCAL for different countries it is possible to distinguish the specific cohorts that contributed most notoriously to the disparity in mortality between countries. The American cohorts born in the 1950s have experienced greater cohort survival than the combined information of other high-longevity countries, and particularly of the long living Japanese counterparts. Opposing this, are those aged 70 to 85 with substantial cohort survival disadvantage.

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1. Introduction

Life expectancy in the United States and other developed countries has been increasing steadily during the past century (Oeppen & Vaupel 2002; White 2002; Canudas-Romo 2010), simultaneously a widening gap between longevity in the United States and other high-income countries has evolved (Ho and Preston 2010; Murray and Frenk 2010; Glei et al. 2010; National Research Council 2011). Life expectancy rankings are exclusively based on the current mortality profile of populations through period life tables. Historical information indicates that an increasing gap exists between period life expectancy and the actual life expectancy experienced by cohorts (Goldstein and Wachter 2006). As such, mortality rankings based uniquely on period information display a limited one-dimensional image of the health of populations, namely current mortality levels. Furthermore, more subtle aspects of how cohorts in a population progressed to these current mortality levels are omitted in such rankings.

The use of period life tables, and in particular of life expectancy, as a measure describing population health, dates back to Dublin and Lotka in the 1920s and 1930s (Robine 2006). Yet, it remains a core production of statistical offices today. New technology and data availability have facilitated the use of historical data for constructing long series of cohort mortality. In this project, we study the mortality experience of each cohort present at a given time. Using the information of all cohorts and a summarizing measure, analogous to life expectancy, we assess and compare the cohort mortality levels between populations.

The focus of the present analysis is on the way cohorts survive over time, how that survival compares across countries, and how that survival contributes to the overall survival level of a population. These objectives are different than cohort analysis, also known as age-period-cohort (APC) models, which aim at distinguishing and separating between the age, period and cohort effects that are constraint by their linear dependency, Age = Period – Cohort (Fu, Land and Yang 2011). Our goal is to compare mortality between populations, similar to the period life expectancy ranking, but based on the available information of cohort survival.

A birth cohort is defined as persons who are born during the same time and are destined to pass through life together, i.e. reach specific ages at the same time (Preston et al. 2001). In the

rest of the text we will refer to this simply as cohorts. The study of specific cohorts' survival has a long tradition and examples of these vary from good to bad outcomes. The cohort in utero during the Spanish Flu of 1918 displayed reduced educational attainment, higher physical disability, lower income and socioeconomic status, compared with other cohorts (Almond, 2006), although its cohort survival disadvantage is not evident (Cohen et al. 2010). Another example of a further granulation of cohorts is the study of adult mortality depending on the season when persons were born and its relation to differences in early-life conditions (Doblhammer and Vaupel 2001). In the present study our effort is to compare survival of cohorts across countries.

The best practice life expectancy – or the world's highest life expectancy in a given year – summarizes the collective experience mortality reductions in countries. As shown in the study by Shkolnikov et al. (2011) the best practice life expectancy based on cohorts has increased at a faster rate than on periods. This notorious gap between the two best-practice life expectancies is a consequence of persistent mortality decline over time (Canudas-Romo and Schoen 2005, Goldstein and Wachter 2006) and it is likely to persist in the near future (Shkolnikov et al. 2011), which underpins the need to study the survivorship of cohorts. However, in many situations mortality comparisons over cohorts are limited to those that have complete mortality information starting at birth. The aim of our study is to use the mortality information of all cohorts present at a given time, irrespective if they have complete or truncated series of mortality history. We achieve our aim by concentrating in cohort survival comparisons between countries.

There are five sections in this study with this introduction as the first one. Sections on data and methods follow and we present the cohort measure TCAL, or truncated cross-sectional average length of life. The methodology to calculate this measure and to decompose its difference between populations over cohorts and age-contribution are included in this section. Results and conclusions are the two final parts, presenting and discussing the cohort mortality comparisons between the United States and Denmark, Japan and other high-longevity countries (HLCs).

2. Data

The data source used in this study is the Human Mortality Database (HMD: www.mortality.org). The HMD database compiles census and vital statistics information for entire country

populations. The HMD has high quality historical mortality data for industrialized countries; the same methodology is used for all countries and times, making the HMD a unique comparative tool. This analysis is based on HMD data from 1949 to 2007 for the United States and 22 other relatively high-longevity countries (HLCs) listed below, with Denmark and Japan highlighted to exemplify cases of low and high mortality profiles within the HLCs group. High-longevity countries included in this analyses for the period (1949-2007) are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Iceland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, Canada, Japan, Australia, and New Zealand. East and West Germany are included from 1956 to 2007 and Luxembourg from 1960 to 2007. These selection of countries is similar to the group of countries used in recent studies (Ho and Preston 2010; Glei et al. 2010) and also referred as high-income countries, and corresponds to countries with high quality of mortality information for an extended period of time.

We constructed life tables using standard methods (Preston et al. 2001) based on age-specific death rates calculated by adding death counts and exposures for all HLCs excluding the US. This is equivalent to have average age-specific death rates weighted by population size. This procedure uses person years to account for differences in population size and therefore allows straight forward comparisons between persons in the HLCs region and the USA.

3. Methods

We take the comparisons between countries at three different levels: differences between mortality rates, between survival functions and between an aggregated measure of cohort survival. A series of age-specific death rates enables the calculation of the life table survival functions. Differences observed between countries at the age-specific death rates level might be perceived also at the aggregated level of the survival functions. One further aggregation now of all the survival functions over age, is life expectancy. However, since our interest is in trajectories of mortality for all the cohorts present at a given time we will instead use the truncated cross-sectional average length of life defined below.

3.1 The cross-sectional average length of life, CAL

The cross-sectional average length of life, *CAL*, was introduced by Brouard (1986), further elaborated by Guillot (2003, 2011) and used in the debate on tempo effects (Bongaarts and

Feeney 2006). *CAL(t)* refers to mortality in a particular period *t*, but takes into account the actual mortality conditions to which cohorts present in the population at time *t* have been subjected. Formally, in order to calculate *CAL(t)* for year *t* the survival functions for all the cohorts present in that year are calculated. These cohorts arrive to year *t* at ages *x*, ranging from zero to the highest age attained by a person in the population $0 \le x \le \omega$, as

$$\ell_c(x,t) = \exp\left[-\int_0^x \mu(a, t-x+a)da \right], \qquad (1)$$

where $\mu(a,t-x+a)$ is the force of mortality at age *a* and time *t-x+a* and $\ell_c(x,t)$ is the cohort survival function reaching age *x* at time *t*. The aggregate measure including the survival information of all the cohorts present in year *t* is calculated as $CAL(t) = \int_0^\omega \ell_c(x,t)dx$.

For countries, such as the United States and Japan, only partial mortality information is available during the first part of the 20th century and thus limiting the use of *CAL* (Guillot 2003; Guillot and Kim 2011). For these countries *CAL* can be approximated in several ways, for instance by back extrapolating their historical mortality information, drawing on available information for some other country, or using model life tables. As our interest is to compare across countries, we opt to construct a truncated *CAL*, denoted as *TCAL* and defined in the next section.

3.2 Formal definition of the truncated cross-sectional average length of life, TCAL

Let Y_1 be the earliest year for the mortality information for the population with the shortest mortality series, and assume that there is no missing mortality information from that year onwards, e.g. here we use $Y_1 = 1950$. The truncated *TCAL(t)*, is constructed similarly to *CAL(t)* by aggregating the survival information of all the cohorts present at time *t*. However, for cohorts born before year Y_1, without complete cohort mortality data, we use the period mortality experienced in the earliest year Y_1 in all the high-longevity countries (HLCs) combined. The survival function at age *x* and year *t* for cohorts born before year Y_1 is calculated as:

$$\ell^*(x,t) = exp\left[-\int_0^z \mu(a,Y_1)da - \int_z^x \mu(a,t-x+a)da \right], \qquad (2)$$

where $z = x-(t-Y_1)$ is the threshold age when the complete cohort mortality information is available, $\mu(a,t-x+a)$ is, as in equation (1), the force of mortality at age *a* and time *t-x+a*, with ages ranging from $z \le a \le x$, and $\mu(a,Y_1)$ is the period mortality in year Y_1 for age *a*, with $0 \le a < z$. Finally *TCAL* in year *t* is defined as the aggregation of all the survival functions in equation (2) as $TCAL(t) = \int_0^\omega \ell^*(x,t)dx$.

TCAL condenses the entire mortality history of cohorts present in a given time into one measure. In order to compare mortality levels of various high-longevity countries, all included mortality series are truncated in the year 1949. The set of weighted average death rates for all HLCs combined is assigned to all countries for the year 1949. The selection of death rates for 1949 might seem arbitrary but our results of comparisons between countries hold as long as there is consistency and the same death rates in year Y_1 are used for all examined countries. Table 1 shows the results of differences in TCALs between the USA and other HLCs based on three different scenarios using different death rates in year Y_1: the USA, Japan and other HLCs.

[Table 1 about here]

The similarity between the values for the difference in TCALs in the fourth column of Table 1 makes a good case for the previously mentioned consistency in comparisons irrespective of the base year information used in year Y_1. It should be noted that this similarity in the values of the fourth column contrasts with the very different results in TCALs in the columns for the USA and HLCs. These differences in the fourth column of Table 1 are the focus of the present study.

3.3 Cohort-decomposition of the difference between two TCALs

General methods of decomposition are widely known (Vaupel and Canudas-Romo 2002, 2003; Canudas-Romo 2003; Horiuchi et al 2008). Also, specialized methods exist for investigating differences between life expectancies (Arriaga, 1984; Pressat 1985; Pollard 1988; Beltran-

Sanchez et al. 2008; Shkolnikov et al 2011;). For our purposes, we are interested in examining the difference between *TCAL*s of two populations and to partition it by cohorts. Let the truncated cross-sectional average length of life for population *i* be denoted as $TCAL_i(t)$. The cohort-decomposition of the difference in *TCAL* between two populations is:

$$TCAL_1(t) - TCAL_2(t) = \sum_{a=0}^{\omega} \int_{a}^{a+n} \left[\ell_1^*(x,t) - \ell_2^*(x,t) \right] dx, \qquad (3)$$

where the integral corresponds to cohorts aged *a* to *a+n* at time *t*, the addition goes in sequences of a, a+n, a+2n, etc, with *n* defined in the range of 1 to 10 years. This simple separation of the *TCAL* differences allows us to identify the cohort mortality contribution for all the cohorts present at a given year/period. This option is different from period or cohort life expectancy decomposition, which can only reveal current mortality conditions or conditions of one specific cohort, respectively. Mortality of cohorts differ from year to year and age to age, *TCAL* condenses all that history in one measure, and its decomposition identifies the cohort-contributions of *TCAL* gaps.

Furthermore, it is possible to further decompose each of the cohorts present in equation (3) by their age-contribution. These age-contributions allow comparing cohorts in different populations and assess their mortality transitions over the life course.

3.4 Age-decomposition of the difference between cohort survival function

The decomposition of the change in the truncated cross-sectional average length of life over a continuous variable is better exemplified by looking at the change of TCAL over time. The derivative of TCAL with respect to time is

$$\dot{TCAL}(t) = \int_{0}^{\omega} \dot{\ell}^*(x,t) dx, \qquad (4)$$

where the dot on top of the variable denotes this derivative with respect to time. The rest of the decomposition requires the use of the probabilities of survival. We denote as ${}_1p_x$ the probability of surviving from age *x* to age *x+1*. The survival function is equal to the product of probabilities

of survival from zero to age *x*, $\ell^*(x) = {}_1p_0\ {}_1p_1\ {}_1p_2\ \cdots\ {}_1p_{x-1}$ and its derivative over time can be substituted in equation (4) as:

$$\dot{TCAL}(t) = \int_0^{\omega} \ell^*(x,t)\left[\sum_{a=0}^{x-1} \frac{{}_1\dot{p}_a}{{}_1p_a}\right]dx, \qquad (5)$$

where the relative derivatives of the probabilities of surviving denoted as $\frac{{}_1\dot{p}_a}{{}_1p_a}$, correspond to the age-contribution of the cohort aged *x* at time *t*, namely $\ell^*(x,t)$, in the overall change in *TCAL*. For the comparison between populations we also use equation (5). If information on two populations is available, e.g. for high-longevity countries (HLC) and for the USA, we estimated the relative derivatives in equation (5) as the logarithm of the ratio of probability functions, $\frac{{}_1\dot{p}_a}{{}_1p_a} \approx ln\left[\frac{{}_1p_a^{HLC}}{{}_1p_a^{USA}}\right]$. Similarly the cohort aged *x* at time *t* in this equation, $\ell^*(x,t)$, is taken as the average of the two populations. The accuracy of equation (5) is shown in Table 2 for the comparison between the countries. One of the differences in Table 2 correspond to observed TCALs in the high longevity countries, Denmark, and Japan minus the TCAL from the USA, the second difference is derived from applying equation (5).

[Table 2 about here]

A further decomposition that can be applied to *TCAL* is by causes of death. For the present project the studied period goes as far as 57 years back and the causes of death information required for applying the cause-decomposition would involve bridging the international coding of disease (ICD) for all these years (Meslé and Vallin 1996). This could be feasible for some broad causes of deaths, although the quality of such historical data over cohorts for all the countries in the analysis would need to be assessed. Even when this goes beyond the scope of the present project we have left the methodology as part of the Appendix.

4. Results

The Lexis surface of the difference in age-specific death rates between the populations of the USA versus other high-longevity countries (HLCs), Denmark and Japan are shown in Figure 1a, 1b and 1c respectively. Similar patterns were found when looking at these differences for females and males separately. In these contour charts, each data point represents the difference in age-specific death rates (scale on the right) for a specific year (horizontal axis) and age (vertical axis). Negative values denoted by blue colors correspond to higher American mortality, while positive values denoted by other colors are associated with higher mortality in the other countries.

[Figure 1a, 1b and 1c about here]

In the last decade of the twentieth century and first years of the new century, higher mortality levels are found in the United States at all ages when compared to Japan (Fig 1c), but this is the case only at ages below 60 when compared to Denmark (Fig 1b). Figure 1a that combines all HLCs shows higher mortality in the USA until age 80 and then for ages above 80 in some years American mortality is higher and in others lower.

American mortality disadvantages are evident for several decades back in time in the age-groups 20 to 70 when compared to Japan, and other HLCs and it is only since the late 1990s that they have been observed in the age group 80 and above. The American higher mortality is found at ages below 40, for the comparison with Denmark, but lower mortality is observed at older ages. The evident change in the 1980s, when American mortality is lower than the Danish at ages 40 and above coincides with the timing of the convergence in life expectancy between the United State and the Scandinavian country.

Figures 1a and 1c reveal another aspect of the American mortality of older cohorts present in the first decade of the 21st century; they had lower mortality than Japan and other high-longevity countries (HLCs) in their early years of life in the 1950s and 1960s. This aspect of changes in the mortality advantage and disadvantage over the life course of cohorts is the primary interest on our cohort perspective.

To further analyze the existent disparities between the USA and other high longevity countries we look at the difference in *TCAL*s for the year of 2007 between the USA and other HLCs, Denmark and Japan. For the USA, *TCAL* had a level of 75.25 years in 2007, practically the same as the Danish *TCAL* of 75.26 years. The American mortality, as captured by *TCAL*, is

behind that of other high-longevity countries by almost a year and over 3 years of gap exists to the Japanese *TCAL*. As presented in equation (3), the difference in *TCAL*s is resultant of adding all the differences between cohort survivals. The age-pattern of these disparities are found in Figure 2.

[Figure 2 about here]

In this Figure at each age a value summarizes the difference in cohort survival up to that age between American cohorts and each of the other populations: other HLCs, Denmark and Japan. Values above zero in the vertical axis represent disadvantages for the American cohorts respect to the other population and the opposite occurs for the negative values. For some ages between 55-60 there are negative values, these correspond to cohorts born during the early 1950s in the USA who have experienced greater cohort survival by 2007 than their Japanese and other HLCs counterparts. This manifested despite the higher mortality at every single age in the USA than in Japan, and for ages up to 80 years for other HLCs, in most recent years (see Figures 1a & 1c). Figure 2, also shows that disadvantages are observed for young American cohorts' survival up to age 70 when compared to Denmark, and then there is a full swapping of roles with lower survival for older Danish cohorts.

To further study the specific contributions of cohorts to the difference in TCALs between USA and other high-longevity countries (HLCs), we look at the age-contribution in each of the cohorts. This methodology is shown in equation (5) and allows assessing the relevance of early life survival in the cohorts that have higher survival in the USA than in other high-longevity countries in 2007. Table 3 shows the age- and cohort-specific contributions to the difference in TCALs between HLCs and USA, as well as the age-contribution for the specific cohorts of 1933, 1950 and 1970.

[Table 3 about here]

The first column in Table 3 corresponds to ages reached by cohorts present in 2007. The second column shows the differences in cohort survival between HLCs and USA up to these ages (also plotted in Figure 2). The greatest gap in American cohort survival is observed between ages 60 and 85, when the biggest positive differences are found. Contrary to this disadvantage is the minor American advantage at ages above 95 and for the cohorts aged 55 and 56 in 2007, with

negative values. The third column in Table 3 includes the cumulative addition of differences in column two which equals to the difference in *TCAL*s as indicated at end of the Table and in equation (3). In our application *TCAL* in the HLCs is 76.10 and 75.25 years in the USA, that is a difference of 0.85 of a year. However, if the researcher is interested to know how each cohort reached the differentials observed in column two in Table 3 it is necessary to study in detail the individual cohort mortality history.

Columns 4 to 9 in Table 3 show the survivorship history for the specific cohorts of 1933, 1950 and 1970. In their respective columns, the age-specific contributions to the difference in that specific cohort survival between HLCs and USA are observed, as well as the cumulative values over age. The last number of the cumulative values for these cohorts corresponds to the cohort-contribution to the difference *TCAL*s, also found in the second column of Table 3. The cohort of 1950 corresponds to one of the cohorts that by 2007 shows greater survival than in the other high-longevity countries combined. As observed in the columns for this cohort it is only at young ages, 0 to 10, that the American survival is greater than in other HLCs, but the effect of this advantage is observed until age 56. For the cohort of 1933 we start at age 17 when the database was truncated for reasons of comparison. However, for those ages when it is possible to do the comparison, ages 17 to 74, it can be appreciated that the USA mortality advantage was observed up to age 35, but lost after that age. The American cohort of 1970 has lived in survivorship disadvantage except for the short period between ages 1 and 4. This represents well what is observed in other American younger cohorts, where only sporadic mortality advantages are observed opposed to the more evident disadvantages.

The overall picture of the experiences of all cohorts present in 2007 can be observed in Figures 3 which shows the Lexis surface for the cumulative age- and cohort−specific contributions to the difference in *TCAL*s between high−longevity countries and the USA.

[Figures 3 about here]

In Figure 3, the long lasting effect of lower mortality at younger ages can be seen for American cohorts from the 50s and 60s. Opposing this is the lower survival starting at birth for all the cohorts born after the 1970s. Americans born in the second quarter of the century, more specifically from 1917 to 1947, face a particular survival disadvantage if only the mortality information from 1950 onwards is taken into account. By the time these cohorts have completed

their observed survival to 2007 their survival disadvantage is of magnitude of 0.74 year less than in other HLCs or 63% of the total TCALs gap.

5. Conclusions

How useful is a measure of mortality depends in its ability to inform us on the health situation of a population respect to others. Period and cohort life expectancies have long been used as measures that represent the mortality of populations even when they correspond to a synthetic cohort or to one specific cohort. For countries with partial mortality information of the cohorts present at a given time it is useful to try to use as much of their actual cohort mortality as possible. This is the aim of the truncated cross-sectional average length of life, TCALs.

The difference between TCALs is comparable to life expectancy differences by informing on the number of years one population is lagging behind another. Analogous to asking which age-groups help explain the gap between life expectancies, for TCAL differences we inquire on the cohort survival contribution. To this authors knowledge this is a novel approach in studies interested to compare mortality of populations.

In recent National Academy of Science publications emphasis to explicate the American lag in mortality has been put on studying adult mortality (30-80) (National Research Council, 2011). Our results agree that the poor survival of cohorts born in the first half of the century up to the end of our study period in 2007 is the main explanatory factor of the gap. However, as shown in Figures 1a, b and c this is not new and for long time the USA has had higher mortality levels than in other higher-longevity countries at these ages. But these Figures reveal something more recent in cohort development, namely the departure for the USA population from lower child and infant mortality levels as well as the low levels of mortality at oldest ages when compared to other high-longevity countries. For cohorts of Americans born after 1970 the disadvantage as opposed to other high-longevity countries is present at practically all ages. However, contrary to the results of studying current morality situation, as in period life tables, our cohort analysis also reveals some survival advantage for specific cohorts of Americans.

The cohorts born between the year of 1946 and 1964, or post world war II cohorts, are also referred as baby-boomers for the high birth rates observed in the post-war period (US Census Bureau, 2012). In terms of health, Easterlin (1987, pg107) mentions that “relatively higher mortality may follow a large generation throughout its life”. Our results, show less pessimistic

survival trajectories for this cohort of Americans when compared to other high-longevity countries (HLC). The higher health status, in terms of low mortality, in the early years of life has a long effect over the survival of cohorts mitigating the deleterious effect of higher mortality observed at older ages. This is the case for some American boomers that by 2007 have higher survival than for other HLCs despite their higher mortality in recent decades. However, there are great differentials among sub-cohorts of baby boomers, and as shown in our results the cohorts born in the late 1950s to 1964 don't have the advantage survival. The latter cohorts are referred as the "trailing edge" of the boomers, and their poorest members might be facing even worse economic well-being and total welfare than their parents (Easterlin, Schaeffer, Macunovich 1983).

The low ranking of the US period life expectancy informs us about the current high mortality conditions in the country as compared to others. These mortality rankings change at a gradual pace so they can be taken as a likely scenario of the near future. For example, the mortality disadvantage observed for the US population when compared to other high-longevity countries at ages below 80 (see Figure 1.a) is likely to be present in the coming decade. However, it is less clear how to infer the cohort survival path for those present at that time with only a narrow window of observation as that used in period life tables.

The truncated cross-sectional average length of life shows a much narrower mortality gap between the US and other HLCs, than life expectancy. This is due partially by the lower mortality levels in the early years of life for the cohorts born in the early 1950s which are included in the *TCAL* measure and not in the period measure. As such *TCAL* can be a useful measure if our interest is in measuring gaps in mortality between populations. Furthermore, the cohort-contribution to differences in *TCAL*s can help us identify specific cohort

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Appendix 1. Cause of death decomposition

The expression in equation (4) also allows expanding the analysis to causes of death. If *n* independent causes of death are available then the survival function is equal to the product of survival functions of the associated single decrements life tables for each of the causes, $\ell^*(x,t) = \ell^*(x,t,1)\ell^*(x,t,2)...\ell^*(x,t,n)$. This relation between cause-specific and the overall mortality survival functions can be substituted in equation (4), and obtain the cause-decomposition of the change in TCAL as

$$\dot{TCAL}(t) = \sum_{i=1}^{n} \int_0^{\omega} \dot{\ell}^*(x,t,i)\ell^*(x,t,-i)dx, \tag{1A}$$

where $\ell^*(x,t,i)$ and $\ell^*(x,t,-i)$ correspond to the associated single decrement life tables where only cause of death *i* and all the rest, *-i*, are present. This equation is analogous to the cause-decomposition of life expectancy at birth shown by Beltrán-Sánchez et al. (2008), but now applied to cohort and period information contained in TCAL.

Appendix 2. Estimation procedures for calculating equation (5).

Table 2 shows the application of equation (5) to the difference in TCALs between the high-longevity countries and the United States of America in the year of 2007. We have further included in this table the age-contribution to the differential in cohort survival for specific cohorts of 1933, 1950 and 1970. This appendix includes the estimation procedures of the derivatives in equation (5).

The cohorts born in 1933, 1950 and 1970 have lived to ages 73, 56 and 36 respectively by 2007. For a cohort born in year (2007-*x*), we estimated the age-contribution to the difference in survivals between HLCs and USA as a combination of the survival from birth to age *x*, the age reached by this cohort in 2007, and the probability of surviving at the specific age *a*:

$$\Delta\text{age - contribution(a)} = \ell^*(x,t)\left[\frac{\dot{{}_1p_a}}{{}_1p_a}\right] \approx \left[\frac{\ell^{HLC}(x) + \ell^{USA}(x)}{2}\right] \ln\left[\frac{{}_1p_a^{HLC}}{{}_1p_a^{USA}}\right], \tag{2A}$$

where the survival function in the cohort perspective is denoted as $\ell^*(x)$, which is equal to the product of probabilities of surviving at each individual age from zero to age *x*,

$\ell^*(x) = {}_1p_0 \; {}_1p_1 \; {}_1p_2 \; \cdots \; {}_1p_{x-1}$.

The addition over ages of the age-contributions, or cumulative differential, is denoted as $\sum_{a=0}^{y} \Delta \text{age-cont(a)}$. The value of $\Delta \text{survival}$ obtained when the addition is up to the last age attained by cohorts in the year of 2007, say 73 for those born in 1933, is what we denote as our age- and cohort-specific contribution to the difference in TCALs. Finally, the addition over ages of the age- and cohort-specific cumulative contributions returns the difference in TCALs:

$$TCAL_{HLC} - TCAL_{USA} = \sum_{0}^{\omega} \Delta \text{survival}. \tag{3A}$$

Table 1. Truncated cross-sectional average length of life (TCALs) for the total population of the USA and for other high-longevity countries (HLCs), and their differences under three scenarios of death rates for the year 1949.

Death rates for year Y_1 from country	$TCAL_{HLC}$	$TCAL_{USA}$	$TCAL_{HLC} - TCAL_{USA}$
USA	76.79	75.92	0.87
Japan	75.18	74.36	0.82
HLCs	76.10	75.25	0.85

Source: HMD; author's calculations.

Table 2. Observed versus estimated differences in TCALs for the USA versus Denmark, Japan and other high-longevity countries (HLCs) combined in 2007.

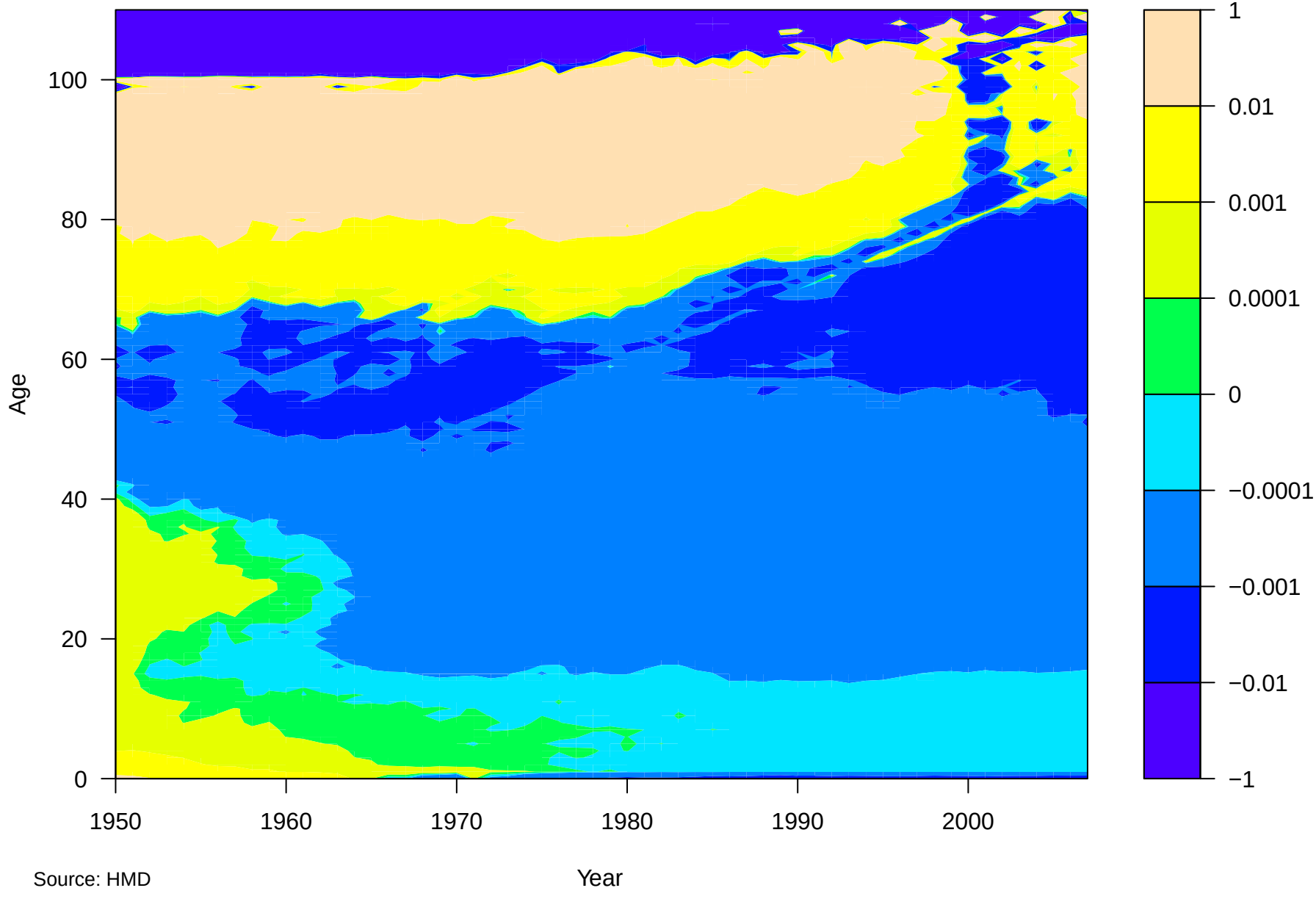
Country X	$TCAL_X$	$TCAL_{USA}$	$TCAL_X - TCAL_{USA}$	Estimated Difference as in eq(5)
Denmark	75.26	75.25	0.01	0.01
Japan	78.28	75.25	3.03	3.05
HLCs	76.10	75.25	0.85	0.85

Table 3. Age- and cohort-specific contributions to differences in TCALs between high longevity countries, HLCs (76.10), and the USA (75.25) in the year of 2007; and for the cohorts of 1933, 1950 and 1970, age-contribution to the differences in cohort survival between HLCs and the USA up to year 2007. Positive values correspond to higher survival in the HLCs than in the USA.

			1970		1950		1933	
Age	Δ survival	ΣΔ survival	Δ age-contribution	ΣΔ age-contribution	Δ age-contribution	ΣΔ age-contribution	Δ age-contribution	ΣΔ age-contribution
0	0.0017	0.0017	0.0007	0.0007	-0.0128	-0.0128		
1	0.0017	0.0034	-0.0002	0.0005	-0.0038	-0.0166		
5	0.0016	0.0103	0	0.0004	-0.0003	-0.0202		
10	0.0017	0.0194	0	0.0004	0	-0.0207		
15	0.0022	0.0288	0.0001	0.0007	0.0001	-0.0206		
17	0.0028	0.0334	0.0002	0.0010	0.0002	-0.0203	-0.0002	-0.0002
20	0.0031	0.0420	0.0002	0.0017	0.0003	-0.0195	0	-0.0005
25	0.0041	0.0598	0.0002	0.0028	0.0003	-0.0180	-0.0001	-0.0007
30	0.0051	0.0829	0.0002	0.0037	0.0003	-0.0168	0	-0.0008
35	0.0048	0.1082	0.0003	0.0051	0.0003	-0.0156	0.0002	0
36	0.0054	0.1130	0.0003	0.0054	0.0003	-0.0153	0.0002	0.0002
40	0.0067	0.1356			0.0003	-0.0138	0.0003	0.0014
45	0.0050	0.1672			0.0005	-0.0117	0.0003	0.0027
50	0.0031	0.1898			0.0005	-0.0093	0.0003	0.0041
55	-0.0021	0.2026			0.0009	-0.0055	0.0007	0.0067
56	-0.0046	0.2005			0.0009	-0.0046	0.0006	0.0074
60	0.0135	0.2267					0.0009	0.0102
65	0.0243	0.3136					0.0014	0.0165
70	0.0289	0.4415					0.0020	0.0252
73	0.0314	0.5288					0.0022	0.0314
75	0.0246	0.5896						
80	0.0258	0.7162						
85	0.0106	0.8174						
90	0.0060	0.8560						
95	-0.0011	0.8620						
100	-0.0010	0.8541						
105	-0.0001	0.8513						
110	0	0.8511						
$TCAL_{HLC} - TCAL_{USA} =$		**0.8511**						

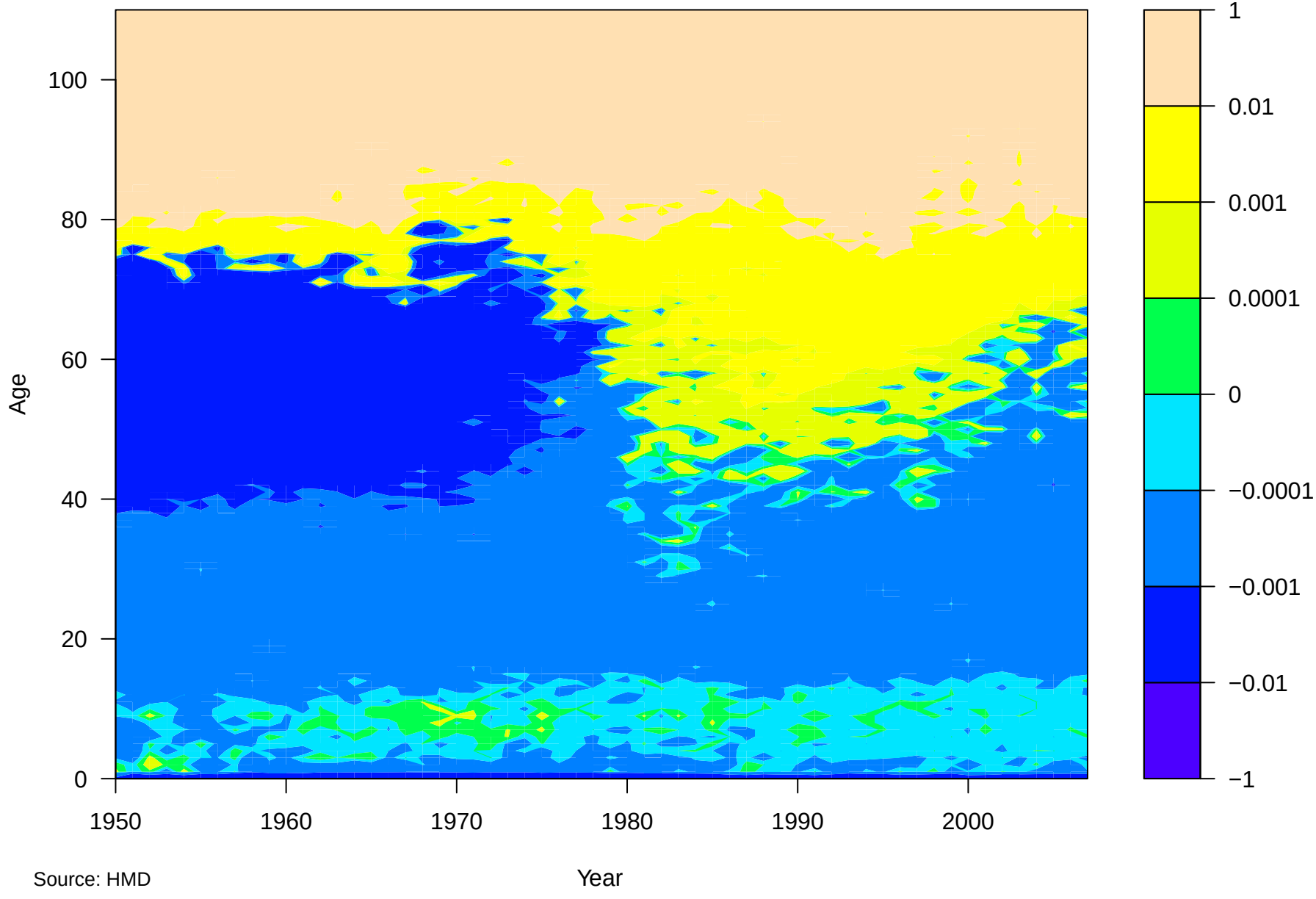
Source: HMD, author's calculations based on equation (5) in the methods section and the details of the estimation procedures are included in Appendix 2. Note: for comparison purposes the data is left truncated in 1949, so the cohort of 1933 is missing its first 16 years of comparison.

Figure 1a. Lexis surface for difference in deaths rates between high−longevity countries (HLCs) and the USA, 1950−2007. Each point represents the difference, Mx(HLC)−Mx(USA). Negative values correspond to higher American mortality.



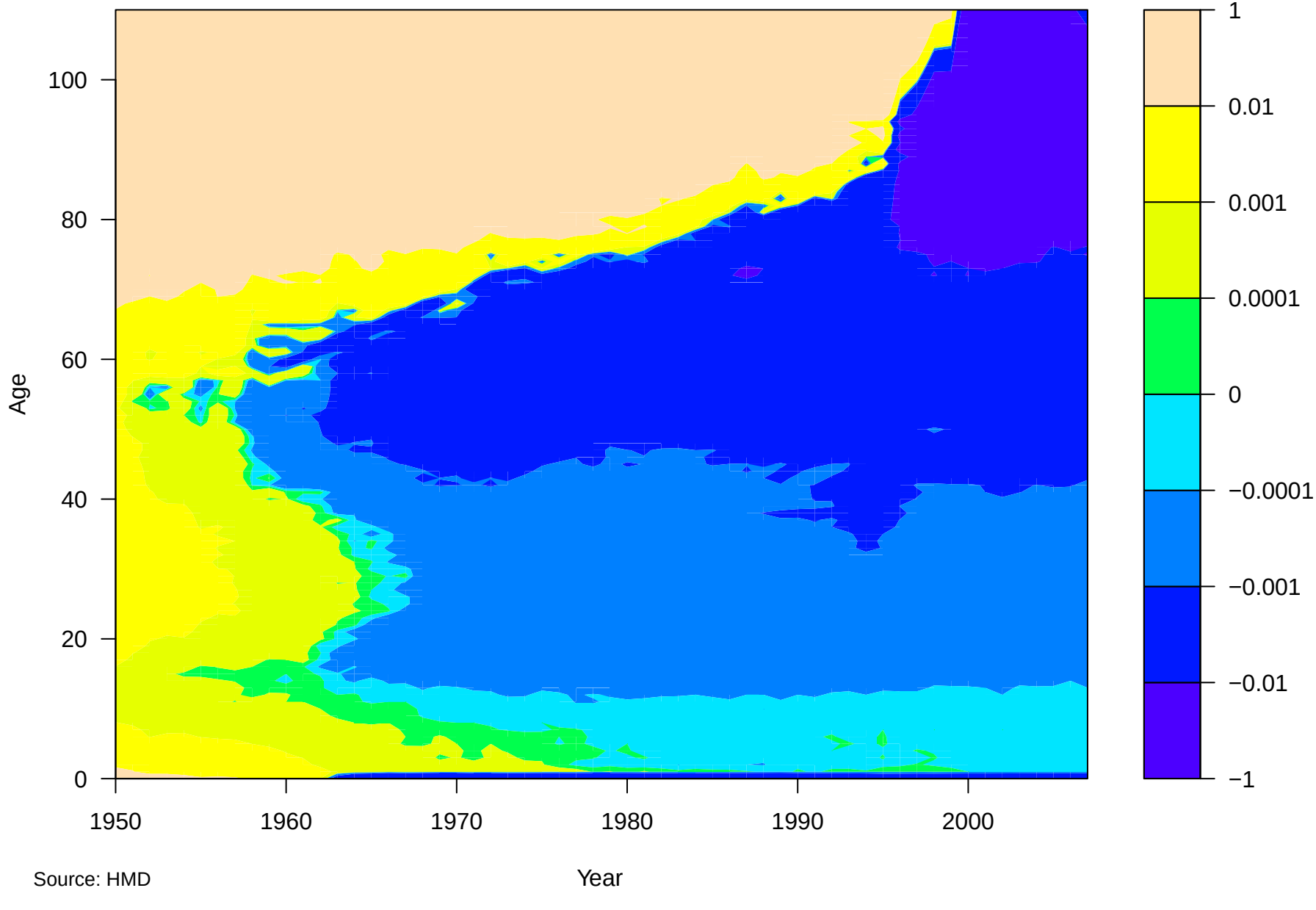
Source: HMD

Figure 1b. Lexis surface for difference in deaths rates between Denmark and the USA, 1950−2007. Each point represents the difference, Mx(DNK)−Mx(USA). Negative values correspond to higher American mortality.



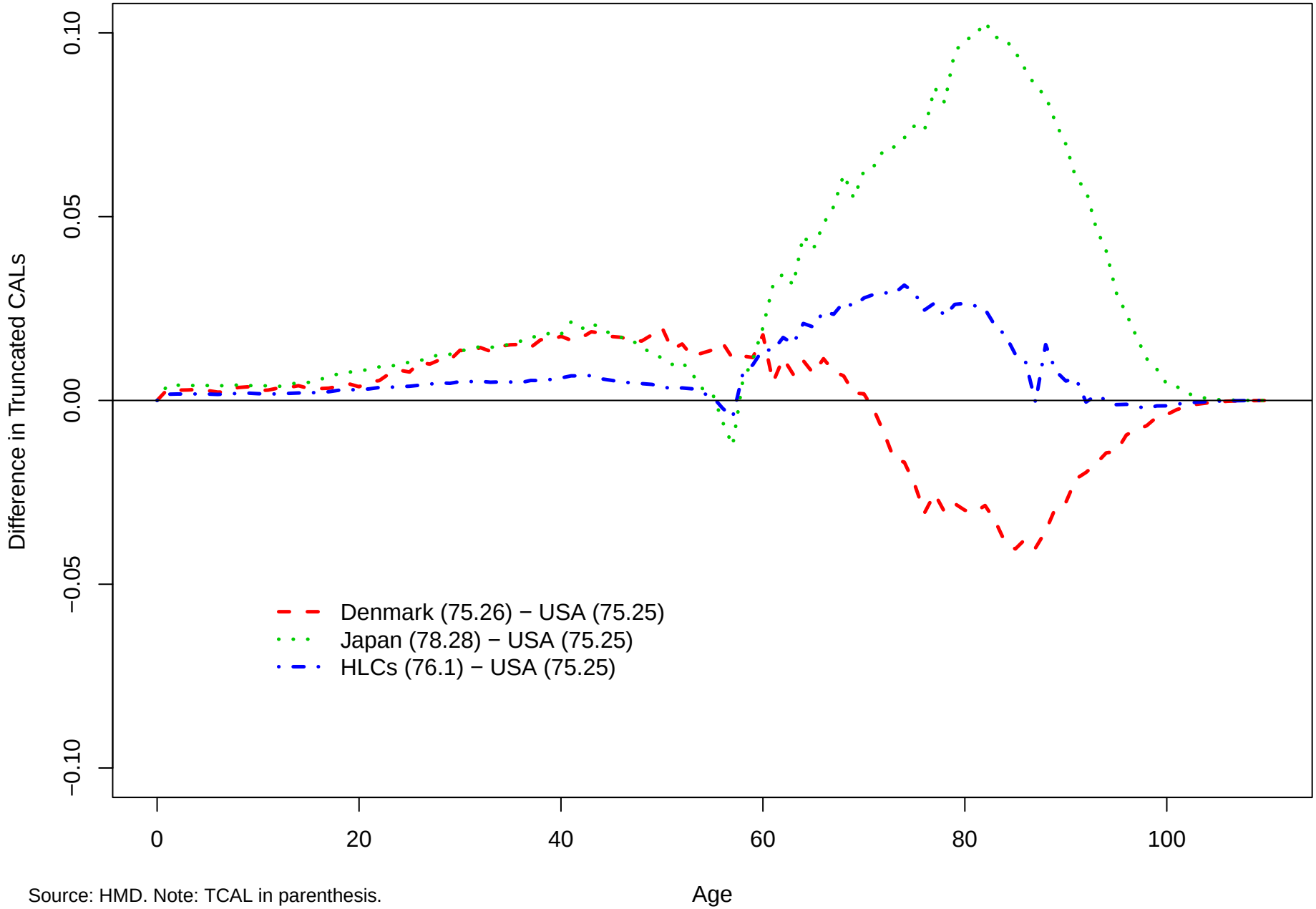
Source: HMD

Figure 1c. Lexis surface for difference in deaths rates between Japan and the USA, 1950−2007. Each point represents the difference, Mx(JPN)−Mx(USA). Negative values correspond to higher American mortality.



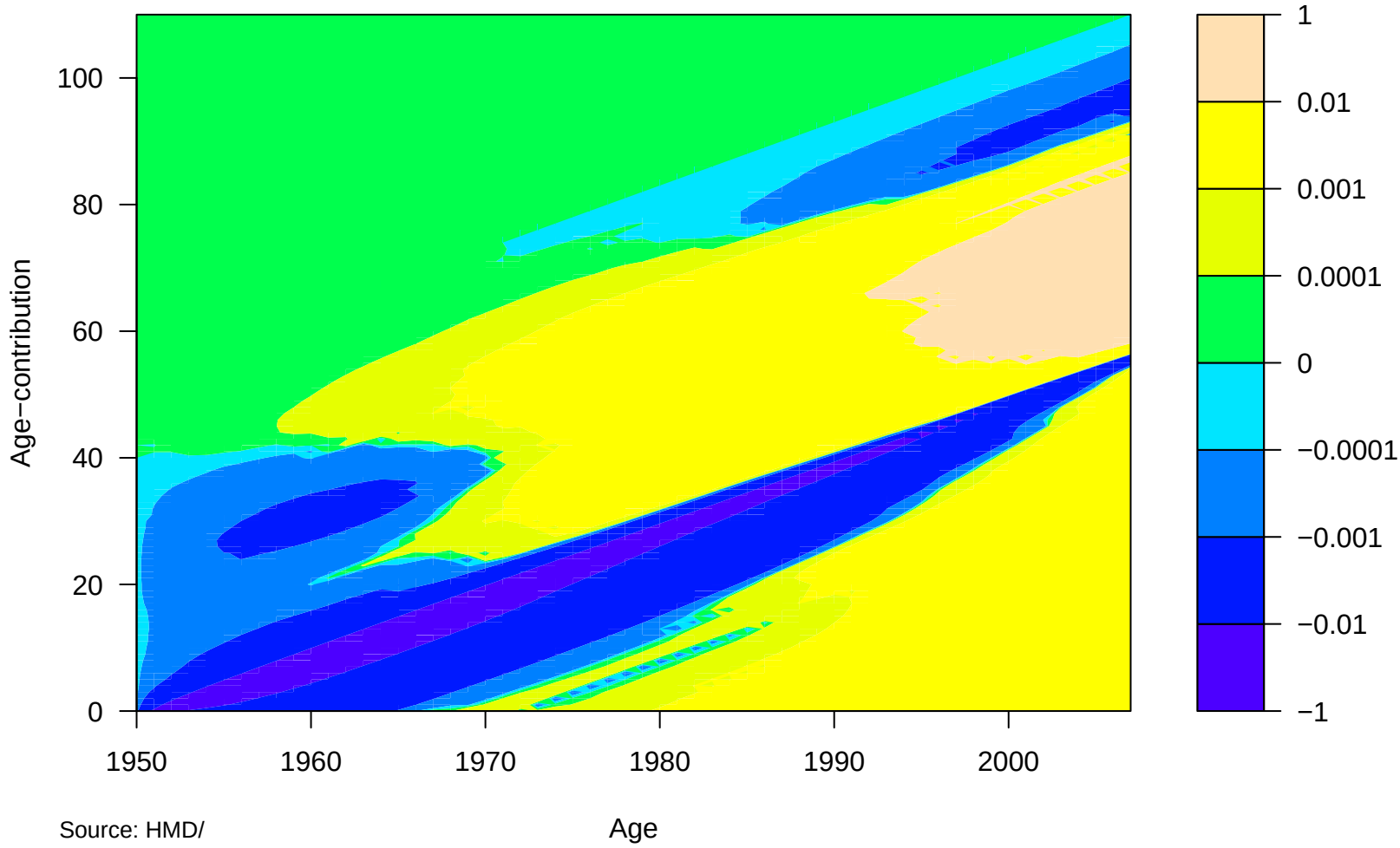
Source: HMD

Figure 2. Differences between Truncated CALs in 2007 for USA versus High Longevity Countries, Denmark and Japan. Initial Common Mortality for all is Data for 1949 for HLCs. Negative values correspond to higher American survival.



Source: HMD. Note: TCAL in parenthesis.

Figure 3. Lexis surface for the cumulative age− and cohort−specific contributions to the difference in TCALs between high−longevity countries and USA, 1950−2007
Negative values correspond to higher American survival.



Source: HMD/