**"The contenders of the future record life expectancy: The widening gap to Japan."**

Vladimir Canudas-Romo     Irene E. Dokko

Abstract

As the world's life expectancy leader, we seek to answer how Japan made, and retained this avant-garde status, and ultimately, whether it will continue to sustain its position at the top. The seven close contenders of the record life expectancy in the first years of the twentieth century are compared against Japanese average length of life. A simple breakup of life expectancy at birth allows disentangling and quantifying the specific contribution at each age to the gap in life expectancy: based on their truncated life expectancy, survival to advanced ages and life expectancy at advanced ages. The predominance of Japanese life expectancy at birth corresponds to the still evident low levels of mortality at older ages as opposed to the nearly equal or even lower survival at younger ages. Preliminary analysis of improvements in mortality at older ages confirm the likely future scenario where Japan continues to draw the line of the record life expectancy at birth.

## INTRODUCTION

A trend, by definition, cannot last forever. Nor is it meant to. Still, demographers must rely heavily on past trends; they are often the only things available to help direct future determinations. One such trend is life expectancy; as a measure of health and wealth, positive changes in period life expectancy values reflect what is popularized as a nation's *progress*. Using data between 1955 and 1996, White's regression analysis of twenty-one high-income countries finds straight-line changes in life expectancy give best-fit time trends for those countries[1] (White, 2002). More importantly, he averaged life expectancy values for the whole group and charts a linear trend in life expectancy at birth that made a near perfect fit[2] (White, 2002). In their famed *Science* article, Oeppen and Vaupel documented another linear trend – that of life expectancy values among record holding, or "best-practice" nations. They call the steady relationship of their own trend, which began in 1840 to the effect of a quarter-year-per-year increase in female life expectancy at birth, "the most remarkable regularity of mass endeavor ever observed" (Oeppen and Vaupel, 2002). It seems, then, that world progress advances along a straight line.

If we are to believe White, the world pattern converges as well, with the nations "behaving increasingly as if it had a single mortality pattern" (White, 2002). In keeping with his argument for convergence, White conjectures that since Japan has enjoyed above average life expectancy, there should be a "substantial

---

[1] In nineteen of those twenty-one nations, the highest R-squared fit comes from regressions in life expectancy; the exceptions are in Canada and Japan.
[2] Ths R-squared value of this regression line (slope is 0.208 years/year) is 0.994.

slowdown toward the group mean in the rate of life expectancy increase" (White, 2002). With the advantage of data past 1996, we see, this was not to be the case. After assuming record holding position in the 1980s, Japanese females conform well with Oeppen and Vaupel's expectations of linear increase. However, in ascertaining whether second-best values confirm this original trend of record life expectancy, Vallin and Meslé found that since 1988, maximum life expectancy diverges from the next highest value. As a development attributed solely to "remarkable" progress in Japanese life expectancy gains, the gap becomes quite wide by 2005 (Vallin and Meslé, 2009), and a slope fitting second-best values would have to be less than 0.20 years/year. But for Japan, the Oeppen-Vaupel line cannot hold, and would be drawn askew in recent years.

It may now come as little surprise that Japanese data deviate from another general norm in the White analysis. In searching for an individual country's best fitting regression line, it seems that a regression on life expectancy gives the highest R-squared value in nineteen of the twenty-one countries analyzed. Only in Japan does a regression of log death rates have a better fit than on life expectancy (White, 2002). Still, age-standardized logged death rates tend to emphasize differences between low levels of mortality and still constitute a good model for mortality change (White, 2002).

And yet, it is for none of these reasons, that Wilmoth calls Japan an "avant-garde country" (Wilmoth, 1998). The reason why he does so is because Japan's overall mortality level has been the lowest attainable (Wilmoth, 1998) since 1981. As the world's life expectancy leader, we seek to answer how Japan made, and retained this avant-garde status, and ultimately, whether it will continue to sustain its position at the top. We do so by not simply by isolating Japan, but by comparing its own developments as they relate to certain other nations. This paper will then begin with a description of the data source and the qualifying measure used to select the countries we will set alongside Japan. After a review of certain life table characteristics, the next section calls special attention to "temporary life expectancy" effects. Following that, our own analysis of mortality change will look at the Japan's rate of mortality decline compared to the other nations'. In the third part, we discuss our findings and conclude our investigation.

**DATA**

For a trend to accurately represent itself, it must come from reliable data sources. The Human Mortality Database (HMD) creates original death rate and life table calculations for a number of different nations and groups with input data consisting of death counts from vital statistics, census counts, birth counts, and other population estimates. Only those countries whose life expectancy at birth in the year 2006[3] differs from the record life expectancy by less than 2 years are included in the following analysis. Of 41 currently available populations, we analyze only a select group, the nations of Australia, France, Iceland, Italy, Spain, Sweden, and Switzerland.

Table 1 lists each of these nations, along with life expectancy at birth ($e_0$) values at another critical juncture –the year when Japan's $e_0$ first surpassed each other nation's. The last row of Table 1 includes current gaps in life expectancy: Japan minus other nations.

---

[3] We will make an exception for Australia, whose data does not extend past the year 2004. Table 1 therefore list's Australia's 2004 $e_0$ value in lieu of its 2006 value.

[TABLE 1 HERE]

It's been pointed out that some of the smaller populations within the Human Mortality Database (including Iceland and Switzerland) may be unduly influenced by minor –though none the less real- fluctuations (Vallin and Meslé, 2008). Our own argument, which focuses on broader trends over time rather than specific aberrations, will further mitigate this limitation by using total (rather than sex-specific) population data counts.

A data issue of greater concern is validity in age reporting, as records that are nearly, or over a century old are subject to less veracity and greater error than more recent data. Nevertheless, we have reason to believe our data to be of very good quality and can be confident in HMD calculations concerning these uppermost ages (Saito, 2009).

**METHODS**

In the life table, let $\ell(x,t)$ be the survival function at age *x,* and time *t.* As calculated from the survival function, life expectancy at age *x* and time *t* can then be expressed as:

$$e_x(t) = \frac{\int_x^{\omega} \ell(a,t)da}{\ell(x,t)}, \qquad (1)$$

with $\omega$ being the terminating age.

Life expectancy at birth *($e_0$)* is a particular case of this, covering the whole age range and defined as

$$e_o(t) = \int_o^{\omega} \ell(a,t)da \quad , \qquad (2)$$

where $\ell(0,t) = 1$ (the radix of the population equals 1).

From equation (2) of life expectancy at birth it can be derived an expression showing that life expectancy at birth is a function of any other life expectancy at older ages, the probability of surviving to that age and a truncated life expectancy as:

$$e_o(t) = {}_x e_o(t) + e_x(t)\ell(x,t), \qquad (3)$$

where

$${}_x e_o(t) = \int_o^{x} \ell(a,t)da \quad , \qquad (4)$$

is a measure of the average number of years a cohort will live between birth and age *x*. Created to debar unreliable statistics, Arriaga calls these "temporary life expectancy" values (Arriaga, 1984). We calculate these abridged, or truncated life expectancy values for purposes of juxtaposition between nations. Therefore, in a given year, we can calculate a value between birth and age 50 (${}_{50}e_0$) for Japan, and compare it with any other nation. Since we are deliberately curtailing values for our own uses, we feel "truncated life expectancy" is a more apt descriptor and will use the term accordingly.

Figure 1 shows this relationship between Japan and Sweden for the year 2006. In subtracting ${}_x e_o$ values at successive ages (Japan minus Sweden), we see Sweden's truncated life expectancy values are higher than Japan's for most ages.

Difference values favor Sweden until age 75, after which Japan rapidly increases its advantage, eventuating in a 1.7-year lead over Sweden by ${}_{110}e_o$.

[FIGURE 1 HERE]

Later in the analysis, we will look into rates of mortality declines, where the average annual rate is denoted as $\rho(x,t)$ and it is calculated from values of the relative derivative of the force of mortality. Using a dot on top of the variable to denote the derivative with respect to time and the notation $\mu(x,t)$ for the force of mortality, the average annual rate of mortality decline is calculated as:

$$\rho(x,t) = -\frac{\dot{\mu}(x,t)}{\mu(x,t)}. \qquad (5)$$

For our preliminary results on these rates of mortality improvement five time intervals are analyzed: between 1950-1959 to 1960-1969; 1960-1961-1969 to 1970-1979; 1970-1979 and 1980-1989; 1980-1989 through 1990-1999; and the time interval beginning with 1990-1999 and ending with 2000-2006, (or the last year for which data was available).

## RESULTS

As the vanguard nation with the highest life expectancy values, Japan has held avant-garde status for over a generation now. Figure 2 shows $e_0$ trends over time for Japan, as well as other current record holders. Within a six-decade period (between 1947 and 2007), Japan raised life expectancy values from 51.74 years to 82.87, averaging a 0.5 year gain per calendar year -a feat unmatched by any other nation.

[FIGURE 2 HERE]

For Japan to hold at least a full year's distance over six of its seven closest competitors, greater truncated life expectancy values are to be expected as a matter of course. However, a look at contour maps mapping the differences in these values over time reveals a surprise: Japan enjoys substantially lower mortality only at older ages. Prior to these thresholds, truncated life expectancy differences are minimal. France provides an interesting, if not prototypical example of this in Figure 3.

[FIGURE 3 HERE]

In 1947, Japanese truncated life expectancy values were significantly lower than French at every age. In that year, ${}_{25}e_0$ was 1.73 years higher in France than in Japan, by ${}_{110}e_0$, it was 12.2 years. Were we to look at differences in ${}_{85}e_0$ between the years 1947 and 2006 we would see those beginning values of 12 years favoring France over Japan (in 1947) shift in a short time period that began in 1963. A rapid reversal of roles countered the balance so that ${}_{85}e_0$ peaked at a 2.1-year difference favoring Japan over France in 1982. France no longer has an ${}_{x}e_0$ advantage over Japan -in any age.

We will focus now on two more things concerning the shifts in temporary life expectancy differences between Japan and France: the first relates to the age when these changes happen; the second, the time frame within which this occurs. The Japanese ${}_{x}e_0$ gains over 0.5 years come by middle age; by 2006, Japanese truncated life expectancy does not accrue this half-year difference until around age 70. Once this happens, it seems the acceleration in truncated differences between ages holds relatively steady; from the late 1970s to the present time, the ages between which differences jump from below 0.5 years to over 1.5 takes place within a 30-year age range.

Life expectancy values through upper ages must always be higher in Japan, but what of those values in younger ages? In some cases, ${}_{x}e_0$ shifts once more to favoring other nations over Japan. Table 2 highlights certain *x*-values for Sweden, Iceland, and Italy. We will emphasize two implications of this finding here. One, it disabuses us of the notion that Japanese life expectancy values are higher at every age for every nation, imputing even greater significance on Japanese life expectancy values beyond age *x*, which must offset the lower values up to that age. Two, it clearly shows that Japan's life expectancy trajectory, as compared through truncated life expectancies, does not distinguish itself from other nations until much later in the life-span.

[TABLE 2 HERE]

The greatest differences in truncated life expectancies between Japan and other nations, then, are given to increasingly older ages with time. Since life expectancy gains are the result of mortality declines at different ages over different times, the reason why this difference increases must be because of continued reductions in mortality in older ages (Rau et. al, 2008); reductions that are probably happening at a much faster rate in Japan than in other nations. In documenting the pace of mortality decline in Japan and Sweden, Wilmoth declares the pace and magnitude of Japanese mortality decline as "unprecedented in human history" (Wilmoth, 1998). Using the same method, we likewise calculated the rate at which age-specific mortality decreased in Japan and the other nations being compared with updated data and longer time intervals.

[FIGURE 4 HERE]

Figure 4 compares rates of Japanese mortality declines with those of the other nations between decennial time periods. As is expected for the time and place (a nation beginning to industrialize and undergoing epidemiologic transitions), the mortality decline that began in the period between 1951-1959 and lasted through 1971-1979 was in earlier ages (Omran, 1971). Vast improvements in mortality would raise the mean rate of mortality decline for all the nations. After that, the rate of reduction converges toward the mean (Wilmoth 1998). In the final period (between 1990-1999 and 2000-2007 for Japan), Japan's rate of progress is much lower than the mean in many ages. Only with continued increases in mortality reductions in old ages does it continue to outpace its peers.

**CONCLUSION**

This paper has been about Japan's remarkable life expectancy changes through documenting historical changes and current trends. The rapidity with which Japan caught up to other industrialized nations within the latter half of the 20th century is indeed remarkable (Yanagashita and Guralnik, 1988). Still more amazing is the steady longevity gains the nation has been making, ahead of its peers and competitors whose $e_0$ values are now converging in the middle. Their particular trajectory leaves us questioning whether or not such increases are sustainable, or whether Japan faces an inevitable slowdown, lending credence to theorists who believe in teleological limits for the human life span.

While many and varied, the specific reasons behind life expectancy gains can be broadly attributed to biological, social, and economic factors (Johannsson and Mosk, 1987); life expectancy at birth rising in conjunction with advances in income, salubrity, nutrition, education, sanitation, and medicine (Oeppen and Vaupel, 2002) interacting in such a way that the whole is greater than the sum of its parts. Through encouraging great increases in all the above factors, Japan has been called a nation whose mortality behavior is deemed worthy of avant-garde status. While life expectancy values are converging toward a mean, Japan has created ever-widening distances between its own life expectancy at birth and that of its closest competitors.

That being said, we feel the term "avant-garde" is something of a misnomer. To stay within the confines of the definition, Japan does have the lowest *overall* mortality level of any nation. But were we to abridge life expectancy values from ${}_{\omega}e_0$ (life expectancy at birth) to any other specific ${}_{x}e_0$, we would find some nations have higher values than Japan. In addition, Japan's pace of mortality decline now lags behind the other nations through many age intervals. For all this, we feel Japanese mortality patterns are perhaps not as exemplary as they once were.

The exception, of course, is the trend in old age mortality. As we noted earlier, White predicted slowdowns in the rate of life expectancy increases as Japan moves toward the group mean. Data proves this not to be the case on the whole. But were it not for the astonishing life expectancy gains in late ages, we could argue this to be true for partial gains –not life expectancy from birth to the end, but life expectancy from birth up to a specific point. Here, the picture is a little different; sometimes other nations have an advantage over Japan. So perhaps it is not so much that the other nations are catching up, but that Japan is falling behind, as it were, for the sake of convergence.

Speculation aside, we reiterate the aim of our analysis was not to look into the *hows* of how Japan attained pre-eminent $e_0$ standing over time, but to investigate the *wherefores* –the means by which Japan got to where it currently stands. By looking at truncated life expectancy values, we discovered Japanese life expectancy is not indicative of best-practice values at every age; rather, it is only at the oldest of ages where Japan continues to make great gains and surpasses its peers. To these mortality decreases in older ages alone does Japan owe its steady increases in life expectancy at birth. And it is because Japan makes gains in life expectancy in later life that the nation continues to carry the Oeppen-Vaupel line – the quarter-year-per-year increase in life expectancy at birth that measures progress for Japan, and the whole world.

A further analysis of Japanese future life expectancy predominance will be carried looking at causes of death. These might help overcome some of the remaining questions regarding the future of record life expectancy.

REFERENCES


Arriaga, Eduardo E. (1984). "Measuring and Explaining the Change in Life Expectancies." *Demography* 21(1):83-96.

Carnes, B.A. & Olshansky, S.J. (2007). "A Realist View of Aging, Mortality and Future Longevity." *Population and Development Review* 33(2), 367-381.

*Human Mortality Database*. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de (data downloaded on [18 Jul 2009]).

Johnsson, S. Ryan and Carl Mosk (1987). "Exposure, Resistance and Life Expectancy: Disease an Death during the Economic Development of Japan, 1900-1960." *Population Studies* 41(2):207-235.

Meslé, France and Jacques Vallin (2006). "Diverging Trends in Female Old-Age Mortality: The United States and the Netherlands versus France and Japan." *Population and Development Review* 32(1):123-145.

Oeppen, J. & Vaupel J.W. (2002). "Broken Limits to Life Expectancy." *Science* (296), 1029-1031.

Olshansky, S. J., B. A. Carnes, & C. Cassel (1990). "In Search of Methuselah: Estimating the Upper Limits to Human Longevity." *Science* (250), 634–640.

Omran AR. (1971). "The epidemiologic transition: A theory of the epidemiology of population change." *Milbank Mem Fund Q*, 49:509-38.

Rau, R., Soroko E., Jasilionis, D., & Vaupel, J.W. (2008). Continued Reductions in Mortality at Advanced Ages." *Population and Development Review* 34(4), 747-768.

Robine, J.M. and Y. Saito (2003). "Survival beyond Age 100: Acceleration of the Evolutions in Japan." *Population and Development Review* 29(supplement): 208-228.

Saito, Yasuhiko. "Supercentenarians in Japan" (forthcoming).

Vallin, Jacques and France Meslé (2008). "Minimum Mortality: A Predictor of Future Progress?" *Population, English edition* 63(4): 557-590.

Vallin, Jacques and France Meslé (2009). "The Segmented Trend Line of Highest Life Expectancies." *Population and Development Review* 35(1):159-187.

White, Kevin M. (2002). "Longevity Advances in High-Income Countries, 1955-96." *Population and Development Review* 28(1): 59-76.

Wilmoth, John R. (1998). "Is the Pace of Japanese Mortality Decline Converging Toward International Trends?" *Population and Development Review* 24(3): 593-600.

Wilmoth, John R. and Jean-Marie Robine (2004). "The World Trend in Maximum Life Span." *Population and Development Review* 29(supplement): 239-257.

Yanagashita, Machiko and Jack M. Guralnik. "Changing Mortality Patterns that Led Life Expectancy in Japan to Surpass Sweden's: 1972-1982." *Demography* 25(4): 611-624.

Table 1. The year when Japan's life expectancy at birth ($e_0$) first surpassed $e_0$ in Australia, France, Iceland, Italy, Spain, Sweden, and Switzerland.

| Year | Italy | Australia | France | Spain | Switzerland | Sweden | Iceland | Japan |
|---|---|---|---|---|---|---|---|---|
| **1963** | **69.35** | 70.99 | 70.36 | 69.85 | 71.31 | 73.56 | 72.98 | **69.81** |
| **1966** | 71.02 | **70.82** | 71.56 | 71.25 | 72.47 | 74.13 | 73.23 | **71.14** |
| **1968** | 70.88 | 70.73 | **71.54** | **71.73** | 72.72 | 74.03 | 73.94 | **71.75** |
| **1978** | 73.83 | 73.88 | 73.95 | 74.58 | **75.34** | **75.53** | 76.42 | **75.7** |
| **1981** | 74.51 | 74.97 | 74.51 | 75.74 | 75.87 | 76.1 | **76.35** | **76.6** |
| **2006** | 81.59 | 81.15* | 80.9 | 80.94 | 81.75 | 80.95 | 81.12 | **82.68** |
| **Difference** | **1.53** | **1.53** | **1.78** | **1.74** | **0.93** | **1.73** | **1.56** | |

Source: Human Mortality Database (2009)

* Data for Australia corresponds to 2004.

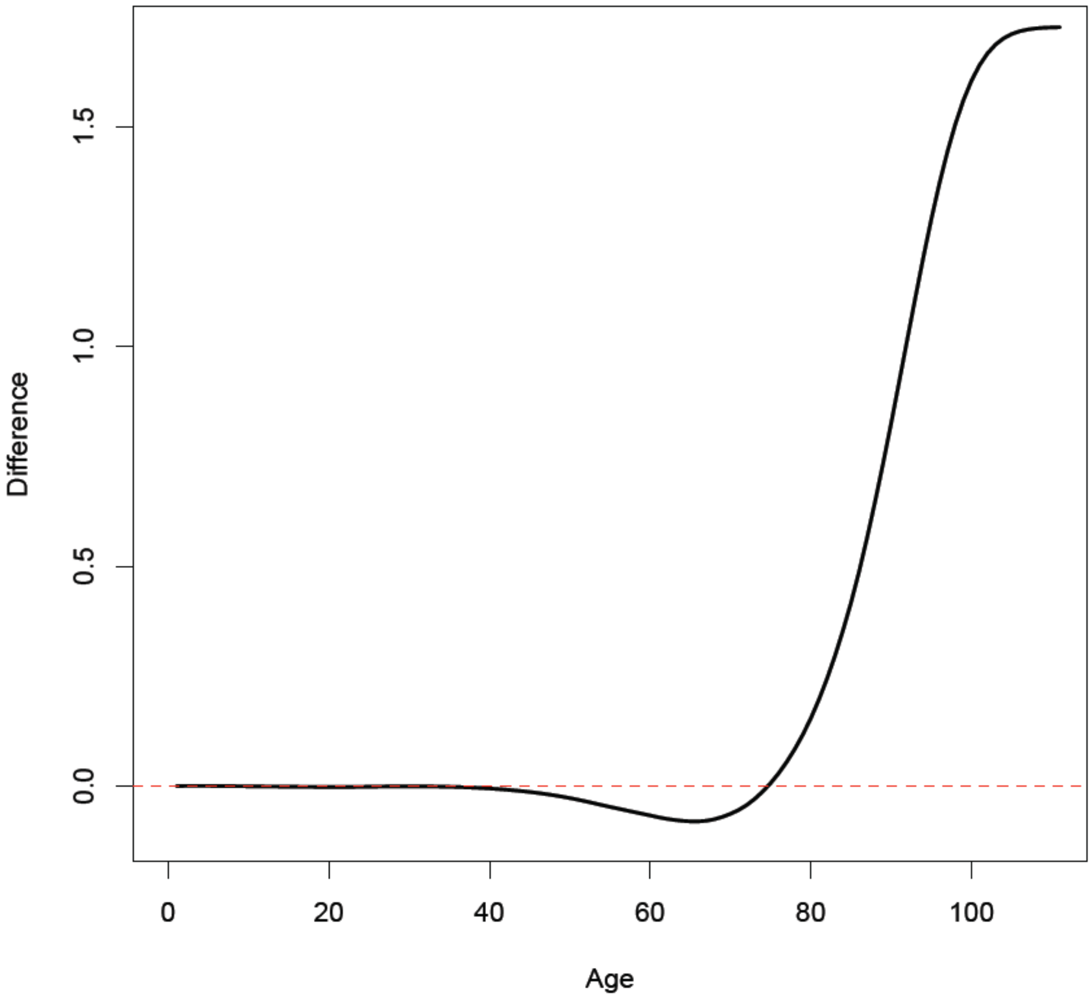
Table 2. The gap in life expectancy decomposed into truncated life expectancy, life expectancy at advanced ages and survival up to that older age for Japan versus Iceland, Italy, and Sweden.

| | Age | A<br>Life expectancy from birth to age x | B<br>Life expectancy at age $v$ | C<br>Probability of surviving from birth to age x | B*C<br>Life expectancy from age x | A + B*C<br>Total life expectancy |
|---|---|---|---|---|---|---|
| | x | ${}_{x}e_0$ | $e_x$ | $\frac{\ell_x}{\ell_0}$ | $(e_x)*\left(\frac{\ell_x}{\ell_0}\right)$ | ${}_{x}e_0 + e_x * \frac{\ell_x}{\ell_0} = e_0$ |
| Sweden | 65 | 63.578 | 19.400 | 0.895 | 17.372 | 80.950 |
| Japan | | 63.498 | 21.400 | 0.896 | 19.175 | 82.672 |
| Difference | | 0.081 | -2.000 | | -1.802 | -1.722 |
| | | | | | | |
| Iceland | 66 | 64.462 | 18.750 | 0.888 | 16.655 | 81.117 |
| Japan | | 64.390 | 20.590 | 0.888 | 18.290 | 82.679 |
| Difference | | 0.072 | -1.840 | | -1.635 | -1.563 |
| | | | | | | |
| Italy | 68 | 66.209 | 17.660 | 0.871 | 15.382 | 81.591 |
| Japan | | 66.150 | 18.960 | 0.872 | 16.526 | 82.675 |
| Difference | | 0.060 | -1.300 | | -1.144 | -1.084 |

Source: Human Mortality Database (2009)
Calculations: Our Own

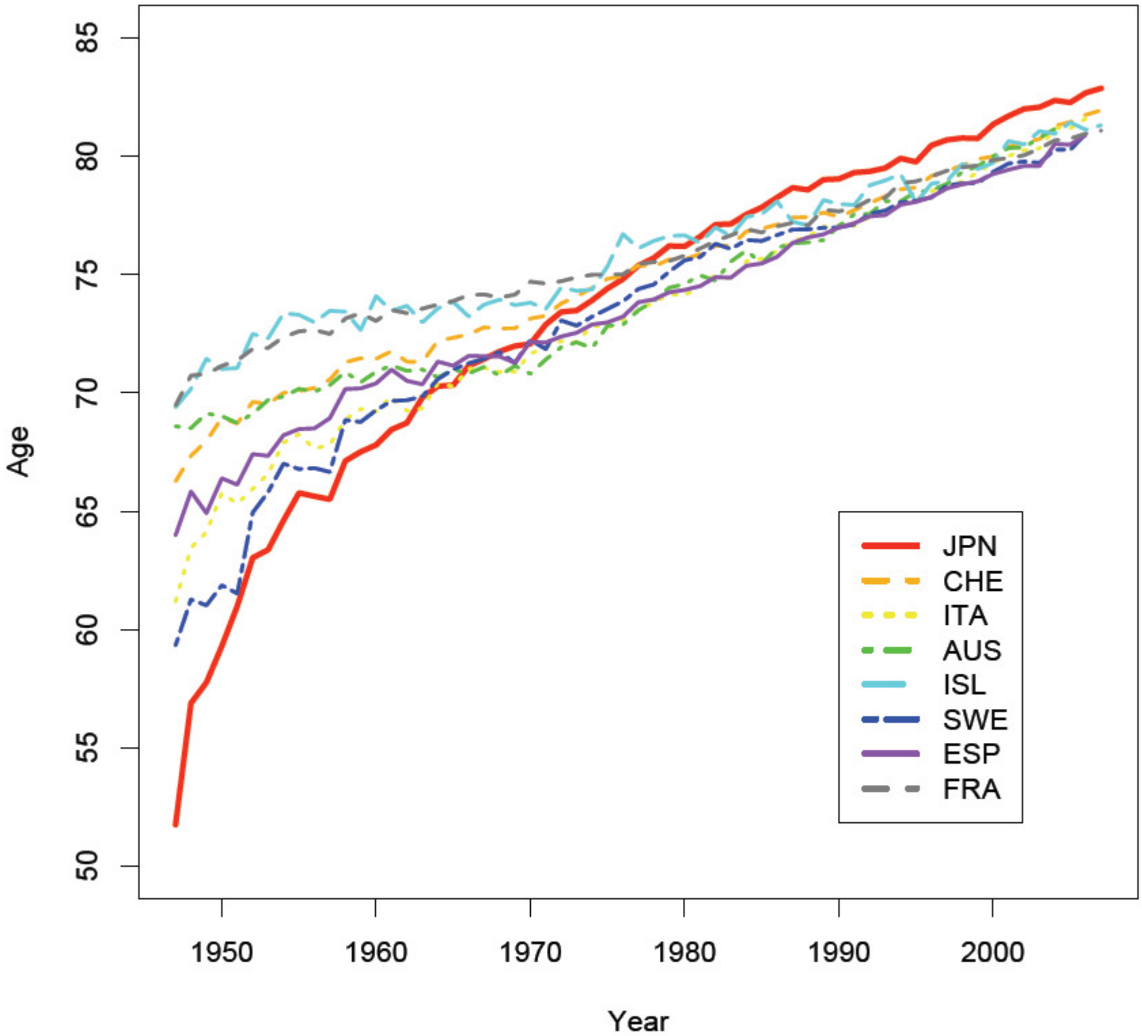
Note: the value of age x is found as the last age where the difference between another nation minus Japanes' truncated life expectancies is positive.

Figure 1. Truncated life expectancy difference: Japan minus Sweden, 2006.




Source: Human Mortality Database (2009)

Figure 2. Life expectancy at birth for the total population of selected countries in 2006: Australia, France, Iceland, Italy, Japan, Spain, Sweden, and Switzerland




Source: Human Mortality Database (2009)

Figure 3. Differences in temporary life expectancies between Japan and other selected nations.

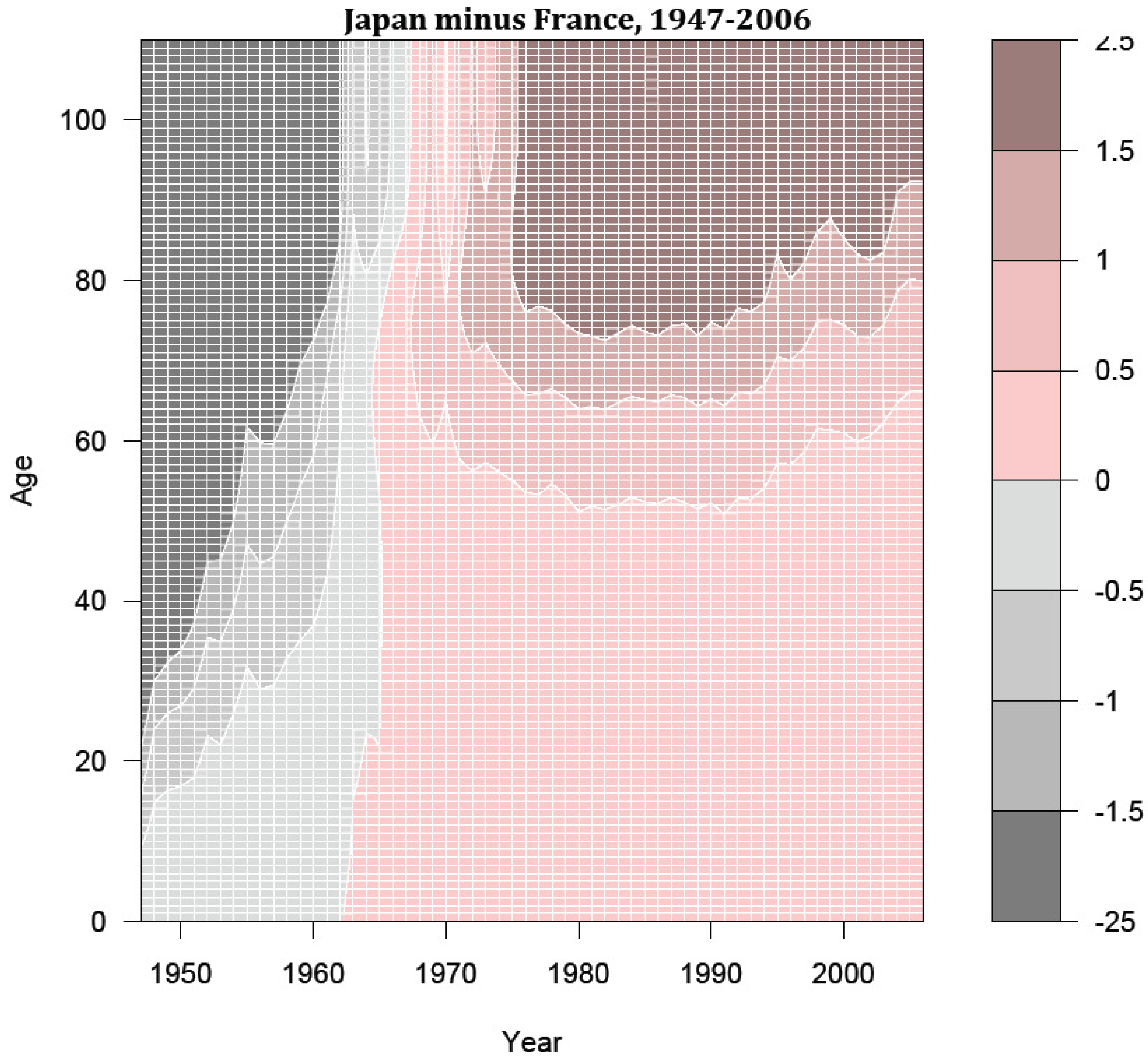


Figure 3. continue…

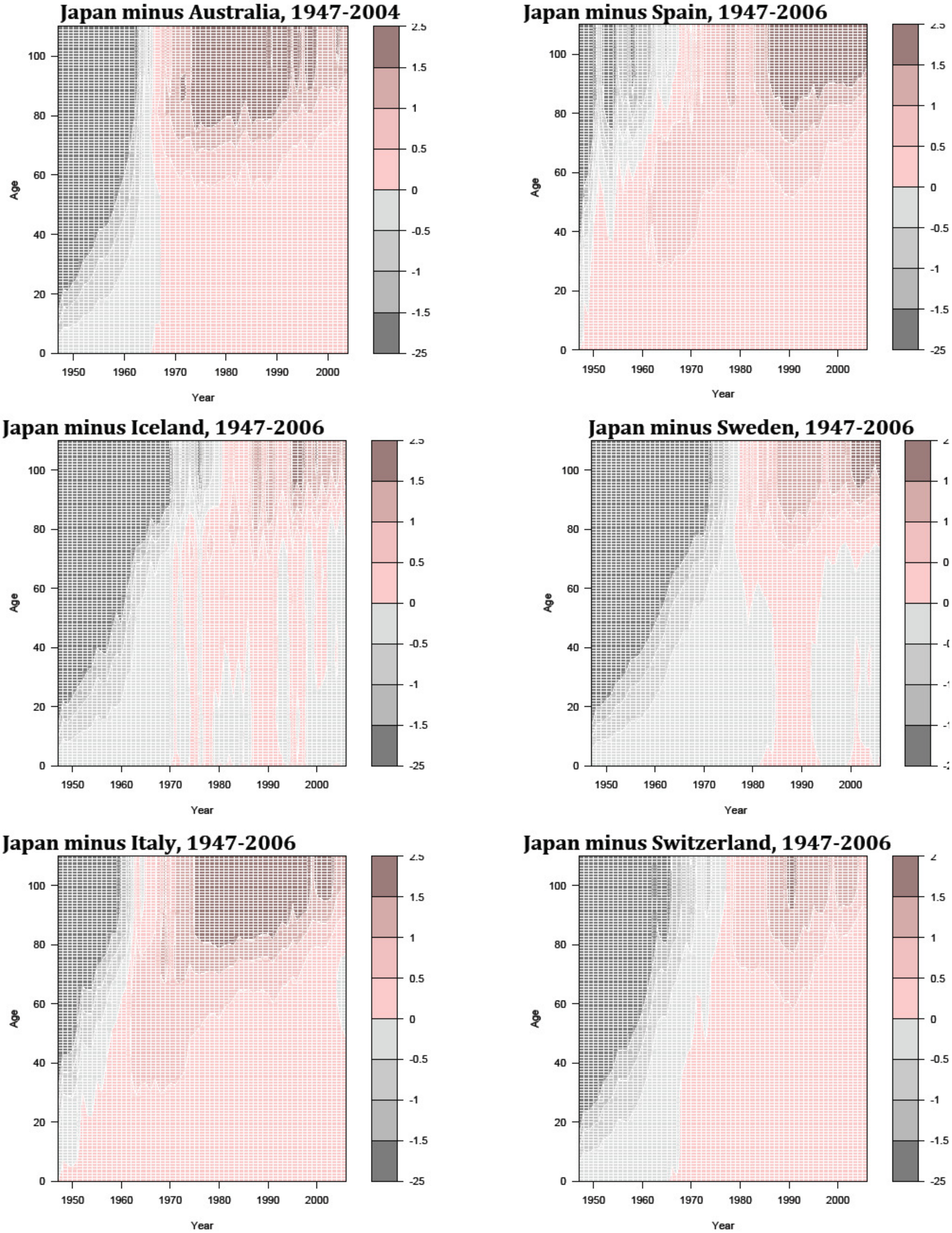
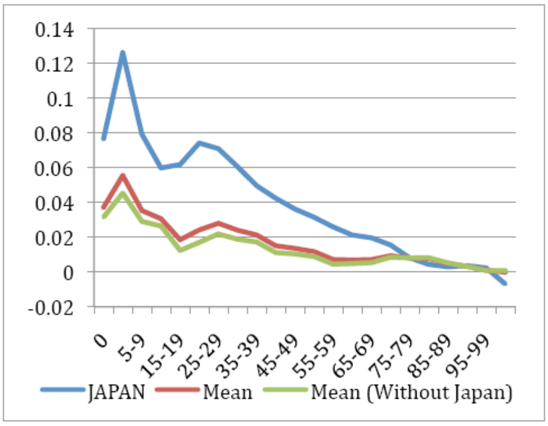
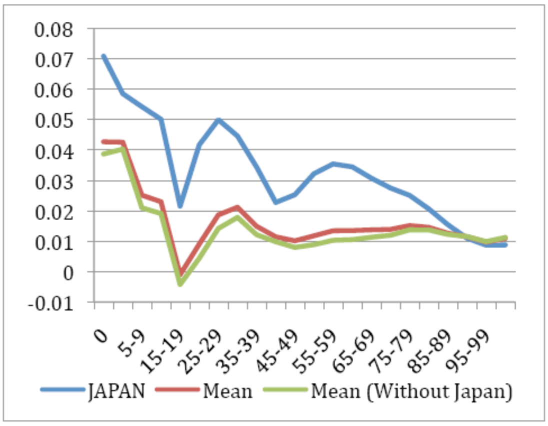


Figure 4. Age pattern of mortality decline for Japan, mean of selected nations with and without Japan in different time periods.

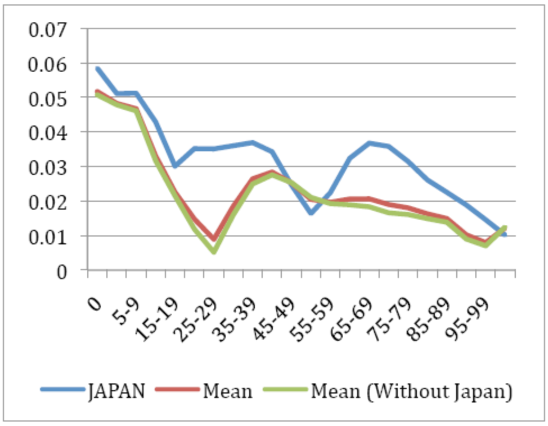
Between 1950-1959 and 1960-1969



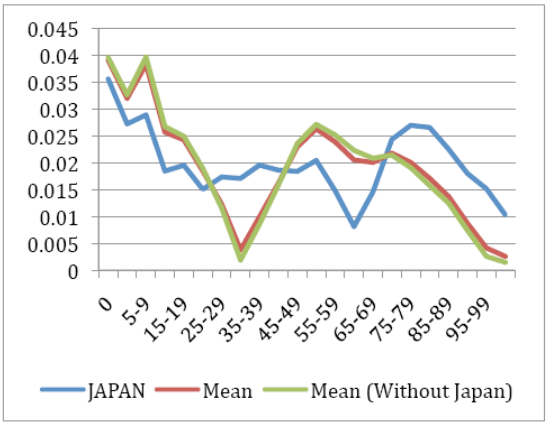

Between 1960-1969 and 1970-1979



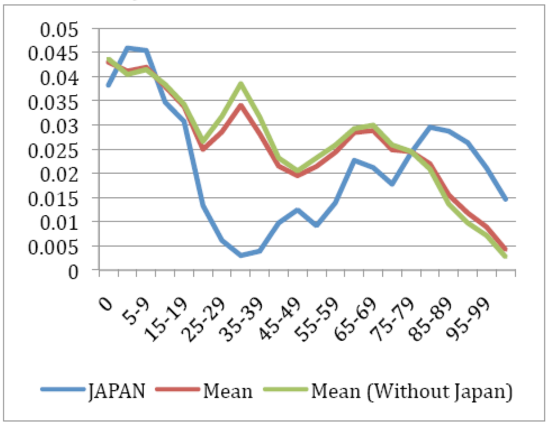

Between 1970-1979 and 1980-1989




Between 1980-1989 and 1990-1999




Between 1990-1999 and 2000-2006(or thereabouts)




Source: Human Mortality Database (2009)
Calculations: Our Own