Cohort Variability in Remaining Life Span at Retirement Age: Evidence from OECD Countries, Russia and Taiwan[†]

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Abstract

This paper investigates the variability of life span at retirement age in 28 developed and transition countries. We analyze trends in cohort mortality for selected OECD countries, Russia and Taiwan and predict life expectancy and inequality at age 60. We find that the average and the standard deviation of (remaining) life span are increasing in all countries but Russia. Average life span tends to increase more rapidly than the standard deviation, resulting in lower levels of relative inequality. We forecast that the life span distribution will continue to shift out and widen. Across birth cohorts 1930–1960, we predict increasing relative inequality in Russia and among Japanese women. In other countries, and among Japanese men, we predict lower relative inequality. The declines are expected to be particularly pronounced among men and in Western Europe. We discuss the findings in the context of the debate on limits to longevity and public pension reform.

Keywords: Mortality, Life Span Inequality, Retirement, OECD Countries, Russia, Taiwan.

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1 Introduction

Clear signs of population aging, such as a rising median age and old-age dependency ratios, are now evident in most countries. This trend is expected to accelerate dramatically in the coming decades, especially in developed and transition countries (e.g., Bloom and Canning 2008).[1] Longer average life spans for each successive cohort due to declining mortality profiles are contributing to this aging phenomenon (e.g., Yin and Bennett 2012).

The amount of resources societies will have to make available for future generations of retirees will crucially depend on the distribution of remaining life spans at retirement age. For example, estimates for the United States suggest that every year in life expectancy increases the outlays of the Social Security program by approximately 1 billion dollars. Without adjustments, the Trustees of Social Security expect that over a 75-year period, the program would require additional revenue equivalent to $8.6 trillion in present value dollars to pay all scheduled benefits (SSA-T 2012).

Looking at average life expectancy, however, provides an incomplete picture of how mortality at old age is affecting individuals' retirement well-being and, in turn, the finances of public pension programs. Individuals who live longer tend to be healthier and have higher lifetime earnings (e.g., De Nardi et al. 2009). Consequently, they also have a greater (annual) claim on pension wealth compared to individuals with average mortality from the same birth cohort.[2] For that reason, the variation or inequality of remaining life span is of particular interest.

In this paper we investigate the distribution of (remaining) life span at retirement age. We estimate models of cohort mortality for selected OECD countries, Russia and Taiwan and predict the distribution of the remaining years of life at age 60. In most countries, age 60 is an important milestone in the life course. Labor force participation rates tend to fall rapidly after age 60 and workers gain eligiblity to collect (reduced) retirement benefits around this age (Gruber and Wise 2005; SSA 2008/2009).[3] To compare the level of dispersion of remaining life span across generations and countries with different

[1] Estimates for the US suggest that there are currently 2.8 workers for each Social Security beneficiary. By 2033 there will be 2.1 workers for each beneficiary.

[2] We note that the health-earnings relationship is thought to be bi-directional.

[3] For example, in the US workers are eligible for early benefits at age 62.

averages, we distinguish between the *absolute* variability, measured by the standard deviation, and the *relative* variability, measured by the Coefficient of Variation (CoV).

The demographic literature has mainly focused on the distribution of life span at birth, that is the entire mortality profile. The seminal work in this area shows a pattern of rising average life span with declining variability over time as advances in medicine and hygiene significantly lowered mortality risks early in life (Fries 1980; Myers and Manton 1984; Wilmoth and Horiuchi 1999; Kannisto 2000, 2001).[4] Using historic data on Sweden, Japan and the United States, Wilmoth and Horiuchi (1999) compare 10 measures of (absolute) variability and show their close correlation. The pattern of declining inequality in life span has also been found in studies of the life span past age 10 ("adult mortality") (Edwards and Tuljapurkar 2005; Edwards 2011).

The variability of remaining life span at retirement age has received less attention. Individuals who reach retirement age are a more homogenous group as a result of mortality selection (Vaupel et al. 1979). However, the composition of the population of individuals who reach a given (nominal) longevity milestone, say age 60, has changed (e.g., Sanderson and Scherbov 2010). Due to medical advances in the treatment of many cancers and the treatment of cardiovascular disease, as well as changes in health behaviors (most notably a decline in smoking), the chances of survival to an older age for all individuals have improved considerably (e.g., Preston et al. 2012). As a result, the distribution of remaining length of life at that age may have become more unequal across cohorts, contrary to the documented trend of increasing mortality compression when the entire life course is considered (or after age 10).

Previous evidence from the analysis of deaths in the United States is consistent with the idea that the spread of the life span distribution at retirement age may not be narrowing. Myers and Manton (1984) report that the standard deviation of deaths above age 60 in the US increased between 1962 and 1979. Subsequent research on the ages at death between 1962 and 1984 by Rothenberg et al. (1991) showed the same pattern. Whether remaining life spans are becoming more concentrated is important for the ongoing debate on the existence of a limit to human longevity (Fries 1980; Olshansky et al. 1990; Oeppen and Vaupel 2002). In light of the US evidence, Wilmoth and Horiuchi (1999, p.476) wrote: *A fixed maximum*

[4]Evidence from in-depth studies on selected countries is also available. See, for example, Nusselder and Mackenbach (1996) for evidence from the Netherlands, Paccaud et al. (1998) for Switzerland, and Cheung and Robine (2007) for Japan.

human life span must result in a continued compression of mortality as death rates decline; therefore the failure to observe such a compression suggests either that no limit exists or that it is not currently in sight.

We analyze old-age mortality profiles of cohorts born since 1900 in 28 developed and transition countries. To our knowledge this is the most comprehensive analysis of remaining life span at retirement age to date. Unlike previous research, we also investigate the variability of life span relative to the mean, allowing us to compare the degree of inequality of life span across cohorts and populations with very different average life spans. We find that, with few exceptions, average remaining life span is increasing at a faster rate than the standard deviation, resulting in a decline in the *relative* dispersion of life span. We project that the distribution of life span at age 60 will continue to shift out and widen. Relative inequality in life span will rise in Russia and among Japanese women across the 1930 and 1960 birth cohorts. In other countries, and among Japanese men, we predict lower relative inequality. The decline is expected to be more pronounced for men and in Western Europe.

2 Methods and Data

To analyze trends in the distribution of mortality at retirement age, we estimate modified logistic models of mortality conditional on survival to age 60 with cohort trends. The standard logistic form, first proposed by Perks (1932) and also known as the Kannisto model, assumes that the death rate, $\mu_a(i)$, at exact age a for birth cohort i takes the form:

$$\mu_a(i) = \frac{\beta\gamma^a}{1+\beta\gamma^a}. \quad (1)$$

The logistic form (1) is known to fit mortality at older ages particularly well (e.g., Thatcher et al. 1998). We enhance the logistic model in two important ways. First, we generalize the form by including a quadratic term for age. Next, we add a cohort trend component to allow for systematic mortality change across generations. The resulting modified Kannisto model takes the following form:

$$\mu_a(i) = \frac{\beta\gamma_1^a\gamma_2^{a^2}\delta^i}{1+\beta\gamma_1^a\gamma_2^{a^2}\delta^i}. \tag{2}$$

Convenient for estimation, the logit of $\mu_a(i)$ is linear in age, age squared and cohort:

$$logit(\mu_a(i)) = \ln(\beta) + \ln(\gamma_1)\cdot a + \ln(\gamma_2)\cdot a^2 + \ln(\delta)\cdot i = \beta' + \gamma_1'\cdot a + \gamma_2'\cdot a^2 + \delta'\cdot i, \tag{3}$$

where $\beta' \equiv \ln(\beta), \gamma_1' \equiv \ln(\gamma_1), \gamma_2' \equiv \ln(\gamma_2)$ and $\delta' \equiv \ln(\delta)$ are parameters to be estimated for the constant, age, age squared and cohort, respectively.

Given actual or predicted death rates, the probability of dying between exact ages a and $a+1$, $q_a(.)$, can be approximated using the following formula:

$$q_a(i) \simeq 1 - \exp(-\mu_{a+0.5}(i)). \tag{4}$$

The approximation is exact if the death rates are constant (e.g., Thatcher et al. 1998).

We estimate models of this form using recent cohort death rates for 28 countries. The data files were extracted from the Human Mortality Database (www.humanmortality.org), the premier source of historic mortality data. We employ single year death rates at ages 60-109 for male and female birth cohorts starting from 1900 (cohort 1900 is denoted by $i = 1$). We also analyze overall death rates in each country.[5]

For each country, observed and projected death rates based on the fitted models are combined to construct the mortality profiles ages 60 to 110 for all cohorts up to birth year 1960. For example, for the 1930 birth cohort in the United States (US), we combine the observed death rates up to age 78 with the projected values for ages 79 to 110. For cohorts born after 1948, the survival curves are entirely based on projected values. Using the survival curves for each cohort, we obtain the distribution of the remaining years of life at age 60. The latter is used to calculate the mean and the standard deviation of

[5]As explained in the notes accompanying the files, single year data are sometimes the product of aggregate raw data, which have been split into single years of age using the methods described in the Methods Protocol. The original raw data are available for download from the HMD website.

the remaining life spans.

Using actual and predicted mortality, we calculate remaining life span at age 60 for cohorts 1900–1960. The life tables are used to calculate the average life span at age 60 (e60) and the standard deviation (s60). The standard deviation is a measure of how concentrated the life spans are around the mean remaining life span. Studies on the compression of mortality have used the standard deviation to describe changes in the inequality of life span (e.g., Myers and Manton 1984; Rothenberg et al. 1991; Wilmoth and Horiuchi 1999; Edwards 2011). If the mean is constant, a greater standard deviation in one population can be unambiguously viewed as evidence of greater inequality of life spans there. However, if the mean is greater in one population, then a greater standard deviation there is less convincing as evidence of greater inequality.

We can apply a stricter criterion to detect rising inequality in remaining life span by using the Coefficient of Variation (CoV). The CoV is the ratio of the standard deviation to the mean. It is a unit-free measure of the spread of a distribution relative to the mean ("relative inequality"). The CoV requires that the variable has non-negative values, a condition that holds by construction for measures of remaining years of life. Looking at the standard deviation and the CoV together enables us to make more nuanced comparisons of the dispersion of the remaining life span distribution across birth cohorts and across countries with different means.

We note that the need to distinguish between absolute and relative dispersion only arises when the standard deviation and the mean go in the same direction. As we discussed in the introduction, studies on life expectancy at birth or remaining life span at age 10 are dealing with a trend of a declining standard deviation and an increasing mean. In this case, reporting the CoV provides no additional insight over the standard deviation.

The underlying fundamental issue is that of a limit to longevity (Fries 1980; Olshansky et al. 1990; Oeppen and Vaupel 2002; Christensen et al. 2009). If there is a common maximum age for all humans, then we would expect the life span distribution to bump up against it. As that starts to happen, the standard deviation of the life span distribution would have to decline while the mean could still rise. In the absence of such a limit, we have no prior on how the distribution is expected to change. Hence, considering the possibility that the standard deviation increases more slowly than the mean—which would result in a decline in the CoV but not the standard deviation—seems appropriate.

3 Results

3.1 Estimation

Tables 4-11 shows the estimated coefficients β', γ_1', γ_2' and δ' of Model 3. We estimated country-specific OLS regressions using the male, female and overall death rates. For example, for the United States (US), our OLS estimates (robust standard errors in parentheses) for men are $\beta_M' = -4.27665$ (0.23952), $\gamma_{M,1}' = -0.03217$ (0.00644), $\gamma_{M,2}' = 0.00074$ (0.00004) and $\delta_M' = -0.01843$ (0.00014), and for women $\beta_W' = -5.03173$ (0.10002), $\gamma_{W,1}' = -0.04329$ (0.00265), $\gamma_{W,2}' = 0.00090$ (0.00002), and $\delta_W' = -0.09984$ (0.0002). R-squared (adjusted) is 0.996 for males and 0.998 for females. In the results tables we group the countries by region as follows: Northern Europe (Finland, Iceland, Norway and Sweden), Western Europe I (Ireland and United Kingdom), Western Europe II (Austria, Germany and Switzerland), Western Europe III (Belgium, Denmark, Luxembourg and Netherlands), Southwestern Europe (France, Italy, Portugal and Spain), Central Europe (Czech Republic, Poland and Slovakia), Eastern Europe (Estonia and Russia), North America (Canada and USA) and Asia Pacific (Australia, New Zealand, Japan and Taiwan). In the next section, we will discuss one country from each region in greater detail.

Figure 1 provides a comparison between the actual and projected probabilities of dying for the 1900 and the 1930 cohort in the US (men and women combined). Death rates are observed up to age 108 for the 1900 cohort and age 78 for the 1930 cohort. The modified logistic model fits the 1930 cohort data very well. For the 1900 cohort, the model predicts slightly greater mortality than observed during ages 78-98. The model captures the key change in the US age-mortality pattern, a proportional decline in age: across cohorts, mortality rates are lower overall but also rises more slowly with age. It is important to note that a parallel shift down in the mortality profile implies longer ...

To show the effects of the parameters, we examine how the predicted probabilities of death change if we substitute another countries' coefficient(s). We select a country with a different mean and standard deviation than the United States for the initial cohort (as observed in Tables 1 and 2), Sweden. Calculating the predicted probability for the US's 1900 and 1930 cohorts using Sweden's larger negative value of the constant term (substituting $\beta' = -6.9531$ for -4.1427), the model predicts a proportional decline in mortality risk profiles. Adopting the Swedish age pattern to the US (and keeping β' and δ' the same) increases the mortality risk profiles and changes the age pattern: the inflection point shifts towards a younger age and the mortality gap across the generations narrow in age. As illustrated by the 1930 cohort, applying the larger negative value of Sweden's cohort effect ($\delta' = -0.0166$) to the US, results in a proportionate decline in mortality risk.

3.2 Trends in the Distribution of Remaining Life Span

We present the results using a series of graphs, one for each country, showing the mean and the standard deviation of the remaining life span for birth cohorts 1900–1960. We also provide summary tables for means and standard deviation (see Tables 1 and 2). For males and females combined, we also report the mean and standard deviation when imputing unobserved death rates using observed mortality of preceding cohorts. This assumes no declines in mortality after 2009, providing a useful reference scenario.

In addition, we show the Coefficients of Variation for birth cohorts 1900, 1930 and 1960 by gender and country in Table 3. The table also reports the change in the CoV between cohorts 1900 and 1930 and between 1930 and 1960. These evenly-spaced cohorts are meant to provide useful reference points. For those born in 1900 the mortality experience is all but complete. For the 1930 cohort the mortality risk profile is observed up to age 78, or 18 years past age 60, which is approximately equal to the average remaining lifespan of individuals born in 1900. Thus, when looking at our results for the 1930 cohorts, it is important to remember that a significant part of the mortality trajectory has been realized; death rates after age 78 obtained from out-of-sample forecasts. The results for the 1960 cohorts are entirely based on predicted death rates.

Northern Europe: Finland, Iceland, Norway and Sweden

As shown in Figure 5(d), the Swedish 1900 birth cohort has an average remaining lifespan at age 60 of 19.7 years (17.7 for men and 21.6 for women). We predict that this number will increase to 23.3 years (21.2 for men and 25.1 for women) for the 1930 cohort and 27.1 years (25.5 for men and 28.3 for women) for the 1960 cohort.

The standard deviation for men and women combined is expected to increase from 9.3 to 10 years between the birth cohorts 1900 and 1930. We project a further increase to 10.5 years by the 1960 cohort. The increase is driven to a large extent by the variability of age at death among Swedish men who are experiencing an increase in the standard deviation from 8.8 to 9.8 years across the 1900-1930 cohorts and who are predicted to see their remaining years at age 60 deviate by 10.4 years from the average life expectancy by the 1960 cohort. For women the variability around the mean is forecast to increase slightly from 9.4 to 9.7 years across the 1900-1930 cohorts and is predicted to reach 10.1 years for the 1960 cohort.

The graphs show that the increases in the mean remaining years will likely outpace the increases in the standard deviation in Sweden. In turn, the relative dispersion of life spans is declining. This is confirmed by declining CoVs: The CoV for combined mortality decreases from 0.47 to 0.43 between cohorts 1900-1930 and is predicted to reach 0.39 for the 1960 birth cohort.

The distributions of remaining life span in Norway and Iceland are fairly similar to those of Sweden. As shown in Figure 5, Iceland displays greater average life spans and standard deviations than Sweden and Norway but the differences are projected to narrow across cohorts. In terms of the relative dispersion as measured by the CoV, the results are almost identical for the three countries (see Table 3.

Some notable differences exist between Finland and the other nordic countries. While the levels of (absolute) variation as measured by the standard deviation are comparable to Sweden and Norway, remaining life expectancy at age 60 is significantly greater in Finland. As a result, the life span distribution is relatively more dispersed in Finland. As shown in Table 3, the overall CoV is 0.53 for the 1900 Finnish birth cohort and is projected to fall to 0.46 by the 1930 cohort and 0.39 by the 1960 cohort. This compares to 0.47 for the 1900 cohorts, 0.42-0.44 for the 1930 cohort, and 0.38-0.40 for the 1960 cohorts in Sweden, Norway, and Iceland.

Western Europe I: Ireland and United Kingdom

As shown in Figure 9(b), the cohort born in 1900 in the UK has an average remaining life span at age 60 of 17.9 years (15.2 for men and 20.3 for women). We predict that life expectancy at age 60 will rise to 22.1 years (20.2 for men and 23.7 for women) for the 1930 cohort and 27 years (26.2 for men and 27.5 for women) for the 1960 cohort.

The standard deviation for men and women combined is expected to increase from 9.5 to 10.5 years between the birth cohorts 1900 and 1930. We project a further increase to 11.3 years by the 1960 cohort. The increase in variability around the average remaining life span reflects a trend apparent in both male and female old-age mortality. For men, the standard deviation of life spans is projected to increase to 10.2 years among those born in 1930 from 8.7 years for those born in 1900. British men born in 1960 are predicted to see their remaining years at age 60 deviate by 11.5 years from the average life expectancy. For women the variability is predicted to increase from 9.5 to 10.2 years across the 1900-1930 cohorts and is projected to reach 10.7 years by the 1960 cohort.

The graphs show that the increases in the mean remaining years are expected to outpace the trend of greater deviation from the mean. In turn, the relative dispersion of life spans is decreasing: The CoV for combined mortality is projected to decrease from 0.53 to 0.47 between cohorts 1900-1930 and it may reach 0.42 by the 1960 cohort.

As shown in Figure 9, the (projected) trend in the life span distribution in Ireland is similar to the UK. Average remaining life spans are lower across cohorts in Ireland while the standard deviations are similar in magnitude up to, approximately, the 1920 cohort. As a result, the relative dispersion among early Irish cohorts is lower than in the UK (see Table 3). This difference is expected to disappear over time as average remaining years are projected to rise faster relative to the standard deviations in Ireland than in the UK.

Western Europe II: Austria, Germany and Switzerland

As shown in Figure 3(a), the cohort born in 1900 in Austria has an average remaining life span at age 60 of 17.5 years (15.1 for men and 19.5 for women). We predict that life expectancy at age 60 will rise to 22.7 years (20.1 for men and 25.1 for women) for the 1930 cohort and 28.2 years (26 for men and 30.4 for women) for the 1960 cohort.

The standard deviation for men and women combined is expected to increase from 9 to 10.3 years between the birth cohorts 1900 and 1930, and reach 10.9 years by the 1960 cohort. The predicted increase in variability around the average life span reflects rising heterogeneity in old-age mortality, especially among Austrian men. The latter experience an increase in the standard deviation from 8.5 to 10.2 years across the 1900-1930 cohorts and are predicted to reach a standard deviation of 11.1 years by the 1960 cohort. For women the variability about the mean is predicted to increase from 9 to 9.9 years across the 1900-1930 cohorts and is projected to reach 10.5 years by the 1960 cohort.

The graphs show that the increases in the average remaining years will outpace the increases in the standard deviation. In turn, the relative dispersion of life spans is declining across Austrian cohorts. We forecast that the CoV for combined mortality will decrease gradually from 0.52 for Austrians born in 1900 to 0.39 for those born in 1960.

As shown in Figure 3, the (projected) trends in the life span distribution in Germany and Switzerland are very similar to Austria. Average remaining life spans are significantly higher in Switzerland and slightly lower in Germany. The early birth cohorts in Switzerland have higher standard deviations but we project a slower rise in (absolute) variability compared to Austria and Germany. As a result, the relative dispersion is expected to come down more rapidly in Switzerland between cohorts 1900 and 1930 (see Table 3). By the 1960 cohort, we project that all three countries will have similar standard deviations. Germany is expected to have the highest (relative) dispersion with a CoV of 0.40 (for males and females combined); Switzerland will have the lowest at 0.37.

Western Europe III: Belgium, Denmark, Luxembourg and Netherlands

As shown in Figure 4(d), the cohort born in 1900 in the Netherlands has an average remaining lifespan at 60 of 19.5 years (17.2 for men and 21.6 for women). We predict that this number will increase to 22.1 years (19.7 for men and 24.2 for women) for the 1930 cohort and 25.3 years (23.5 for men and 26.6 for women) for the 1960 cohort.

The standard deviation for men and women combined is predicted to rise from 9.4 to 9.9 years between the birth cohorts 1900 and 1930. A further increase to 10.3 years by the 1960 cohort is projected. The increase is driven almost entirely by Dutch men who are experiencing an increase in the standard deviation from 8.9 to 9.6 years across the 1900-1930 cohorts and whose distribution is predicted to reach a standard deviation of 10.2 years by the 1960 cohort. For women the variability around the mean is predicted to increase marginally from 9.4 to 9.6 across the 1900-1930 cohorts and is projected to increase to 9.8 years by the 1960 cohort.

The graphs show that the increases in the average remaining years will outpace the increases in the standard deviation. In turn, the relative dispersion of life spans is declining in the Netherlands across cohorts. We forecast that the CoV for combined mortality will decrease from 0.48 to 0.45 between cohorts 1900-1930 and reach 0.41 by the 1960 cohort.

As shown in Figure 4, the distributions of remaining life span across generations in Denmark are very similar to those in the Netherlands. Belgium and Luxembourg are noticeably different and similar to one another. The latter have lower life spans and variability for the 1900 cohort but are expected to see more rapid increases in both dimensions but especially in average life spans than Denmark and the Netherlands. As a result, we observe greater (relative) dispersion in Belgium and Luxembourg than in Denmark and the Netherlands for early cohorts but forecast more rapid declines in dispersion across generations and ultimately less dispersed distributions in the former countries (see Table 3).

Southwestern Europe: France, Italy, Portugal and Spain

As shown in Figure 8(a), the cohort born in 1900 in France has an average remaining life span at 60 of 19 years (16.3 for men and 21.5 for women). We predict that life expectancy at age 60 will rise to 24.3

years (21.1 for men and 27.2 for women) for the 1930 cohort and 29.4 years (26.5 for men and 32 for women) for the 1960 cohort.

The standard deviation of remaining years of life for men and women combined is expected to increase from 9.7 to 10.8 years between the birth cohorts 1900 and 1930. We project a further increase to 11.4 years by the 1960 cohort. The increase in variability around the average remaining life span reflects greater variability in life spans among both the male and the female population. For men, the standard deviation of life spans is projected to increase to 10.5 years among those born in 1930, up from 9.1 years for those born in 1900. French men born in 1960 are predicted to see their remaining years vary about the average life expectancy by 11.2 years. For women the standard deviation is predicted to gradually increase from 9.6 to 10.9 across the 1900-1960.

The graphs show that the mean remaining years are expected to increase faster than the standard deviation. In turn, the dispersion of life spans is decreasing in France: The CoV for the total population is projected to decrease from 0.51 to 0.39 across birth cohorts 1900-1960.

As shown in Figure 8, the (projected) trends in the life span distribution in Italy, Spain and Portugal are quite similar to France. The average remaining life spans and standard deviations are lower in Portugal. The variation of life spans relative to the average (CoV) ranges from 0.47 in Portugal to 0.51 in France for the 1900 birth cohort (combined data). We predict that the dispersion will decline and cross-country differences will narrow over time. By the 1960 cohort, we project that the CoV will reach 0.39-0.41 for these Southwestern European countries (see Table 3).

Central Europe: Czech Republic, Poland and Slovakia

As shown in Figure 6(b), the average life span of the 1900 birth cohort in Poland is 18.1 years (15.9 for men and 19.8 for women). This number is expected to increase to 19.3 years (16.4 for men and 22 for women) for the 1930 cohort and 21.2 years (17.8 for men and 24.6 for women) for the 1960 cohort.

The standard deviation for men and women combined increased from 8.9 to 9.9 years between the birth cohorts 1900 and 1930. We project a further increase to 10.1 years by the 1960 cohort. The increase is driven by male and female mortality which are experiencing increases. For men the standard deviation is forecast to increase from 8.5 to 9.5 years across the 1900-1930 cohort and is predicted to remain at 9.5 years by the 1960 cohort. The standard deviation among the female population is expected to reach 9.7 years for the 1930 cohort and 10.1 years for the 1960 cohort, compared to 8.9 years for the 1900 cohort.

The graphs show that the increases in the standard deviation of life spans are projected to outpace the increases in the mean for cohorts born up to 1930. For cohorts born after that the increase in the mean dominates. As a result the dispersion as measured by the CoV is projected to rise across the 1900-1930 cohorts and decline across the 1930-1960 cohorts. The overall CoV increases from 0.49 to 0.51 between cohorts 1900-1930 and is predicted to reach 0.47 by the 1960 cohort.

The trend in the distribution of remaining life span in Slovakia is similar to Poland. As shown in Figure 6, Slovakia displays similar levels of longevity for the initial cohort but lower (absolute) variability. While the mean and the spread are predicted to rise across cohorts, we predict that the levels remain below those of Poland. In terms of the relative dispersion, similar as in the case of Poland, we forecast an increase from 0.49 to 0.51 across the 1900-1930 cohorts, followed by a decline to 0.48 (see Table 3.

More notable differences exist between Poland and the Czech Republic. While the average life spans are lower for the 1900 cohort in the Czech Republic than in Poland, they are projected to be greater by the 1960 cohort. The standard deviation is lower initially and comparable to levels predicted for Poland by the 1960 cohort. Taken together, this evolution will result in a distribution that is much less dispersed in the Czech Republic than in either Poland or Slovakia (see Table 3).

Eastern Europe: Estonia and Russia

As shown in Figure 7(b), the cohort born in 1900 in Russia has an average remaining life span at age 60 of 17.9 years (14.8 for men and 19.2 for women). We predict that this number will decrease to 16.6 years (13.6 for men and 19.1 for women) for the 1930 cohort and 15.1 years (12.5 for men and 18.2 for women) for the 1960 cohort. These are the shortest life spans among the 28 developed and transition countries considered here and Russia is the only country where life spans are expected to decline. Furthermore, the absolute difference in life expectancy between men and women is among the largest in our set of countries. Cockerham (2012) reviews the social determinants of Russian mortality with a focus on gender differences. He identifies stress and negative health lifestyles as the primary causes for higher mortality rates for women and men, respectively.

We project that the standard deviation for men and women combined will increase slightly from 8.8 to 8.9 years between the birth cohorts 1900 and 1930. However, we predict a decline for subsequent cohorts to 8.2 years by the 1960 cohort. This is mostly driven by the variability of age at death among Russian men, who are forecast to experience a decrease in the standard deviation from 8.4 to 7.7 years across the 1930-1960 birth cohorts. Across those same cohorts, the variability around the mean number of remaining years is projected to decrease slightly from 8.8 to 8.6 for Russian women.

The graphs show that the projected decreases in the mean remaining years may outpace the decreases in the standard deviation. In turn, the dispersion of remaining years of life at age 60 may actually increase in Russia for both sexes. This is confirmed by increasing CoVs: For example, we predict that the CoV for combined mortality will increase from 0.49 to 0.53 between cohorts 1900-1930 and it may increase to 0.54 by the 1960 cohort. Shkolnikov et al. (2004) confirm this inequality in Russian life expectancy at birth using an alternate statistical method.[6] Russia is the only country for which we see a persistent trend of greater relative dispersion for males and females.

Remaining life expectancy at age 60 in Estonia is projected to change little across cohorts 1900-1930. For later cohorts, we predict increases average life spans (more pronounced for women) as shown in Figure 7). The spread of the distribution is expected to widen significantly across the 1900-1930 cohorts and decline modestly after that. As a result, remaining life spans are predicted to be more dispersed by the 1930 cohort than for the 1900 cohort but similarly dispersed by the 1960 cohort (see Table 3).

North America: Canada and United States

As shown in Figure 2(b), the average life span of the 1900 birth cohort in the US is 18.6 years (15.9 for men and 21 for women). This number is expected to increase to 22.3 years (20.5 for men and 23.8 for women) for the 1930 cohort and 25.9 years (25.1 for men and 26.1 for women) for the 1960 cohort.

The standard deviation for men and women combined increased from 10.3 to 10.6 years between the

[6] The authors utilize the average inter-individual difference in age of death, which is the product of the Gini coefficient of inter-individual inequality in age at death and the average life expectancy at birth.

birth cohorts 1900 and 1930. We project a further increase to 11.2 years by the 1960 cohort. The increase is driven by male mortality which is experiencing an increase in the standard deviation from 9.5 to 10.4 years across the 1900-1930 cohort and is predicted to reach 11.3 years by the 1960 cohort. For women the variability declined slightly from 10.4 to 10.3 years across the 1900-1930 cohorts but is projected to increase to 10.6 years by the 1960 cohort.

The graphs show that the increases in the average life span outpace the increases in the standard deviation of life span. As a result the dispersion of the distribution is declining, as evidenced by falling CoVs. Specifically, the overall CoV decreases from 0.55 to 0.47 between cohorts 1900-1930 and is predicted to reach 0.43 by the 1960 cohort. The greater decline in the dispersion for male mortality reflects the more dramatic gains in life expectancy among men compared to women in the US.

As shown in Figure 2, the (projected) trends in the life span distribution in Canada are very similar to the US. The average remaining life spans and standard deviations are projected to rise more in Canada than in the US. As in the US, we project a gradual decline in the dispersion of the distribution across cohorts (see Table 3).

Asia Pacific: Australia, New Zealand, Japan and Taiwan

As shown in Figure 10(c), the cohort born in 1900 in Japan has an average remaining life span at age 60 of 18.8 years (16.8 for men and 20.8 for women). We predict that life expectancy at age 60 will rise to 25.6 years (22.1 for men and 29 for women) for the 1930 cohort and 30.9 years (27.6 for men and 32.3 for women) for the 1960 cohort. The latter levels are the highest found among the set of developed and transition countries studied here.

The standard deviation for men and women combined is expected to increase from 9.8 to 11.2 years between the birth cohorts 1900 and 1930. We project a further sizeable increase to 12.8 years by the 1960 cohort. The increase in variability around the average life span is largely attributable to greater variability in female old-age mortality. The standard deviation of the life span of Japanese women is projected to reach 11.1 years among those born in 1930, up from 9.6 years for those born in 1900. Women born in 1960 who reach age 60 are predicted to see their remaining years deviate from average (remaining) life expectancy by 14.8 years. This is the greatest variability found in any of the 28 countries investigated here. For Japanese men the variability is predicted to increase from 9.2 to 12 years across the 1900-1960 cohorts.

Figure 10(c) shows that the increases in the mean remaining years of Japanese men are expected to outpace the increases in the standard deviation. We forecast that the opposite will hold for Japanese women born since 1930. Consequently, the dispersion of life spans is decreasing for Japanese men and, since the 1930 cohort, increasing for women: We forecast that the CoV for men will decrease from 0.55 to 0.47 between cohorts 1900-1930 and it may reach 0.41 by the 1960 cohort. The CoV for Japanese women is projected to reach 0.46 by the 1960 birth cohort, compared to 0.38 for the 1930 cohort and 0.47 for the 1900 cohort.

Average remaining life spans among the 1900 cohorts in Australia, New Zealand and Taiwan are lower than in Japan and we predict that this pattern will persist across cohorts (see Figure 10) despite rapid increases, especially in Australia. The (predicted) distributions in those countries also tend to be more concentrated around the mean. Taken together, this results in relative dispersion that is greater among the earlier birth cohorts than in Japan but declines more rapidly in Australia, New Zealand and Taiwan. By the 1960 cohort, we expect Coefficients of Variation of 0.39 for Australia, 0.41 for New Zealand and Japan, and 0.43 for Taiwan. This compares to 0.45 for Australia, 0.46 for New Zealand, 0.49 for Taiwan, and 0.44 for Japan for the 1930 (combined) birth cohorts (see Table 3).

4 Discussion and Conclusion

This research provides a comprehensive analysis of the cohort trends in the distribution of remaining life span at retirement age. We estimate models of cohort mortality for 28 countries—selected OECD countries, Russia and Taiwan—and project the distribution of the remaining years of life at age 60. Unlike previous research, we carefully distinguish between absolute and relative variability. We find that this distinction is important when looking at remaining life span, because, unlike in the case of life span analysis at birth (or age 10), at older age the mean and the standard deviation of the life span distribution are positively correlated.

Specifically, with few exceptions, we find that average remaining life span is increasing at a faster rate than the standard deviation, resulting in a decline in the *relative* dispersion of life span. We project that the distribution of life span at age 60 will continue to shift out and widen. We predict increasing relative dispersion of life span in Russia and among Japanese women across the 1930 and 1960 birth cohorts. In other countries and among Japanese men, we predict lower relative dispersion. The decline is expected to be more pronounced for men and in Western Europe.

Our analysis of life span past age 60 confirms a well-documented secular trend toward longer lives (Edwards 2011; Christensen et al. 2009). We forecast significant increases in retirement life spans for current and future generations. Our predictions extrapolate from the mortality experience of cohorts in the (more recent) past. Risk to these forecasts exists in the form of structural changes and uncertainty regarding the determinants of mortality (Bennett and Olshansky 1996; Olshansky et al. 2009). For example, the consequences of the obesity epidemic for remaining life spans have yet to be fully realized and understood (Preston et al. 2012; Olshansky et al. 2005).

If our predictions hold true, the outlays by Social Security programs for retirement benefits are likely to rise substantially. Moreover, the greater variation of remaining life span among future generations of retirees implies more uncertainty about the actual outlays by the program for these cohorts. Given estimates for the US that every year in average life span increases Social Security outlays by approximately 1 billion dollars, the 3.4 year increase in remaining life span at age 60 between birth cohorts 1930 and 1960 (see Table 1) may result in 3.4 billion dollars in additional expenses. The Social Security Administration has implemented increases in the Full Retirement Age (FRA), that is the age at which full benefits can be received (SSA-S 2012, Table 2.A17.1). The FRA is (gradually) rising from 65 for Americans born before 1938 to 67 for Americans born after 1959. However, given our predictions, the scheduled increases in the FRA in the US are likely insufficient to offset the longer life spans at age 60. The adjustments implemented in other developed countries may be similarly inadequate (e.g., Queisser and Whitehouse 2006).[7]

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[7] In December 2010 the National Commission on Fiscal Responsibility and Reform (NCFRR) proposed steps to address the long-run solvency problems of Social Security. The commission recommended that retirement benefits be reduced by

Since individuals who live longer tend to have higher lifetime earnings (e.g., De Nardi et al. 2009; Lee and Tuljapurkar 1997), they are expected to also have a greater (annual) claim on pension wealth compared to the average mortality individual in their birth cohort. Using data on individuals' pension wealth (Primary Insurance Amount, PIA) and longevity from the Health and Retirement Survey (HRS), a survey of a recent cohort of American retirees, we observe a correlation coefficient of 0.14 between PIA and remaining life span. While this is a modest level of correlation, it does suggest that longevity gains disproportionately benefit those who are better-off.

The evidence provided here also relates to the debate on whether there is a limit to human longevity (Olshansky et al. 1990; Oeppen and Vaupel 2002). If a common maximum age exists, then the life span distribution would encounter it at its end. As that starts to happen, the standard deviation of the life span distribution would have to decline. This could occur while the mean life span is still rising. The evidence from developed countries presented here and earlier evidence from the US (Myers and Manton 1984; Rothenberg et al. 1991) shows that the standard deviation has been increasing in developed and transition countries. This is certainly counter to the idea that populations are approaching a longevity limit.

indexing the retirement ages to approximate gains in life expectancy. Specifically, the NCFRR suggested that the Early Retirement Age (ERA) and the FRA be increased by one month every two years after FRA reaches age 67 under current law. According to their calculations, the ERA would increase to 63 by 2046 and 64 by 2070 while the FRA would reach 68 and 69 in those years.

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Table 1: **Average Remaining Life Span, Birth Cohorts 1900, 1930 and 1960**[a]

	Birth Cohort 1900				*Birth Cohort 1930*				*Birth Cohort 1960*			
	All	Male	Female	Imputed	All	Male	Female	Imputed	All	Male	Female	Imputed
Finland	17.54	14.87	19.65	17.54	22.79	19.84	25.45	22.39	28.29	25.84	30.76	23.34
Iceland	21.00	18.79	22.95	21.00	23.66	22.01	25.27	23.25	27.14	25.81	28.60	23.76
Norway	19.59	17.39	21.60	19.59	22.69	20.54	24.64	22.53	26.17	24.33	27.56	23.46
Sweden	19.68	17.66	21.57	19.68	23.30	21.23	25.14	23.08	27.07	25.46	28.28	23.94
Ireland	17.32	15.51	19.11	17.32	21.48	19.26	23.69	21.38	26.75	24.44	28.72	22.87
UK	17.92	15.19	20.28	17.92	22.13	20.24	23.71	21.90	26.95	26.21	27.45	23.22
Austria	17.52	15.10	19.51	17.52	22.73	20.14	25.09	22.29	28.22	26.00	30.38	23.29
Germany	17.67	15.34	19.61	17.67	22.20	19.58	24.63	21.75	27.32	25.05	29.67	22.56
Switzerland	19.35	16.80	21.49	19.35	24.35	21.79	26.59	23.87	29.32	27.26	31.07	24.70
Belgium	17.87	15.43	20.06	17.87	22.74	20.06	25.13	22.30	27.78	25.41	29.78	23.07
Denmark	19.15	17.09	21.03	19.15	20.57	18.88	22.02	20.62	22.95	21.80	23.66	21.99
Luxembourg	17.15	14.90	19.22	17.15	22.33	19.86	24.55	21.85	28.10	25.74	30.02	23.18
Netherlands	19.53	17.22	21.61	19.53	22.08	19.74	24.16	22.06	25.30	23.49	26.56	23.21
France	19.04	16.25	21.54	19.04	24.30	21.09	27.21	23.76	29.43	26.50	32.03	24.65
Italy	18.90	16.71	20.85	18.90	23.72	20.91	26.27	23.12	29.11	26.40	31.44	23.82
Portugal	18.99	16.89	20.61	18.99	22.28	19.72	24.72	21.75	26.61	23.78	29.51	22.76
Spain	19.40	17.17	21.14	19.40	23.78	20.94	26.77	23.31	28.33	24.98	32.00	24.20
Czech Republic	16.59	14.33	18.52	16.59	19.51	16.96	21.75	19.56	23.17	20.70	25.41	20.83
Poland	18.11	15.85	19.81	18.10	19.33	16.43	22.00	19.54	21.24	17.82	24.60	20.59
Slovakia	17.62	15.93	19.18	17.62	18.41	15.61	20.90	18.60	19.81	16.41	22.95	19.71
Estonia	18.38	15.47	19.98	18.38	18.31	14.97	21.13	18.68	19.65	15.72	23.48	20.20
Russia	17.90	14.84	19.20	17.90	16.66	13.64	19.09	17.08	15.19	12.49	18.19	17.56
Canada	18.95	16.49	21.47	18.95	23.45	21.25	25.29	22.97	27.93	26.35	28.76	23.59
USA	18.55	15.93	20.97	18.55	22.31	20.45	23.76	22.15	25.87	25.11	26.07	23.05
Australia	18.19	15.60	20.67	18.19	24.26	22.12	26.23	23.43	30.42	29.24	31.51	24.60
New Zealand	18.03	15.86	20.15	18.03	23.10	21.26	24.67	22.54	28.51	27.44	29.16	23.21
Japan	18.82	16.80	20.80	18.82	25.56	22.12	28.96	24.83	30.85	27.64	32.30	25.67
Taiwan					22.02	20.59	23.95	21.69	27.95	26.32	29.74	22.76

Notes: [a]Due to missing data the first cohort for Taiwan is 1910.

Table 2: **Standard Deviation of Remaining Life Span, Birth Cohorts 1900, 1930 and 1960**[a]

	Birth Cohort 1900				*Birth Cohort 1930*				*Birth Cohort 1960*			
	All	Male	Female	Imputed	All	Male	Female	Imputed	All	Male	Female	Imputed
Finland	9.38	8.76	9.32	9.38	10.41	10.25	9.87	9.91	11.17	11.38	10.62	9.39
Iceland	9.80	9.56	9.60	9.81	9.91	9.81	9.78	9.46	10.44	10.39	10.17	9.06
Norway	9.27	8.83	9.22	9.27	9.96	9.71	9.63	9.69	10.43	10.39	9.88	9.14
Sweden	9.31	8.81	9.36	9.30	9.96	9.75	9.69	9.60	10.48	10.39	10.07	9.08
Ireland	8.89	8.33	9.08	8.89	10.21	9.87	10.06	10.06	10.99	10.87	10.72	9.32
UK	9.47	8.65	9.51	9.46	10.47	10.24	10.19	10.12	11.28	11.46	10.66	9.47
Austria	9.04	8.49	8.99	9.04	10.33	10.19	9.90	9.81	10.91	11.09	10.50	9.26
Germany	9.02	8.45	9.03	9.02	10.33	10.02	10.00	9.83	10.95	10.87	10.64	9.29
Switzerland	9.61	9.10	9.50	9.61	10.26	10.15	9.77	9.75	10.74	10.84	10.15	9.20
Belgium	9.27	8.66	9.26	9.27	10.25	9.88	9.89	9.73	11.00	10.84	10.46	9.34
Denmark	9.41	8.90	9.47	9.41	9.97	9.65	9.90	9.96	10.22	10.12	9.89	9.37
Luxembourg	9.03	8.51	9.00	9.03	10.41	10.10	10.06	9.79	11.21	11.30	10.51	9.08
Netherlands	9.42	8.89	9.41	9.42	9.87	9.58	9.55	9.77	10.26	10.23	9.75	9.20
France	9.70	9.06	9.58	9.69	10.78	10.47	10.20	10.14	11.41	11.23	10.87	9.60
Italy	9.38	8.96	9.30	9.37	10.57	10.25	10.20	9.94	11.31	11.04	10.98	9.42
Portugal	8.93	8.64	8.84	8.92	10.10	9.82	9.92	9.45	10.94	10.68	10.87	8.88
Spain	9.41	9.10	9.31	9.41	10.31	10.06	10.07	9.75	10.97	10.76	11.08	9.23
Czech Republic	8.42	7.94	8.33	8.42	9.78	9.51	9.49	9.72	10.40	10.26	10.07	9.21
Poland	8.92	8.52	8.85	8.91	9.89	9.47	9.70	9.98	10.08	9.54	10.10	9.60
Slovakia	8.55	8.27	8.50	8.55	9.39	8.95	9.25	9.57	9.51	8.93	9.55	9.23
Estonia	8.77	8.30	8.62	8.77	9.77	9.09	9.66	10.11	9.67	8.97	9.77	9.68
Russia	8.77	8.38	8.63	8.77	8.93	8.36	8.77	9.42	8.32	7.74	8.57	9.40
Canada	10.14	9.43	10.23	10.14	10.67	10.35	10.31	10.14	11.34	11.27	10.69	9.77
USA	10.28	9.51	10.37	10.28	10.57	10.40	10.25	10.31	11.16	11.31	10.56	9.88
Australia	9.78	9.02	9.85	9.78	10.85	10.66	10.45	9.99	11.84	11.88	11.10	9.26
New Zealand	9.45	8.74	9.63	9.45	10.67	10.37	10.39	10.06	11.55	11.61	10.77	9.59
Japan	9.75	9.24	9.84	9.74	11.20	10.46	11.14	10.30	12.78	11.33	14.81	9.78
Taiwan					10.74	10.55	10.75	10.26	12.14	12.00	12.40	9.76

Notes: [a]Due to missing data the first cohort for Taiwan is 1910.

Table 3: **Coefficient of Variation (CoV) and Change in CoV, Birth Cohorts 1900, 1930 and 1960**[a]

	Coefficient of Variation									Change in CoV					
	Birth Cohort 1900			*Birth Cohort 1930*			*Birth Cohort 1960*			*All*		*Male*		*Female*	
	All	Male	Female	All	Male	Female	All	Male	Female	00-30	30-60	00-30	30-60	00-30	30-60
Finland	0.53	0.59	0.47	0.46	0.52	0.39	0.39	0.44	0.35	-0.08	-0.06	-0.07	-0.08	-0.09	-0.04
Iceland	0.47	0.51	0.42	0.42	0.45	0.39	0.38	0.40	0.36	-0.05	-0.03	-0.06	-0.04	-0.03	-0.03
Norway	0.47	0.51	0.43	0.44	0.47	0.39	0.40	0.43	0.36	-0.03	-0.04	-0.03	-0.05	-0.04	-0.03
Sweden	0.47	0.50	0.43	0.43	0.46	0.39	0.39	0.41	0.36	-0.05	-0.04	-0.04	-0.05	-0.05	-0.03
Ireland	0.51	0.54	0.47	0.48	0.51	0.42	0.41	0.44	0.37	-0.04	-0.06	-0.02	-0.07	-0.05	-0.05
UK	0.53	0.57	0.47	0.47	0.51	0.43	0.42	0.44	0.39	-0.06	-0.05	-0.06	-0.07	-0.04	-0.04
Belgium	0.52	0.56	0.46	0.45	0.49	0.39	0.40	0.43	0.35	-0.07	-0.05	-0.07	-0.07	-0.07	-0.04
Denmark	0.49	0.52	0.45	0.48	0.51	0.45	0.45	0.46	0.42	-0.01	-0.04	-0.01	-0.05	0.00	-0.03
Luxembourg	0.53	0.57	0.47	0.47	0.51	0.41	0.40	0.44	0.35	-0.06	-0.07	-0.06	-0.07	-0.06	-0.06
Netherlands	0.48	0.52	0.44	0.45	0.49	0.40	0.41	0.44	0.37	-0.04	-0.04	-0.03	-0.05	-0.04	-0.03
Austria	0.52	0.56	0.46	0.45	0.51	0.39	0.39	0.43	0.35	-0.06	-0.07	-0.06	-0.08	-0.07	-0.05
Germany	0.51	0.55	0.46	0.47	0.51	0.41	0.40	0.43	0.36	-0.05	-0.06	-0.04	-0.08	-0.05	-0.05
Switzerland	0.50	0.54	0.44	0.42	0.47	0.37	0.37	0.40	0.33	-0.08	-0.05	-0.08	-0.07	-0.07	-0.04
France	0.51	0.56	0.44	0.44	0.50	0.37	0.39	0.42	0.34	-0.07	-0.06	-0.06	-0.07	-0.07	-0.04
Italy	0.50	0.54	0.45	0.45	0.49	0.39	0.39	0.42	0.35	-0.05	-0.06	-0.05	-0.07	-0.06	-0.04
Portugal	0.47	0.51	0.43	0.45	0.50	0.40	0.41	0.45	0.37	-0.02	-0.04	-0.01	-0.05	-0.03	-0.03
Spain	0.49	0.53	0.44	0.43	0.48	0.38	0.39	0.43	0.35	-0.05	-0.05	-0.05	-0.05	-0.06	-0.03
Czech Republic	0.51	0.55	0.45	0.50	0.56	0.44	0.45	0.50	0.40	-0.01	-0.05	0.01	-0.06	-0.01	-0.04
Poland	0.49	0.54	0.45	0.51	0.58	0.44	0.47	0.54	0.41	0.02	-0.04	0.04	-0.04	-0.01	-0.03
Slovakia	0.49	0.52	0.44	0.51	0.57	0.44	0.48	0.54	0.42	0.02	-0.03	0.05	-0.03	0.00	-0.03
Estonia	0.48	0.54	0.43	0.53	0.61	0.46	0.49	0.57	0.42	0.06	-0.04	0.07	-0.04	0.03	-0.04
Russia	0.49	0.56	0.45	0.54	0.61	0.46	0.55	0.62	0.47	0.05	0.01	0.05	0.01	0.01	0.01
Canada	0.54	0.57	0.48	0.45	0.49	0.41	0.41	0.43	0.37	-0.08	-0.05	-0.08	-0.06	-0.07	-0.04
USA	0.55	0.60	0.49	0.47	0.51	0.43	0.43	0.45	0.40	-0.08	-0.04	-0.09	-0.06	-0.06	-0.03
Australia	0.54	0.58	0.48	0.45	0.48	0.40	0.39	0.41	0.35	-0.09	-0.06	-0.10	-0.08	-0.08	-0.05
New Zealand	0.52	0.55	0.48	0.46	0.49	0.42	0.41	0.42	0.37	-0.06	-0.06	-0.06	-0.06	-0.06	-0.05
Japan	0.52	0.55	0.47	0.44	0.47	0.38	0.41	0.41	0.46	-0.08	-0.02	-0.08	-0.06	-0.09	0.07
Taiwan				0.49	0.51	0.45	0.43	0.46	0.42		-0.05		-0.06		-0.03

Notes: [a]Due to missing data the first cohort for Taiwan is 1910.

Table 4: **Mortality Estimates[a]: Northern Europe (Finland, Iceland, Norway and Sweden)**

	Finland			Iceland			Norway			Sweden		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female	(10) All	(11) Male	(12) Female
Age	-0.0352	-0.0267	0.0128	-0.0131	-0.0138	0.0037	0.0115	0.0317	-0.0036	0.0095	0.0181	0.0126
[γ_1]	(0.01005)	(0.01637)	(0.00840)	(0.01525)	(0.01936)	(0.01889)	(0.01292)	(0.01566)	(0.01255)	(0.01170)	(0.01556)	(0.01142)
Age^2	0.0008	0.0007	0.0006	0.0007	0.0007	0.0007	0.0006	0.0004	0.0007	0.0006	0.0005	0.0006
[γ_2]	(0.00007)	(0.00011)	(0.00006)	(0.00010)	(0.00013)	(0.00013)	(0.00009)	(0.00010)	(0.00008)	(0.00008)	(0.00010)	(0.00008)
Cohort	-0.0229	-0.0237	-0.0251	-0.0155	-0.0166	-0.0150	-0.0153	-0.0167	-0.0138	-0.0166	-0.0184	-0.0149
[δ']	(0.00018)	(0.00025)	(0.00027)	(0.00050)	(0.00066)	(0.00078)	(0.00022)	(0.00032)	(0.00021)	(0.00017)	(0.00025)	(0.00018)
Constant	-4.5922	-4.2835	-7.2307	-6.1658	-5.8502	-7.3260	-6.9662	-7.3048	-7.1241	-6.9531	-6.9240	-7.6986
[β']	(0.37150)	(0.59972)	(0.31027)	(0.56222)	(0.70746)	(0.70275)	(0.47984)	(0.57813)	(0.46541)	(0.43503)	(0.57390)	(0.42490)
N	1,220	1,210	1,218	1,247	1,233	1,240	1,225	1,218	1,222	1,273	1,266	1,272
R^2	0.993	0.972	0.994	0.966	0.934	0.943	0.990	0.980	0.992	0.993	0.983	0.993

Notes: [a]Robust standard errors in parentheses.

Table 5: **Mortality Estimates[a]**: Western Europe I (Ireland and UK) and North America (Canada and US)

	Ireland			United Kingdom (UK)			Canada			United States (US)		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female	(10) All	(11) Male	(12) Female
Age	-0.0042	0.0651	-0.0105	0.0080	0.0274	0.0108	-0.0201	-0.0072	-0.0261	-0.0483	-0.0322	-0.0433
[γ_1]	(0.02072)	(0.01743)	(0.01598)	(0.00267)	(0.00915)	(0.00264)	(0.00311)	(0.01229)	(0.00341)	(0.00230)	(0.00644)	(0.00265)
Age^2	0.0006	0.0002	0.0007	0.0005	0.0004	0.0006	0.0007	0.0006	0.0008	0.0009	0.0007	0.0009
[γ_2]	(0.00014)	(0.00012)	(0.00011)	(0.00002)	(0.00006)	(0.00002)	(0.00002)	(0.00008)	(0.00002)	(0.00001)	(0.00004)	(0.00002)
Cohort	-0.0214	-0.0211	-0.0219	-0.0194	-0.0237	-0.0159	-0.0179	-0.0201	-0.0148	-0.0143	-0.0184	-0.0100
[δ']	(0.00037)	(0.00041)	(0.00037)	(0.00020)	(0.00021)	(0.00019)	(0.00016)	(0.00020)	(0.00015)	(0.00015)	(0.00014)	(0.00016)
Constant	-5.7269	-8.0446	-6.0012	-6.2077	-6.4661	-7.0059	-5.3398	-5.4378	-5.8257	-4.1427	-4.2767	-5.0317
[β']	(0.76826)	(0.64256)	(0.59416)	(0.10424)	(0.34124)	(0.10353)	(0.11599)	(0.45391)	(0.12746)	(0.08656)	(0.23952)	(0.10002)
N	1,218	1,214	1,218	1,225	1,225	1,225	1,128	1,128	1,128	1,225	1,225	1,225
R^2	0.976	0.970	0.984	0.998	0.994	0.998	0.998	0.992	0.998	0.998	0.996	0.998

Notes: [a]Robust standard errors in parentheses.

Table 6: **Mortality Estimates[a]: Western Europe II (Austria, Germany and Switzerland)**

	Austria			Germany			Switzerland		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female
Age	-0.0351	-0.0203	0.0013	-0.0013	-0.0066	0.0256	-0.0553	-0.0417	-0.0447
[γ_1]	(0.00877)	(0.01042)	(0.00808)	(0.00277)	(0.01199)	(0.00325)	(0.00564)	(0.01228)	(0.00618)
Age^2	0.0008	0.0007	0.0007	0.0006	0.0006	0.0005	0.0010	0.0009	0.0010
[γ_2]	(0.00006)	(0.00007)	(0.00005)	(0.00002)	(0.00008)	(0.00002)	(0.00004)	(0.00008)	(0.00004)
Cohort	-0.0224	-0.0230	-0.0243	-0.0204	-0.0213	-0.0225	-0.0214	-0.0225	-0.0215
[δ']	(0.00020)	(0.00022)	(0.00025)	(0.00019)	(0.00022)	(0.00021)	(0.00014)	(0.00020)	(0.00021)
Constant	-4.7603	-4.7822	-6.7901	-6.0424	-5.3666	-7.6651	-4.3097	-4.3665	-5.4250
[β']	(0.32575)	(0.38378)	(0.30081)	(0.10738)	(0.44473)	(0.12377)	(0.20850)	(0.45207)	(0.22920)
N	1,267	1,257	1,268	1,176	1,175	1,176	1,218	1,211	1,218
R^2	0.994	0.989	0.995	0.998	0.992	0.998	0.997	0.990	0.996

Notes: [a]Robust standard errors in parentheses.

Table 7: **Mortality Estimates[a]: Western Europe III (Belgium, Denmark, Luxembourg and the Netherlands)**

	Belgium			Denmark			Luxembourg			Netherlands		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female	(10) All	(11) Male	(12) Female
Age	-0.0272	-0.0285	-0.0099	-0.0074	0.0305	-0.0189	-0.0197	0.0172	-0.0192	-0.0172	0.0270	-0.0116
[γ_1]	(0.00551)	(0.01155)	(0.00581)	(0.00978)	(0.00970)	(0.00807)	(0.01651)	(0.01606)	(0.01958)	(0.00751)	(0.01503)	(0.00855)
Age^2	0.0008	0.0008	0.0007	0.0007	0.0004	0.0008	0.0007	0.0004	0.0008	0.0008	0.0005	0.0008
[γ_2]	(0.00004)	(0.00008)	(0.00004)	(0.00006)	(0.00006)	(0.00005)	(0.00011)	(0.00011)	(0.00013)	(0.00005)	(0.00010)	(0.00006)
Cohort	-0.0212	-0.0222	-0.0215	-0.0091	-0.0121	-0.0059	-0.0233	-0.0237	-0.0238	-0.0137	-0.0161	-0.0114
[δ']	(0.00017)	(0.00021)	(0.00023)	(0.00025)	(0.00029)	(0.00027)	(0.00034)	(0.00046)	(0.00051)	(0.00019)	(0.00029)	(0.00018)
Constant	-5.0187	-4.5477	-6.4124	-6.0609	-7.1141	-6.2280	-5.1343	-6.0425	-5.9028	-5.8844	-7.0813	-6.8752
[β']	(0.20538)	(0.42480)	(0.21634)	(0.36356)	(0.35822)	(0.30026)	(0.60639)	(0.58465)	(0.71931)	(0.27936)	(0.55493)	(0.31797)
N	1,217	1,211	1,217	1,221	1,212	1,221	1,202	1,191	1,199	1,225	1,218	1,225
R^2	0.997	0.990	0.996	0.992	0.988	0.993	0.977	0.957	0.972	0.996	0.985	0.996

Notes: [a]Robust standard errors in parentheses.

Table 8: **Mortality Estimates[a]: Southwestern Europe (France, Italy, Portugal and Spain)**

	France			Italy			Portugal			Spain		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female	(10) All	(11) Male	(12) Female
Age	-0.0477	-0.0546	-0.0210	-0.0067	-0.0267	0.0146	0.0706	0.0640	0.0933	0.0116	0.0026	0.0398
[γ_1]	(0.00334)	(0.01122)	(0.00433)	(0.00318)	(0.01514)	(0.00377)	(0.00997)	(0.01146)	(0.00897)	(0.00462)	(0.01172)	(0.00701)
Age^2	0.0009	0.0009	0.0008	0.0006	0.0007	0.0006	0.0002	0.0002	0.0001	0.0005	0.0006	0.0004
[γ_2]	(0.00002)	(0.00007)	(0.00003)	(0.00002)	(0.00010)	(0.00002)	(0.00007)	(0.00008)	(0.00006)	(0.00003)	(0.00008)	(0.00005)
Cohort	-0.0213	-0.0212	-0.0231	-0.0222	-0.0215	-0.0241	-0.0190	-0.0175	-0.0226	-0.0193	-0.0166	-0.0256
[δ']	(0.00014)	(0.00015)	(0.00021)	(0.00019)	(0.00026)	(0.00018)	(0.00028)	(0.00027)	(0.00032)	(0.00021)	(0.00020)	(0.00026)
Constant	-4.2756	-3.5511	-6.1209	-5.8796	-4.7293	-7.3639	-8.8608	-8.1959	-10.2976	-6.8226	-6.0724	-8.4722
[β']	(0.12547)	(0.41769)	(0.16176)	(0.12103)	(0.55878)	(0.14128)	(0.37240)	(0.42232)	(0.33622)	(0.17295)	(0.43487)	(0.26287)
N	1,225	1,225	1,225	1,176	1,175	1,176	1,224	1,218	1,224	1,225	1,224	1,225
R^2	0.998	0.994	0.997	0.998	0.987	0.998	0.992	0.987	0.993	0.997	0.992	0.996

Notes: [a]Robust standard errors in parentheses.

Table 9: **Mortality Estimates[a]: Central Europe (Czech Republic, Poland and Slovakia)**

	Czech Republic			Poland			Slovakia		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female
Age	0.0347	0.0338	0.0825	0.0793	0.1342	0.1089	0.0164	-0.0074	0.0842
[γ_1]	(0.00517)	(0.01371)	(0.00747)	(0.00945)	(0.01324)	(0.00977)	(0.01209)	(0.01515)	(0.00630)
Age^2	0.0004	0.0003	0.0002	0.0001	-0.0003	-0.0000	0.0005	0.0006	0.0002
[γ_2]	(0.00003)	(0.00009)	(0.00005)	(0.00006)	(0.00009)	(0.00006)	(0.00008)	(0.00010)	(0.00004)
Cohort	-0.016	-0.0159	-0.0172	-0.0087	-0.0064	-0.0125	-0.0064	-0.0029	-0.0100
[δ']	(0.00031)	(0.00035)	(0.00032)	(0.00031)	(0.00033)	(0.00032)	(0.00029)	(0.00037)	(0.00025)
Constant	-7.1853	-6.6081	-9.7314	-9.0638	-10.5755	-10.8438	-6.8481	-5.5289	-10.0399
[β']	(0.19999)	(0.50855)	(0.28138)	(0.35479)	(0.49395)	(0.36539)	(0.44963)	(0.56172)	(0.23605)
N	1,220	1,216	1,221	1,225	1,225	1,225	1,217	1,211	1,217
R^2	0.993	0.977	0.994	0.988	0.975	0.991	0.989	0.975	0.995

Notes: [a]Robust standard errors in parentheses.

Table 10: **Mortality Estimates[a]: Eastern Europe (Estonia and Russia)**

	Estonia			Russia		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female
Age	-0.0001	-0.0032	0.0642	0.0571	0.0717	0.1225
[γ_1]	(0.00686)	(0.01543)	(0.00681)	(0.00594)	(0.00655)	(0.00556)
Age^2	0.0006	0.0006	0.0003	0.0003	0.0001	-0.0001
[γ_2]	(0.00004)	(0.00010)	(0.00004)	(0.00004)	(0.00004)	(0.00004)
Cohort	-0.0046	-0.0019	-0.0100	0.0057	0.0047	0.0019
[δ']	(0.00039)	(0.00043)	(0.00044)	(0.00032)	(0.00031)	(0.00030)
Constant	-6.1616	-5.4266	-9.2274	-8.4951	-8.1712	-11.6197
[β']	(0.26285)	(0.56783)	(0.26094)	(0.22504)	(0.24708)	(0.21101)
N	1,259	1,248	1,259	1,275	1,274	1,275
R^2	0.985	0.949	0.987	0.99	0.985	0.993

Notes: [a]Robust standard errors in parentheses.

Table 11: **Mortality Estimates[a]: Asia Pacific (Australia, New Zealand, Japan and Taiwan[b])**

	Australia			New Zealand			Japan			Taiwan		
	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female	(7) All	(8) Male	(9) Female	(10) All	(11) Male	(12) Female
Age	-0.0338	-0.0275	-0.0290	-0.0158	0.0070	-0.0496	0.0195	0.0118	0.0148	0.0304	0.0233	0.0651
[γ_1]	(0.00502)	(0.01206)	(0.00469)	(0.01064)	(0.01562)	(0.02218)	(0.00301)	(0.00945)	(0.00369)	(0.01249)	(0.01612)	(0.00603)
Age^2	0.0008	0.0007	0.0008	0.0007	0.0005	0.0009	0.0004	0.0005	0.0005	0.0003	0.0004	0.0002
[γ_2]	(0.00003)	(0.00008)	(0.00003)	(0.00007)	(0.00010)	(0.00015)	(0.00002)	(0.00006)	(0.00002)	(0.00008)	(0.00011)	(0.00004)
Cohort	-0.0259	-0.0285	-0.0238	-0.0221	-0.0251	-0.0191	-0.0255	-0.0215	-0.0321	-0.0243	-0.0231	-0.0267
	(0.00020)	(0.00023)	(0.00018)	(0.00029)	(0.00037)	(0.00031)	(0.00021)	(0.00017)	(0.00023)	(0.00020)	(0.00028)	(0.00020)
Constant	-4.6101	-4.4141	-5.5068	-5.2712	-5.7501	-4.6413	-6.8228	-6.3527	-7.0774	-6.6537	-6.0971	-8.4045
	(0.18765)	(0.44678)	(0.17494)	(0.39481)	(0.57616)	(0.81790)	(0.11549)	(0.35210)	(0.13886)	(0.47016)	(0.60595)	(0.22738)
N	1,225	1,222	1,225	1,172	1,168	1,171	1,225	1,225	1,225	1,218	1,216	1,218
R^2	0.997	0.990	0.997	0.990	0.978	0.979	0.997	0.994	0.997	0.990	0.980	0.996

Notes: [a]Robust standard errors in parentheses. [b]Due to missing data the first cohort for Taiwan is 1910.

Figure 1: Actual and predicted probability of dying, United States, cohorts 1900 and 1930.

(a) Canada

(b) USA

Figure 2: Life Span past Age 60, Average and Standard Deviation, Canada and USA. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Austria

(b) Germany

(c) Switzerland

Figure 3: Life Span past Age 60, Average and Standard Deviation, Austria, Germany and Switzerland. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Belgium

(b) Denmark

(c) Luxembourg

(d) Netherlands

Figure 4: Life Span past Age 60, Average and Standard Deviation, Belgium, Denmark, Luxembourg and the Netherlands. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Finland

(b) Iceland

(c) Norway

(d) Sweden

Figure 5: Life Span past Age 60, Average and Standard Deviation, Denmark, Finland, Iceland, Norway and Sweden. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Czech Republic

(b) Poland

(c) Slovakia

Figure 6: Life Span past Age 60, Average and Standard Deviation, Czech Republic, Poland and Slovakia. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Estonia

(b) Russia

Figure 7: Life Span past Age 60, Average and Standard Deviation, Estonia and Russia. (Source: Authors' calculation based on cohort life table data and projections.)

(a) France

(b) Italy

(c) Portugal

(d) Spain

Figure 8: Life Span past Age 60, Average and Standard Deviation, France, Italy, Portugal and Spain. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Ireland

(b) UK

Figure 9: Life Span past Age 60, Average and Standard Deviation, Ireland and UK. (Source: Authors' calculation based on cohort life table data and projections.)

(a) Australia

(b) New Zealand

(c) Japan

(d) Taiwan

Figure 10: Life Span past Age 60, Average and Standard Deviation, Australia, New Zealand, Japan and Taiwan. (Source: Authors' calculation based on cohort life table data and projections.)