Future mortality improvements in the G7 countries

This paper provides projections of future life expectancy for the G7 countries. It is shown that a continuing increase in life expectancy is probable in all considered countries

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Introduction

Life expectancy at birth in high developed countries has increased significantly over the last 50 years, for example, by about nine years in the USA, 11 years in Germany and even 17 years in Japan. In the recent past, this development has come along with another phenomenon. The increase in male life expectancy has been higher than in female life expectancy in six of the seven G7 countries. For example, from 1980 to 2003, male life expectancy at birth rose by 5.7 years in England and Wales whereas female life expectancy at birth increased by 3.9 years. Only in Japan, the increase in female life expectancy (6.6 years) exceeds the corresponding rise in male life expectancy (5.1 years) in this period. The question is now, if these trends – an increasing life expectancy and an accelerating decline in male mortality – will persist in the future. Moreover, the assessment of the future behaviour of life expectancy is important for the (financial) stability of social security systems and the life insurance and pension industry. For example, most premium and risk capital calculations of life insurers are based on life tables which summarise the mortality rates of a population. The German Institute of Actuaries (DAV 2004) considers the accurate projection of future death rates as one of the most pressing issues in the German insurance and pension industry.

The paper is organised as follows. The next section starts with the data description and an investigation of the goodness of fit of the used mortality model. Thereafter, we present the results of our projections[1] for life expectancy – due to practical applicability – at age 30 and 60 over the time horizon 2003 to 2050 for the G7 countries for period and cohort perspective. Then, we analyse the effect of changes in the observation horizon of the used data on the results for life expectancy. Finally, we illustrate our findings by calculating a single net premium for a deferred annuity.

Material and Methods

The mortality model that follows will be applied to death rates $q_x(t)$ obtained from the Human Mortality Database (www.mortality.org, downloaded 26 April 2007). In addition to deaths and population, this database contains life tables with death rates depending on sex, individual age x and observation year t for 26 countries. For our purposes, we select the G7 countries which are highly developed and comprise a sufficiently large population size: Canada, England and Wales, France, Germany, Italy, Japan and the United States of America.[2] For the considered countries, the data are recorded for time horizons having different lengths. We choose the common time horizon from 1957 to 2003, for which historical data are available in all of these countries.

To project future death rates we use the log-linear model of Bomsdorf and Trimborn (1992).[3] In their approach, one-year death rates $q_x(t)$ depend on age x and year t. More precisely, the age specific death rates $q_x(t)$ depend log-linearly on the observation year t:

$$q_x(t) = e^{\alpha_x + \beta_x \cdot t}$$

Thus, the parameters α_x and β_x are age specific. The sex indexing is suppressed for notational convenience. In order to incorporate the current death rate (at time $t0$)[4], this log-linear function will be rewritten as:

$$q_x(t) = q_x(t_0) \cdot e^{\beta_x \cdot (t - t_0)}$$

The expression e^{β_x} is interpreted as an age specific growth factor (or reduction factor). More precisely, $100 \cdot (e^{\beta_x} - 1)$ shows the annual percentage change in death rates of x-year old persons: $\beta_x < 0$ indicates a decline of $q_x(t)$, whereas $\beta_x > 0$ implies an increase of $q_x(t)$. The growth rates β_x are estimated for ages

1 The following calculations should be interpreted as projections. They illustrate, what would happen if the current mortality trends persisted in the future. For a forecast, a stochastic model would be needed, which could consider the uncertainties about the future development and allows for the specification of confidence intervals; see e.g. Tuljapurkar (2000) or Babel/Bomsdorf/Schmidt (2007b) for stochastic forecasts of death rates and life expectancy.

2 Note that for small population sizes, no or very few deaths are observable in the lower age groups. We consequently use West German life tables, which is in line with Bomsdorf (2004) and Babel/Bomsdorf/Schmidt (2007b).

3 The DAV (2004) analysed several deterministic projection models for German death rates with different cohort and period trend-functions and came to the conclusion that a log-linear approach (log-linear with time) is most suitable (see also Lee/Carter, 1992, and Helberger/Rathjen, 1998). Concerning the relationship and comparison of the approach of Bomsdorf/Trimborn (1992) to other mortality models, we refer to Babel/Bomsdorf/Schmidt (2007a). A review of the literature on mortality models is given in Pitacco (2004) and Booth et al. (2005). Tuljapurkar et al. (2000) also provide projections for the G7 countries based on the popular stochastic model of Lee/Carter (1992); however, they only use the period approach, which causes a systematic underestimation of life expectancy.

4 The insertion of the most recently available mortality rate, as initial value, into the mortality projection model is common practice in life insurance. This approach guarantees that the short-term forecasts have a smooth transition from the most recent mortality rate.

Figure 1a. Difference between actual and projected death rates for females in USA for ages 30, 50 and 70

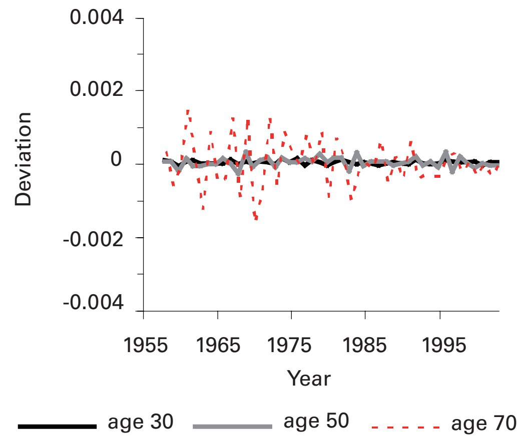


Figure 1b. Difference between actual and projected death rates for females in England & Wales for ages 30, 50 and 70

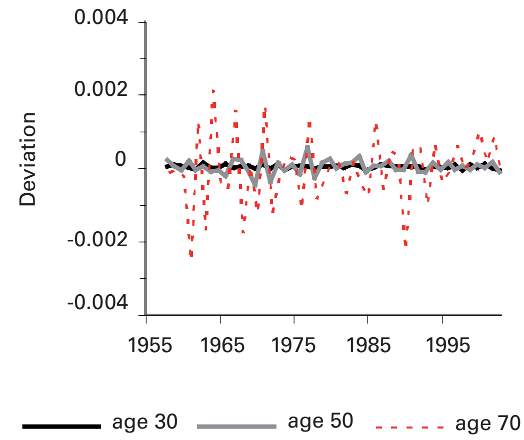


Figure 2a. Relative deviations between actual and projected death rates for females in USA for age 30, 50 and 70

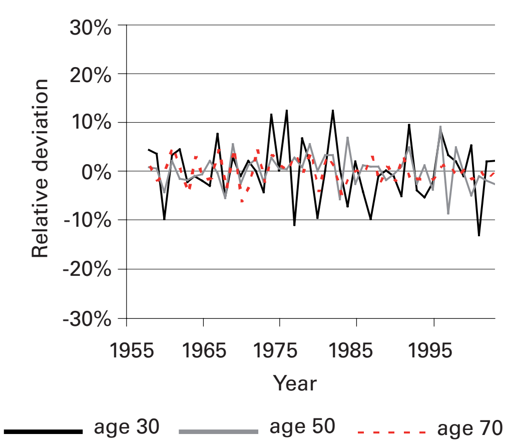
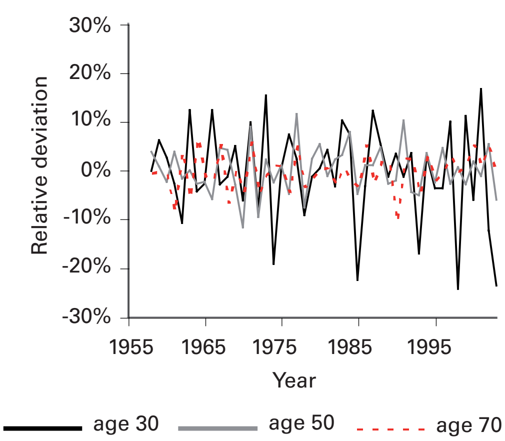


Figure 2b. Relative deviations between actual and projected death rates for females in England & Wales for age 30, 50 and 70



x=0 up to x=89 from historical death rates via a standard OLS estimator.

Figure 1 exemplary shows the residuals, i.e. the differences between the actual and projected death rates, for females in the USA and England and Wales for age 30, 50 and 70 dependent on time. A projected death rate for a given year – in our model – is based on the (realised) death rate in the preceding year multiplied by the average growth factor β_x. The results for the other countries are comparable. Although the residuals increase with rising age, the relative deviations – due to higher death rates in higher ages – decrease (see Figure 2). This tendency is also visible in Figure 3, which compares the actual death rates and the projected death rates in 1960 and 2000 for ages 0 to 89.

Obviously, the differences between the actual and projected death rates are marginal in 1960 and 2000; visible deviations only occur in the younger ages under 30, which are not considered in our following calculations of life expectancy. To validate these graphical observations, we calculate a measure of goodness of fit that has been introduced by Lee and Carter (1992). This measure M_x is given by one minus the ratio of the sample variance of the differences between the actual death rates $q_x(t)$ and the projected death rates $\hat{q}_x(t)$ with respect to the sample variance of the actual death rates and can be interpreted as the explained variance:

$$M_x = 1 - \frac{\text{VAR}\,[q_x - \hat{q}_x]}{\text{VAR}\,[q_x]}$$

A larger value of this measure implies a better fit. Table 1 provides the average results for this measure for the age groups 30 to 89 and 60 to 89, respectively. For comparison, the corresponding figures are also given for a Gompertz-Makeham approach, which is a common function in the actuarial context.[5] This function is given by:

$$\mu_x = A + B \cdot c^x$$

5 Note that Gompertz-Makeham is a static approach which models log-linearity with age in one year, whereas our model - like the popular model of Lee/Carter (1992) - models for individual age log-linearity with time (see also Melnikov and Romaniuk, 2006). Moreover the goodness of fit for our approach is based on one-year forecasts, whereas the results for the Gompertz-Makeham approach are based on a comparison between the actual and fitted death rates; for projecting death rates, the yearly estimated parameters of Gompertz-Makeham must be extrapolated into the future. See also Milevsky (2006) for a description of the Gompertz-Makeham model and a comparison to a Gompertz and Exponential approach.

Table 1: Goodness of fit of the models of Bomsdorf/Trimborn and Gompertz-Makeham for age group 30-89 and 60-89								
	Female				**Male**			
	Bomsdorf/Trimborn		Gompertz-Makeham		Bomsdorf/Trimborn		Gompertz-Makeham	
Age group	30-89	60-89	30-89	60-89	30-89	60-89	30-89	60-89
Canada	90.0%	95.4%	-103.0%	94.1%	88.5%	90.7%	54.4%	95.5%
England & Wales	91.0%	93.2%	54.9%	87.3%	87.2%	92.4%	-137.8%	97.7%
France	92.9%	96.3%	22.9%	90.2%	88.6%	92.7%	48.1%	97.5%
Germany	93.4%	96.0%	43.0%	94.7%	89.7%	90.6%	-2.2%	94.6%
Italy	94.2%	94.8%	22.1%	96.1%	89.6%	88.7%	75.9%	96.1%
Japan	98.2%	97.9%	-36.8%	95.7%	97.0%	96.2%	44.4%	97.4%
USA	96.0%	96.0%	45.5%	94.3%	94.9%	96.5%	57.3%	98.1%

Table 2: Life expectancy at age 60 in 2003 and 2050 in period and cohort perspective								
	Period perspective				**Cohort perspective**			
	Female		Male		Female		Male	
	2003	2050	2003	2050	2003	2050	2003	2050
Canada	24.9	29.5	21.2	25.2	26.7	31.3	22.5	26.5
England & Wales	23.5	27.9	20.3	25.3	25.1	29.6	21.9	27.1
France	25.6	31.4	20.8	26.3	28.1	33.8	22.6	28.3
Germany	23.9	28.8	20.0	24.2	25.8	30.6	21.3	25.6
Italy	25.1	31.2	20.9	26.0	27.7	33.8	22.6	27.9
Japan	27.5	35.3	22.0	29.0	31.4	38.7	24.6	31.8
USA	23.6	27.5	20.4	24.6	25.1	29.0	21.7	25.9

Table 3: Single net premium for a 35-year deferred whole life annuity-due (amount €1,000 p.a.) for an individual aged 30 in 2007 (cohort perspective) dependent on the starting year of the observation horizon								
	Female				**Male**			
	Life table 2003	Projection, model estimated from			Life table 2003	Projection, model estimated from		
Underlying death rates		1957-2003	1975-2003	1990-2003		1957-2003	1975-2003	1990-2003
Canada	6,927	8,450	8,498	8,075	5,677	7,033	7,520	7,792
England & Wales	6,500	7,962	8,068	8,135	5,380	7,057	7,517	8,038
France	7,151	9,052	9,070	8,681	5,334	7,131	7,328	7,323
Germany	6,659	8,304	8,509	8,049	5,208	6,628	7,158	7,299
Italy	7,078	9,120	9,108	8,858	5,602	7,331	7,595	7,701
Japan	7,754	10,291	10,801	10,776	5,883	8,196	8,450	8,078
USA	6,383	7,666	7,621	7,195	5,177	6,538	7,068	7,243

with $c>1$, $B>0$, $A\geq -B$ and μ_x as the force of mortality. The parameters were estimated for each year (1957-2003) from the age range x=30 to 89 using a Standard Least Squares procedure (Melnikov and Romaniuk, 2006).

The results in Table 1 show that both models fit the death rates well in the age group 60-89. In the younger ages log-linearity with age does not appear, therefore the results for the Gompertz-Makeham approach worsen. Partially, even negative figures occur: i.e. per average the variance of the differences between the actual death rates $q_x(t)$ and projected death rates $\hat{q}_x(t)$ is higher than the variance of the actual death rates. By contrast, the approach of Bomsdorf/Trimborn (1992) – that models age-specific log-linearity with time – performs well: the fit exceeds at least 87%.[6]

Due to the increasing trend of future life expectancy, we are interested in

Figure 3a. Actual and projected death rates for females in USA in 1960 and 2000

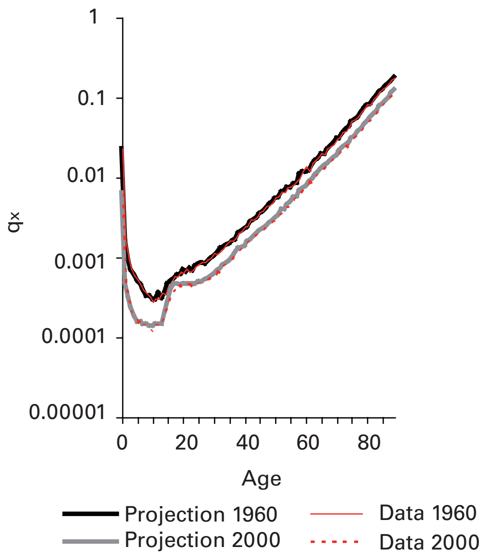


Figure 3b. Actual and projected death rates for females in England & Wales in 1960 and 2000

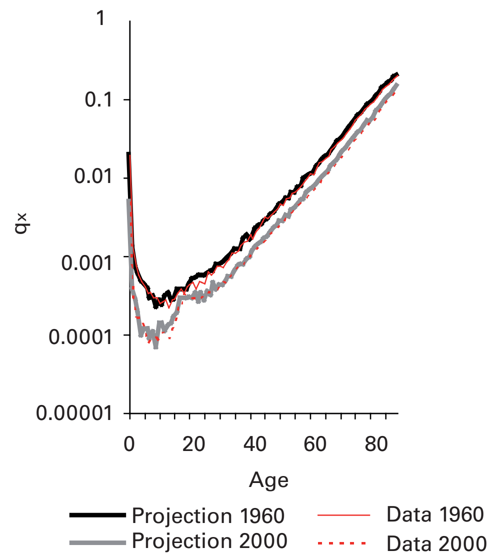


Figure 4a. Life expectancy at age 30 for females in period perspective 2003-2050

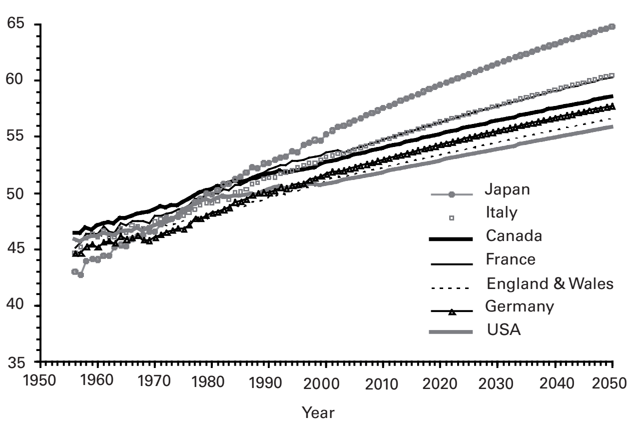
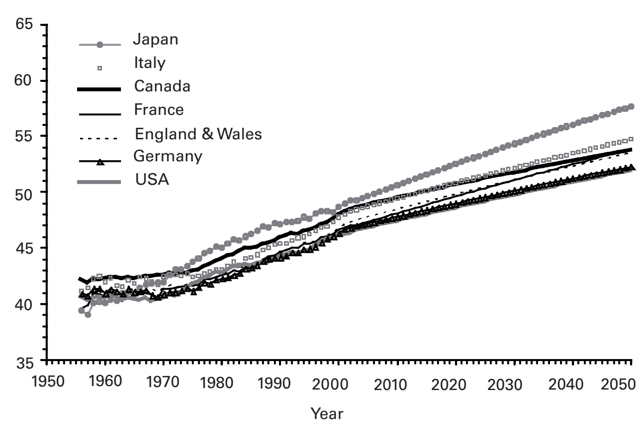


Figure 4b. Life expectancy at age 30 for males in period perspective 2003-2050



death rates up to the age of 115. We do not use the death rates from the Human Mortality Database for the ages above 89 since these are based only on small numbers of deaths, and, therefore, apply the Kannisto model (Thatcher, Kannisto and Vaupel, 1998) in order to extrapolate the death rates given in year 2003 up to the age of 115.[7] In addition, we assume that the average annual mortality decline at the age of 115 equals zero ($\beta_{115}=0$). Between the ages of 90 and 115, we interpolate β_x linearly.

Results

After performing the projection of death rates as described above, future life expectancy is then calculated from 2003 to 2050. Periodic life expectancies are derived from $q_x(t)$ for a fixed year t, which is usually called the period perspective. Due to the continuous decrease of death rates, this period approach causes a systematic underestimation of life expectancy. In addition, we therefore consider a more realistic approach, the cohort perspective. For the calculation of life expectancies based on the cohort perspective the following projected death rates are used: $q_x(t)$, $q_{x+1}(t+1)$, $q_{x+2}(t+2)$,..., $q_{x+115}(t+115)$.[8] Figure 4 illustrates the empirical life expectancies at age 30 for females and males from 1957 to 2003 as well as the results of our projections from 2004 to 2050 in period perspective.[9]

In 2003, female life expectancy at age 30 varies between 51.0 years in the USA and 56.0 years in Japan. Until 2050 female life expectancy increases in all regions. The highest rise occurs in Japan with 8.8 years and the lowest in the USA with 4.7 years. Japanese females have the highest life expectancy at age 30 with 64.8 years in 2050, followed by Italy (60.5 years) and France (60.3 years). The results for males are similar, but the level of life expectancy is significantly lower. Japanese males have a life expectancy at age 30 of 49.3 years in 2003 and 57.6 years in 2050 (an increase of 8.3 years). Italy comes next in 2050 with 54.7 years (48.4 years in 2003), males in the USA have the lowest life expectancy in 2050 with 51.9 years.

Figure 5a. Life expectancy at age 30 for females in cohort perspective 2003-2050

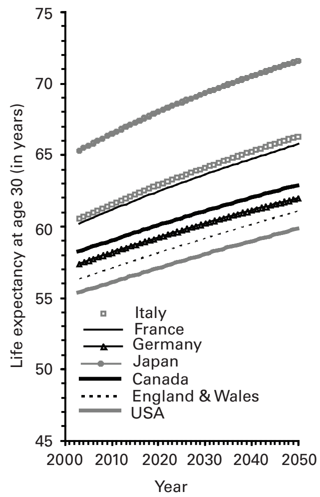


Figure 5b. Life expectancy at age 30 for males in cohort perspective 2003-2050

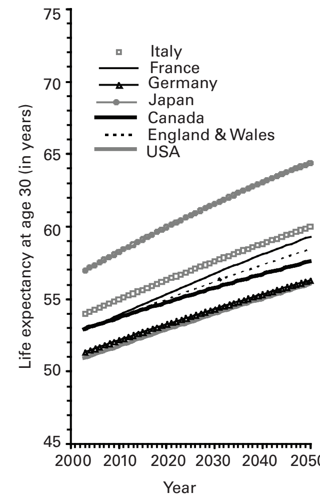


Figure 6a. Life expectancy at age 30 in 2007 for females in cohort perspective dependent on the starting year of the observation horizon

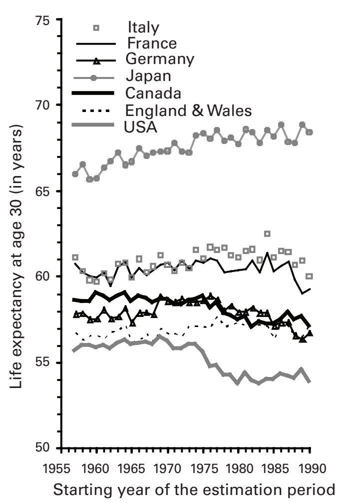
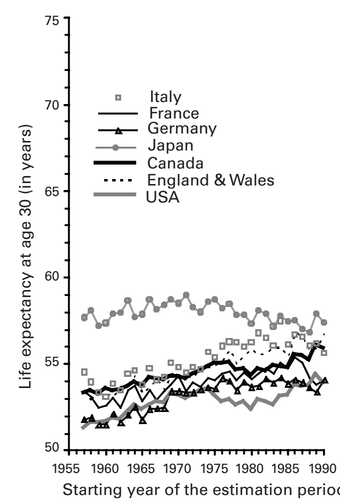


Figure 6b. Life expectancy at age 30 in 2007 for males in cohort perspective dependent on the starting year of the observation horizon



The results for the more realistic cohort perspective show similar tendencies as for the period perspective, but the levels are – due to the further decline of the death rates – higher (Figure 5).[10] Life expectancy at age 30 for females (for males) in 2003 reaches from 55.3 (50.8) years in the USA to 65.3 (56.9) years in Japan. In 2036, female life expectancy in Japan exceeds 70 years and increases up to 71.6 years in 2050. Japanese males have a life expectancy of 64.4 years in 2050, whereas male life expectancy in the USA is 8.4 years lower (56.0 years in 2050). With regard to possible financial applications, Table 2 provides the corresponding life expectancies at age 60.

As mentioned before, the projections presented above (Figures 4 and 5, and Table 2) are based on the death rates from 1957 to 2003, which was the longest common possible observation horizon for the considered countries. The question is in which way the results change (or whether they change at all) if the chosen observation horizon is shortened to the recent past. Therefore we repeat the estimation of the growth rates β_x and our calculations dependent on the starting year of the observation horizon of the mortality data. The final year is always the year 2003.[11] Due to the practical application, we focus on cohort life expectancies in 2007. Figure 6 first shows the results for life expectancy at age 30 (dependent on the used observation horizon).

6 The R^2 - which measures the fraction of the total squared error that is explained by our model - is close to 100% for all considered regions, also indicating a good fit. The R^2 for the Gompertz-Makeham approach is above 90%.

7 Thatcher, Kannisto and Vaupel (1998), p.30, and the German Institute of Actuaries (DAV 2004, pp.79-83) analyse the goodness of fit of various extrapolation methods for ages beyond x=100. Both references conclude that the Kannisto model fits the empirical data well. Analogously to Thatcher, Kannisto and Vaupel (1998), we base the estimation of the parameters in the Kannisto model from the ages x=80 to 98.

8 See Goldstein and Wachter (2006), Canudas-Romo and Schoen (2005) and Bomsdorf (2002) for a detailed comparison between period and cohort perspective.

9 Total life expectancy could easily be calculated by adding the 30 survived years to life expectancy at age 30.

10 Note that the cohort life expectancies 2003 are not observable yet and are based on projections: e.g. the cohort life expectancies in 2050 are calculated from death rates until 2135. Thus, they should be seen for illustration only.

Figure 7a. Life expectancy at age 60 in 2007 for females in cohort perspective dependent on the starting year of the observation horizon

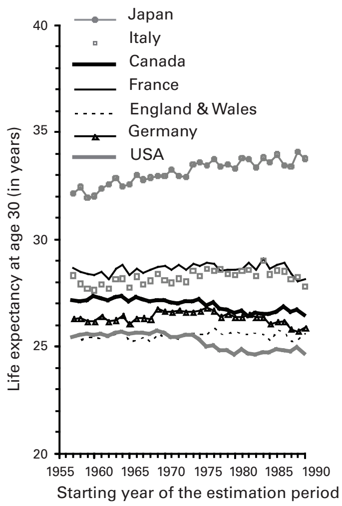
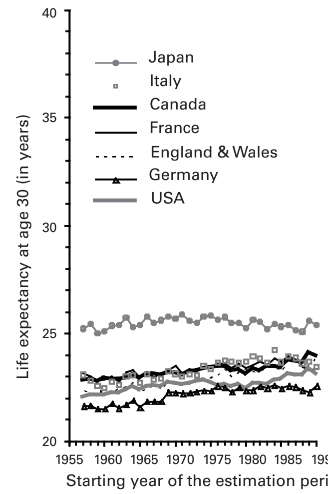


Figure 7b. Life expectancy at age 60 in 2007 for males in cohort perspective dependent on the starting year of the observation horizon



The figure shows that (except for Japan) the projected life expectancies for females in 2007 in tendency fluctuate or decrease whereas the corresponding figures for males increase when the estimation period is shortened to the recent past.[12] For example, the resulting life expectancy at age 30 in 2007 for Canadian females remains nearly stable with 58.6 years until 1975 (data considered from 1975 to 2003), but then declines to 57.1 years (data considered from 1990 to 2003). By contrast, life expectancy at age 30 for Canadian males rises from 53.3 years (data considered from 1957 to 2003) to 54.9 years (data considered from 1975 to 2003) and finally 55.9 years (data considered from 1990 to 2003). Only in Japan, the country with the highest life expectancy, female life expectancy increases while male life expectancy fluctuates and finally goes down. Figure 7 now provides the corresponding life expectancies in 2007 at age 60.

The described tendencies for life expectancy at age 30 also result for age 60, but the changes are – due to the shorter forecast horizon – smaller. Again Japan is the only country with an increasing female life expectancy. In the other countries the female life expectancies remain stable or decrease, while male life expectancies increase when the estimation period is shortened to the recent past. The results also imply that differences in life expectancy between females and males decrease in six of the G7 countries if only the mortality data of the recent past are considered for model estimation. For example, the difference at age 30 in Germany in 2007 decreases from 6.0 years (estimation period 1957-2003) to 5.0 years (1975-2003) and finally just 2.7 years (1990-2003). In the USA male life expectancy at age 30 may even equal female life expectancy if the recent mortality trends of the last years (1990-2003) persisted in the future.

Application to life insurance

As mentioned before, the choice of the observation horizon has an explicit impact on the projected death rates and life expectancies. We now analyse the consequences of the observed trends for the pricing of a life insurance product which obviously is exposed to the risk of longevity: an annuity insurance. More precisely, we use the projected death rates to exemplarily calculate the single net premium for an n-year deferred whole life annuity-due which is given by (cf. Bowers et al. 1997, p145):[13]

$$ {}_{n|}\ddot{a}_x = \sum_{k=n}^{\infty} v^k \cdot {}_k p_x $$

where $v = \frac{1}{1+i}$ is the discount factor at interest rate i and ${}_k p_x$ is the probability for an individual aged x to survive k years. The premium calculations are carried out at an interest rate of i=2.25%, which is the current standard interest rate for premium reserves in Germany.[14] The illustration focuses on individuals aged 30 in 2007. The annuity payments of €1,000 start from age 65 onward and are made at the beginning of each year as long as the individual is alive. Therefore, the actual single net premium comes to $1000 \cdot {}_{35|}\ddot{a}_{30}$. Table 3 provides the resulting premiums in 2007 (cohort perspective) dependent on the starting year of the observation horizon. For comparison, the table also contains the single net premium which could be obtained using the mortality rates from the last available life table in 2003.

The resulting premiums for the deferred annuity in 2007 reflect mortality differences between countries and sexes. For example, in Japan, the country with the highest life expectancy, the highest premium also occurs. Using the last available life table, i.e. assuming no further decline in death rates, obviously leads to – in comparison to the results based on the projection – smaller premiums and, hence, an underestimation of the risk of longevity. Regarding the results based on projected death rates as described in section 2, the premi-

11 For example, 1990 means that the data from 1990 to 2003 is considered for model estimation.

12 The cohort life expectancies at age 30 in 2007 are calculated from death rates until 2092, the corresponding figures at age 60 require death rates until 2062. Dinkel/Luy (1998) analysed sex mortality differences of German cloister population. They concluded that the differences are significantly lower than in the whole German population. Furthermore, sex differences in smoking seem to be an important factor for sex mortality differences (see e.g. Case, 2005, and Pampel, 2003); in this context, Preston and Wang (2006) came to the conclusion that recent changes in smoking pattern will lead to a decrease of sex differences in mortality in coming decades in the USA.

13 Note that insurers usually use their own life tables for calculating premiums. Therefore, our results based on the whole population should be seen for illustration. See e.g. Olivieri (2001) for an analysis of the use of projected life tables for life insurance valuations. See also Lin and Cox (2005) and Dahl (2004) for an introduction of mortality-linked insurance contracts.

14 Our calculations have been carried out using the current standard interest rate for premium reserves in Germany. Although this interest rate varied throughout the last decades, once the policy has been issued it is fixed for the whole duration of the contract. Hence, we assume the interest rate to be constant over the time horizon considered. Naturally, using another interest rate would affect the magnitude of the figures but not the findings in general.

ums for males increase – due to an accelerating decrease in male mortality in the recent past – when using current data for model estimation only. By contrast, the corresponding figures for females (except for England & Wales and Japan) first almost remain stable and then decrease. For example, the resulting premium for Canadian males rises from €7,033 (data considered from 1957 to 2003) by 10.8% to €7,792 (data considered from 1990 to 2003), whereas the premium for females decreases by 4.4%. The highest increase for males occurs in England & Wales with 13.9% (from 7,057 to 8,038), the highest decrease for females in the USA with 6.1% (from 7,666 to 7,195). A future continuation of the latest mortality developments (1990-2003) would even lead to a higher premium for males (7,243) than for females (7,195) in the USA.

Conclusion

The presented calculations for the G7 countries show a further increase in life expectancy for both sexes. In the more realistic cohort perspective, Japanese females may even exceed a total life expectancy of 100 years in the near future. Regarding the recent mortality trends, the projections show an acceleration in male mortality decline which may lead to decreasing sex differences in life expectancy between females and males in six of the G7 countries. More precisely, in comparison to the projections based on the long-term trend, the more current the mortality data, the lower the projected male death rates are and the higher the resulting male life expectancy is – whereas female life expectancy remains stable or declines. These trends have a significant influence on the pricing of life insurance products, as the exemplary pricing of a deferred annuity illustrates. Therefore, life tables used for premium calculation should account for modelling the (recent) trends of mortality, otherwise insurers run the risk of charging inadequate premiums. L&P

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