International Mortality: Patterns and Projections

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Introduction

Patterns and trends in late-life mortality are of growing financial importance. The growth in pension liabilities, both public and private, are of crucial interest to governments, insurers and companies with defined-benefit pension schemes. On March 19th 2007, a paper was presented to the Faculty of Actuaries in Scotland which compared patterns in international mortality data, and drew important lessons for actuaries dealing with pensioner liabilities. The paper can be downloaded from the U.K. profession's website at www.actuaries.org.uk.

Mortality patterns in the United Kingdom have been increasingly studied by actuaries of late. The reasons are simple. Longevity risks represent a growing share of the risk profile of many insurance companies as their books mature and business mixes evolve. Increased focus on the size of pension-scheme deficits means that pensions actuaries also need to know more about the possible trends in future life span. Much attention in the U.K. has focused recently on the so-called 'cohort effect', with the generations born between 1925 and 1940 experiencing unprecedented rapid falls in mortality rates at older ages when compared with previous generations.

Chief amongst the questions asked by actuaries and those whom they advise are "Is the cohort effect unique to the U.K.?'' and "What further improvements can be expected?''. Using the techniques most recently developed by the Continuous Mortality Investigation Bureau (CMIB) in the U.K., the paper compared and contrasted the mortality patterns of various countries to gain insight into these questions. The authors looked at cohort effects and period effects in different countries' mortality patterns, and demonstrated that even where one effect is dominant it did not mean that the other is not also significant. In closing, the authors looked at models which actuaries can apply to their portfolio experience data to separate time trends from cohort-based patterns.

Format and Source of Mortality Data

Table 1. Life expectancy at age 65. Selected countries in order of decreasing female life expectancy.

		Life expectancy at 65:		
Country	Year	Males	Females	Difference
Japan	2004	18.24	23.27	5.03
France	2004	17.69	22.12	4.43
Canada	2003	17.35	20.69	3.34
Sweden	2005	17.36	20.58	3.22
Germany (West)	2002	16.19	19.75	3.56
U.S.A.	2003	16.78	19.59	2.81
England and Wales	2003	16.41	19.23	2.82

The data were taken from the Human Mortality Database (2007), and summary details for the seven countries selected are shown in Table 1. Although the seven countries chosen have many similarities (all are G8 members apart from Sweden), they were chosen for their differences. For example, the United States of America were reputed not to have cohort effects, or at least to have very weak cohort effects compared with other countries. Canada was chosen to contrast with the U.S.A. in the North American continent, not least because it has a very different approach to healthcare. England and Wales were included as territories of particular interest to U.K. actuaries, of course, but also because of the strength of the well-documented cohort patterns in generational mortality. Japan was included both as having particularly long-lived citizens, but also because of a pronounced cohort effect. Sweden was chosen because of its long history of high-quality mortality data and its consequent frequent use in other mortality and demographic studies. France was selected as a nation with strong differences in male and female mortality, and Germany was chosen due to its starkly different social and economic history over the 20th century.

Comparisons by country

One of the features of U.K. mortality is the strong cohort effect, i.e. the tendency for particular generations to exhibit strong and sustained patterns of mortality improvement compared to their predecessors. The paper used a local smoothing methodology known as P-splines to find cohort effect as expected in the U.K., but also Germany, France, Japan and, to a lesser extent, Sweden. Weaker cohort effects were observed in the U.S.A, which also had a period of particularly strong mortality improvements during the 1970s.

The paper contains social and economic histories of each of the seven countries studied, in an attempt to provide a backdrop for the different mortality patterns. These histories are quite revealing of strong cultural differences. Take the example of smoking, the prevalence of which is shown in Table 2.

Table 2. Smoking prevalence by gender.

Country	Males	Females	Period
Japan	47	12	2000
France	30	21	2002–2005
Canada	24	20	2001
Sweden	14	19	2002–2005
Germany (West)	37	30	2002-2005
U.S.A.	24	18	2005
U.K.	25	23	2005

Japanese males have by far the highest smoking prevalence, and also the most pronounced difference between males and females. This doubtless contributes to the relatively large gap between male and female life expectancies in Table 1. Also of interest is the low smoking prevalence amongst Swedes, including the unusual feature whereby fewer men smoke than women. The Swedes are unique in this group of countries in that they often take snuff, or *snus*, in preference to smoking cigarettes. Despite studies which show that use of snus leads to no material increase in mortality rates (either from cardiovascular diseases, pulmonary diseases, or oral or other cancers), snus is prohibited in every other country in the European Union, where rates of smoking — and smoking-related deaths — are far higher.

There has been discussion of a European Union-wide smoking ban, but this has been left up to national legislatures so far, with starkly different legal environments as a result. Germany, however, has a unique history regarding cigarette consumption. The earliest research providing a clear link between smoking and lung cancer was conducted in Germany, preceding the results in Doll *et al* (1954) by at least a decade: work by Schairer & Schöniger (1943) at the Institute for Research into Tobacco Risks at the University of Jena provided conclusive links, as did even earlier work by Lickint (1929). Partly as a result of this, Germany had some of the earliest government anti-smoking campaigns prior to and during the Second World War, including a ban on smoking in universities, post offices and military hospitals. However, this anti-smoking drive was a Nazi measure: a review of early German research into smoking and mortality — and its unfortunate sidelining because of Nazi involvement — is described by Proctor (2001). Perhaps as a reaction to this, post-war Germany has noticeably lagged other countries such as Italy, France, Ireland and Scotland in the banning of smoking in enclosed public spaces. Culturally, modern Germany has quite a different attitude towards smoking from the likes of the U.K.: non-smoking sections of restaurants and cafes are largely unheard of and, until January 2007, anyone with a few euro coins — including, doubtless, under-age children — could buy cigarettes from vending machines on most street corners. Germany's smoking prevalence — 37% for males and 30% for females — is high for the countries surveyed here.

The Fall in Circulatory Disease

Circulatory disease plays a key role as a major killer of older people and changes in this were the biggest contributor to the improvement in mortality rates between 1990 and 2000, as shown in Tables 3 and 4. This applied to all countries, and the broad trend for the 20th century is illustrated for England and Wales in Figure 1.

Table 3. Percentage reduction in death rates by cause of death between 1990 and 2000 for males ages 65–74.

Country	Total	Circulatory	Cancers	Respiratory	Other
Japan	9.4	8.3	−2.3	2.3	1.2
France	4.9	4.1	1.3	0.4	−0.9
Canada	19.4	12.9	4.1	2.3	0.1
Sweden	19.3	16.8	2.0	0.4	0.1
Germany	17.8	13.1	1.5	1.6	1.5
U.S.A.	14.7	11.3	3.5	0.9	−1.0
U.K.	18.1	13.9	4.8	−1.3	0.7

Table 4. Percentage reduction in death rates by cause of death between 1990 and 2000 for females ages 65–74.

Country	Total	Circulatory	Cancers	Respiratory	Other
Japan	22.7	14.1	2.2	2.3	4.1
France	3.6	6.0	−0.3	0.1	−2.2
Canada	11.4	10.6	1.1	0.5	−0.8
Sweden	13.3	12.9	1.0	−1.1	0.5
Germany	19.5	13.0	2.7	0.4	3.5
U.S.A.	3.5	7.8	0.7	−1.8	−3.1
U.K.	11.9	12.2	2.4	−4.3	1.5

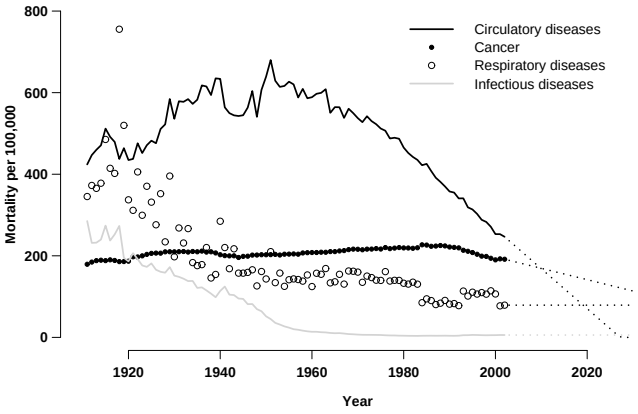

Figure 1. Mortality rates per 100,000 for England and Wales by main causes of death. Source: ONS data with own extrapolations beyond 2002. Taken from Richards, Kirkby and Currie (2006).

Despite these large falls, cardiovascular mortality remains the leading cause of death amongst the over-75s for both genders in all the countries surveyed. Thus, trends in this cause of death will be critical in determining future mortality improvements. The prevention or delay of deaths resulting from circulatory diseases can be attributed to two broad factors, namely medical treatment and changes in risk factors in the population. Treatment and changes in risk factors have been estimated to have contributed 40% and 60% respectively of the fall in death rates relating to coronary heart disease (CHD) in Scotland, with similar results were estimated for New Zealand and England and Wales. The percentage contribution of treatment and changes in risk factors to the total fall in CHD mortality based on the findings of Capewell and colleagues are summarised in Table 5.

Table 5. Components of reduction in mortality due to coronary heart disease. Adapted from Capewell *et al* (1999), Capewell *et al* (2000) and Unal *et al* (2004).

Proportion of reduction due to changes in:	Scotland	England and Wales	New Zealand
Smoking	36	48	30
Population blood pressure	6	10	8
Cholesterol	6	10	12
Deprivation	3	3	n/a
Other factors	9	−13	4
Risk-factor reduction (%)	60	58	54
Heart failure	8	13	6
Secondary prevention	6	11	7
Acute myocardial infarction	10	8	12
Hypertension treatment	9	3	7
Aspirin for angina	5	3	9
CABG surgery	2	4	5
Treatment reduction(%)	40	42	46
Overall (%)	100	100	100

Changes in risk factors and treatment could prevent or postpone deaths at two levels — the occurrence of the disease on the one hand, and the fatality from the disease on the other. The World Health Organisation Multinational Monitoring of Trends and Determinants in Cardiovascular Disease (WHO MONICA) Project has been set up to monitor the trends in determinants of mortality and morbidity due to cardiovascular disease. Studies on the MONICA data have shown that two-thirds of the fall in CHD deaths can be attributed to the fall in occurrence rates and one-third to the fall in fatality rates. In other words, reductions in the causes of heart attacks have contributed more to mortality improvement than the factors that help people survive one, i.e. prevention is better than cure.

Projecting national mortality using P-splines

In the U.K., one commonly applied technique for both smoothing and projecting mortality rates is that of penalised-spline regression (often just shortened to P-splines). This is a localised smoothing mechanism, which can carry out a graduation in two dimensions: smoothing takes place in both the age and time direction. The so-called *penalty function* provides the smoothness in the graduation, and also forms the basis for the two-dimensional projections into the future. A further advantage of this methodology is that standard errors for these projected values can also be obtained from the model. One way to test the appropriateness of a projection methodology is to conduct a back test, i.e. to fit the model to the first half of the data and then to compare the resulting projection with the subsequently observed values. Figure 2 shows the results of just such a back test applied to data for French males. Clearly the P-spline methodology, had it been available in the past, would have provided a very good projection of the future force of mortality. This does not mean that P-spline projections applied now will give as good a projection in the future, but it does give confidence that the methodology is not obviously flawed.

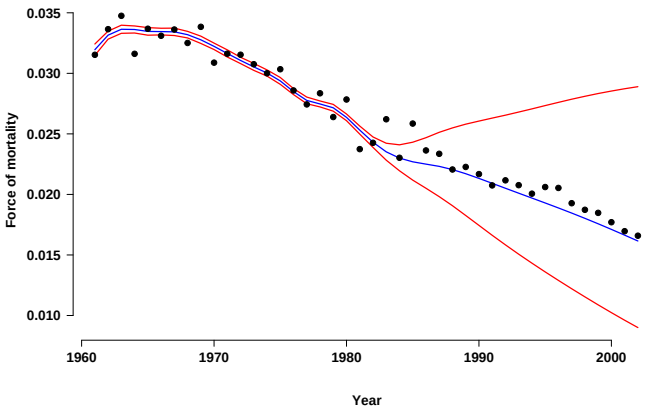

Figure 2. Observed force of mortality for French males at age $65\frac{1}{2}$ (•), together with projected values and $2\frac{1}{2}$% and $97\frac{1}{2}$% percentiles based on a P-spline model using only the first half of the data to 1982 (age-cohort penalty). The projection from 1982 has proved remarkably prophetic

Another test, albeit a subjective one, is whether a projection method produces a natural-looking extrapolation of actual data. Figure 3 shows the smoothed actual improvements observed for males in the 1931 birth cohort in England and Wales. The P-spline projections arguably show a more intuitive short-term extrapolation of past improvements than other projection bases, such as the medium-cohort projection which is still in common use. Given that the past twenty years have seen a steady *acceleration* in improvement rate — from $3\frac{1}{2}$% to $4\frac{1}{2}$% p.a. — the sharp deceleration of the medium cohort does not look like a natural extrapolation. Furthermore, the low rate of improvement of under $\frac{1}{2}$% from age 91 onwards suggests that some kind of floor value should be used.

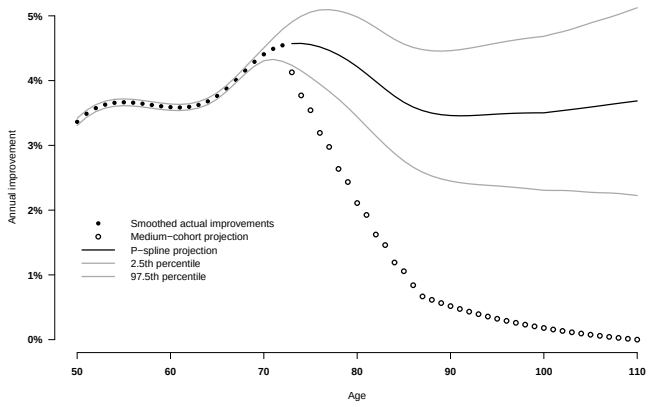

Figure 3. Observed smoothed improvement in force of mortality for males born in 1931 in England and Wales (•), together with projected improvements in q_x according to the medium cohort (○) and the projected improvements in force of mortality according to a P-spline model using age-cohort penalties (solid black line). 2.5% and 97.5% percentiles for the fitted and projected P-spline values are indicated by the solid grey lines

Using survival models to analyse portfolio trends

The results in the paper were primarily from P-splines applied to population data. But what about actual portfolio data? Many life offices in the U.K. use generalised linear models (GLMs) to analyse pensioner mortality. However, GLMs have a number of limitations, and some life offices have started switching to a more powerful set of techniques called *survival models*.

A survival model can be defined very simply. In this example, each life i is observed alive at the start at exact age x_i, and survives t_i years. The probability that life i survives t_i years is ${}_{t_i}p_{x_i}$, while the force of mortality at age $x_i + t_i$ is denoted $\mu_{x_i+t_i}$. All that remains is to define μ_x. In this case, we use a simple Gompertz model for the force of mortality, namely:

$$\mu_{x,y} = e^{\alpha+\beta x+\delta y}$$

where the values of α and β will be built up individually from risk components for each life i, and where δ represents the time trend at year y (y is measured from the start of 2000, i.e. 1^{st} January 2000 is $y = 0$).

We illustrate this approach by using the Longevitas system on an insured data set comprising 92,890 males in receipt of a private pension. The pension records have been deduplicated, i.e. multiple records paid to the same person were identified and merged to form a single record. This is essential for statistical modelling at the individual level in order to preserve the independence assumption. The matching scheme used was based on a combination key of (i) date of birth, (ii) gender, (iii) surname, (iv) first initial, and (v) postcode. If all five data elements matched for two or more records, then they are assumed to be for the same person and they were replaced with a single merged record with the total pension. An algorithm called 'metaphone phonetic matching' (Phillips, 1990) was further used to catch common alternative spellings of surnames, e.g. Richie and Ritchie, and such records were also merged if the other four fields matched.

15,961 deaths were observed amongst the 92,890 males over a period of six calendar years. Exposure outside these dates was discarded, giving a total exposed-to-risk of 461,026 life-years, measured daily. This figure excludes any exposure or deaths either under age 60 or over age 95: the younger-age exposure is not modelled because it does not exhibit the same log-linear pattern of age-related mortality, while the exposure and deaths over age 95 are not felt to be wholly reliable. Note that not all 92,890 males were observed at the start of the period as some were new entrants to the portfolio during the period of observation. The elegance of this kind of survival modelling is that it can effortlessly handle fractional years of exposure.

Using this data set we can fit this model structure, and also an extension to investigate a time-trend parameter, δ. The results are shown in Table 6. Here we use Akaike's Information criterion (AIC, Akaike, 1987) to compare the four models: the lower the AIC, the better the model. The AIC balances goodness of fit with the number of parameters in the model, so any difference in the AIC can be regarded as statistically significant.

Table 6. Results of various models with time-based and cohort-based parameters applied to an insured data set. The best-fitting model (lowest AIC) has both cohort and time-trend effects.

Model number and description	Improvement in AIC relative to model 1
1. α, β constant, $\delta = 0$	0
2. α, β constant and $\delta = -0.032823$	67
3. α and β vary by cohort, $\delta = 0$	349
4. α and β vary by cohort, $\delta = -0.0210656$	368

Models 3 and 4 in Table 6 include cohort effects, and here we have used a function to find the optimum three breakpoints among the years of birth to create four broad cohorts: years of birth 1903–1909, 1910–1923, 1924–1932 and 1933–1944. Note that we have assumed four cohorts, but it is also possible to optimise not just the breakpoints, but also the number of cohorts as well. The optimal breakpoints between the years of birth are found by minimising the value of the AIC.

We can see evidence of significant cohort effects as the AIC values for models 3 and 4 are much lower than Model 1. The time trend suggested in Model 2 is an improvement of around 3.23% p.a. (3.23% $= 100\% - e^{-0.032823}$). Although the parameter values in different models are not strictly comparable, the suggestion in Model 4 is that this value of 3.23% is in part due to the cohort effect, as the not-quite-equivalent figure in Model 4 drops to 2.08% when the cohort effect is allowed for explicitly ($2.08\% = 100\% - e^{-0.0210656}$). In fact, we can see that the cohort effects are more significant than the time trend overall: adding the time trend on its own caused the AIC to fall by 67, whereas adding the cohort parameters caused the AIC to fall by 349. The two drops in the AIC can be compared, suggesting (i) that both cohort effects and a time trend are present, and (ii) that cohort effects are the stronger of the two.

Conclusion

Despite faster improvements in male mortality over recent decades, the difference in life expectancy between males and females remains pronounced and there are no signs of it vanishing. Although recent mortality improvements have been particularly strong in many countries, there seem few grounds for assuming that they will slow down or stop anytime soon. The low international ranking of both male and female life expectancies in the U.S.A. and England & Wales suggests that continued strong improvements are at least very possible. Also, the example of Japanese females between 1990 and 2000 shows that relatively low mortality rates in the first place are no barrier whatsoever to further dramatic improvements. This should be borne in mind by anyone tempted to argue that strong past improvements must somehow mean that future improvements will be less.

The extent to which period or cohort effects dominate mortality patterns differs among countries, even to the extent that one can dominate for males and the other for females within the same country. Where one is dominant, however, this does not imply that the other is not significant: a simple statistical model shows how one can separate cohort effects from any long-term trend improvement using population data. This model can also be used to separate cohort effects and trends in an insured population, and can also allow for any complications caused by changes in business mix.

Finally, where an actuary chooses to apply a cohort-based projection of future mortality rates, evidence from both the general population and an insured data set in England and Wales suggests that a floor value of improvements may be required.

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