Mortality improvements and evolution of life expectancies

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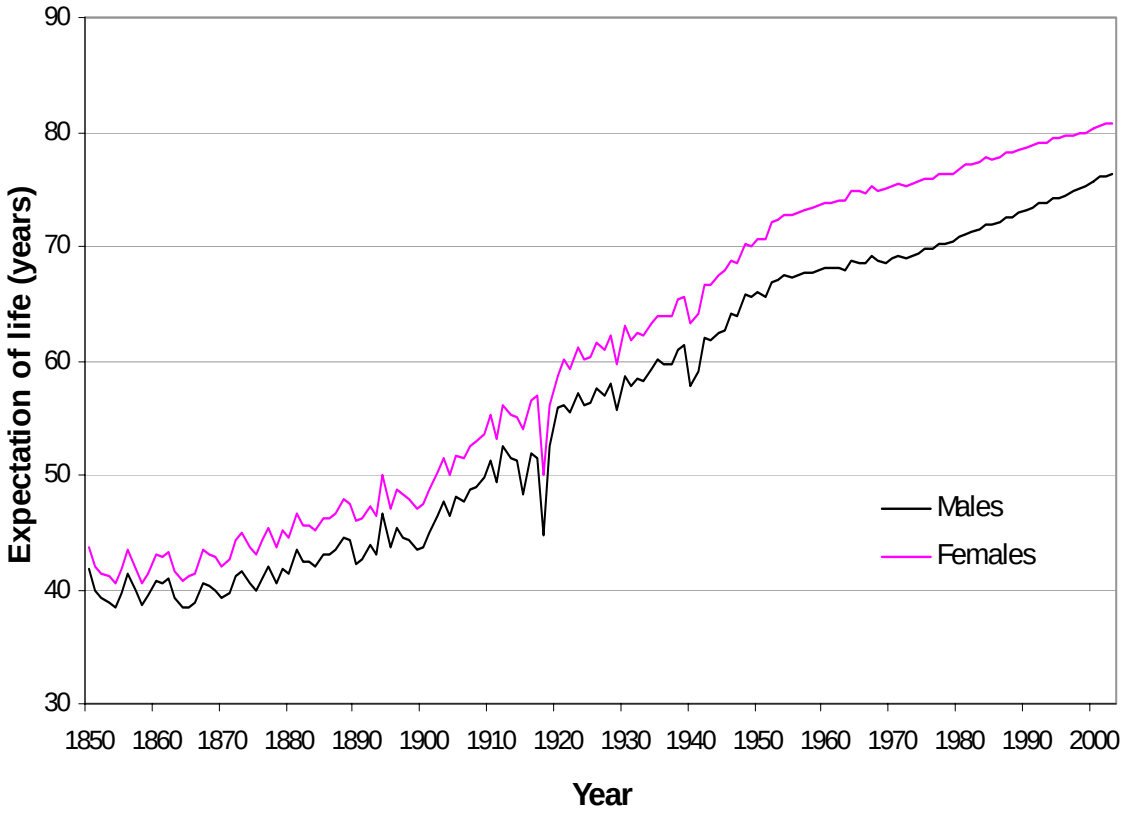
Mortality in the United Kingdom – 20th century trends

During the course of the 20th century, the United Kingdom saw a continuation of the pattern of falling death rates that began around the beginning of the 19th century. Over these two centuries there has been a change from a regime of high infant and child mortality, with a preponderance of acute and infectious diseases, to a new regime in which adult mortality predominates and chronic and degenerative diseases are the most common causes of death. Period life expectancy at birth in the mid-19th century was around 40 years for males and 42 years for females. These figures increased to around 45 and 50 years respectively by 1901. Life expectancy then rose dramatically until the mid-1950s. Since then, life expectancy at birth has continued to increase but at a less rapid rate (see Fig 1). Life expectancy for males rose at a lower rate than for females during the 1950s and 1960s, with the difference between males and females rising to a high of 6.3 years in 1970. Since 1970, male expectation of life has been increasing faster than female and the differential has fallen to 4.4 years by 2003.

Figure 1: Period expectation of life at birth, England and Wales, 1850-2003



Tables 1 and 2 show how period life expectancies for England and Wales have changed over the 20th century for selected ages. Much of the increase in expectation of life at birth in the first half of the 20th century arose through the reduction of infant and child mortality to very low levels by the mid-1950s. These rates are now so low that further reductions can have little effect on the expectation of life at birth. The most important factor driving this has been the increasing control of infectious diseases through improved sanitation, better public health measures and the development of vaccines and antibiotics. Compared to the improvement in mortality rates at younger ages, there was very little improvement in mortality rates at the older ages.

Table 1: Life expectancy – England and Wales, males

	Total life expectancy on reaching age shown				
Year	At birth	At age 15	At age 45	At age 65	At age 80
1901-10	48.5	62.3	68.3	75.8	84.9
1910-12	51.5	63.6	68.9	76.0	84.9
1920-22	55.6	65.1	70.2	76.4	84.9
1930-32	58.7	66.2	70.5	76.3	84.7
1940-42					
1950-52	66.4	69.4	71.5	76.7	84.9
1960-62	68.1	70.3	72.1	77.0	85.2
1970-72	69.0	70.8	72.4	77.2	85.5
1980-82	71.0	72.3	73.7	78.0	85.8
1990-92	73.4	74.3	75.7	79.3	86.4
2000-02	75.9	76.6	78.0	81.0	87.1

Source: English Life Tables and GAD Interim life tables

Table 2: Life expectancy – England and Wales, females

	Total life expectancy on reaching age shown				
Year	At birth	At age 15	At age 45	At age 65	At age 80
1901-10	52.4	65.1	70.5	77.0	85.4
1910-12	55.4	66.4	71.3	77.4	85.5
1920-22	59.6	68.1	72.7	77.9	85.6
1930-32	62.9	69.3	73.3	78.1	85.5
1940-42					
1950-52	71.5	74.0	75.8	79.3	85.8
1960-62	74.0	75.9	77.1	80.3	86.4
1970-72	75.3	76.8	77.9	81.1	87.0
1980-82	77.0	78.0	79.0	82.0	87.5
1990-92	79.0	79.7	80.5	83.1	88.4
2000-02	80.6	81.1	81.9	84.1	88.7

Source: English Life Tables and GAD Interim life tables

In the second half of the century, the increase in life expectancy at older ages has been much more marked and accounts for an increasingly higher proportion of the overall increase in life at birth.

Figure 2 shows that period life expectancy at age 65 was fairly stable at around 10.5 years for male and 11.5 years for females during the latter half of the 19th century. These figures began to rise during the 20th century, initially more rapidly for women than for men. However, the greatest decline in death rates for advanced ages has occurred since the 1970s, from when large increases in expectation of life at age 65 have been seen, particularly for males as mortality at older ages began to improve more rapidly than female mortality; as a result, the differential between males and females has reduced from highs of around 4.0 years during the 1970s and early 1980s to 2.8 years in 2003.

Figure 2 suggests that this is rather more a case of the mortality rates for older males falling to the levels they would have reached had they followed the reductions in female mortality rates during the 1950s and 1960s, rather than a convergence of male mortality rates to those for females. A partial explanation for this may be the different historical patterns in cigarette smoking between men and women, with a higher proportion of males smoking in the past than females and the peak consumption for males being earlier (1940-1960) than for females (1960). This might suggest that the rate of increase in female expectation of life at 65 may experience a further slowing down relative to that for males over the next few years.

Figure 2: Period expectation of life at age 65, England and Wales, 1850-2003

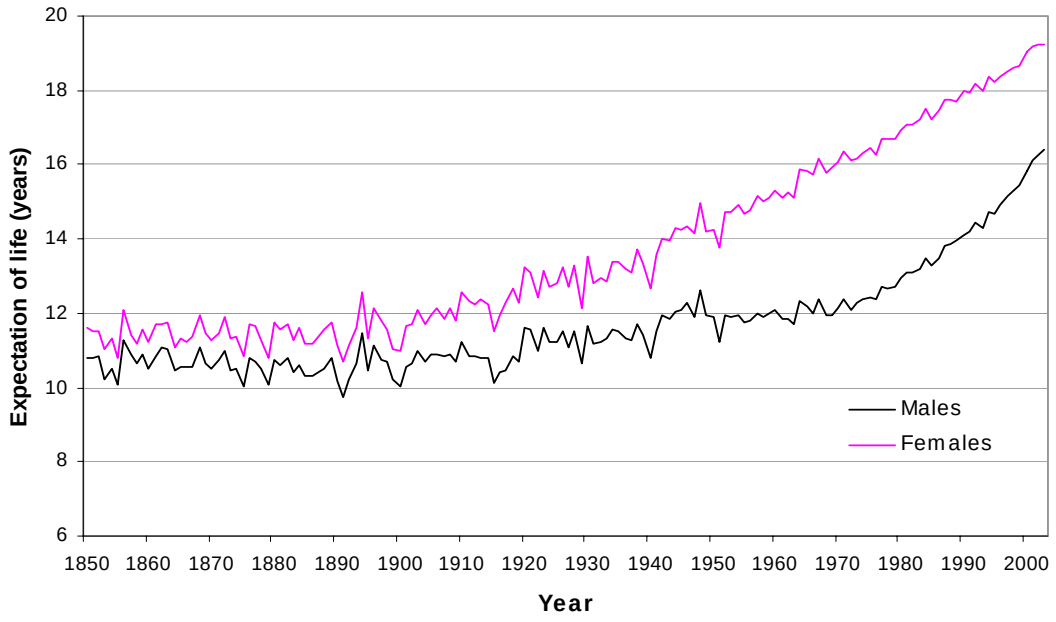


Table 3 shows the average annual rates of improvement in age standardised mortality rates for 5-year age groups between successive England and Wales life tables. The average rate of improvement for ages 0 to 99 over the 91-year period 1910-12 to 2001-03 was around 1.0% per annum (pa) for males and 1.1% pa for females. The average rate of

improvement over successive decades since 1930-32 remained relatively constant for females; for males, the table shows a relatively constant rate over the period 1930-32 to 1970-72, lower than that experienced by females, followed by a period of increasing mortality improvement. Over the 41 year period 1960-62 to 2001-03, the rates of improvement were around 1.4% pa for males and 1.2% pa for females.

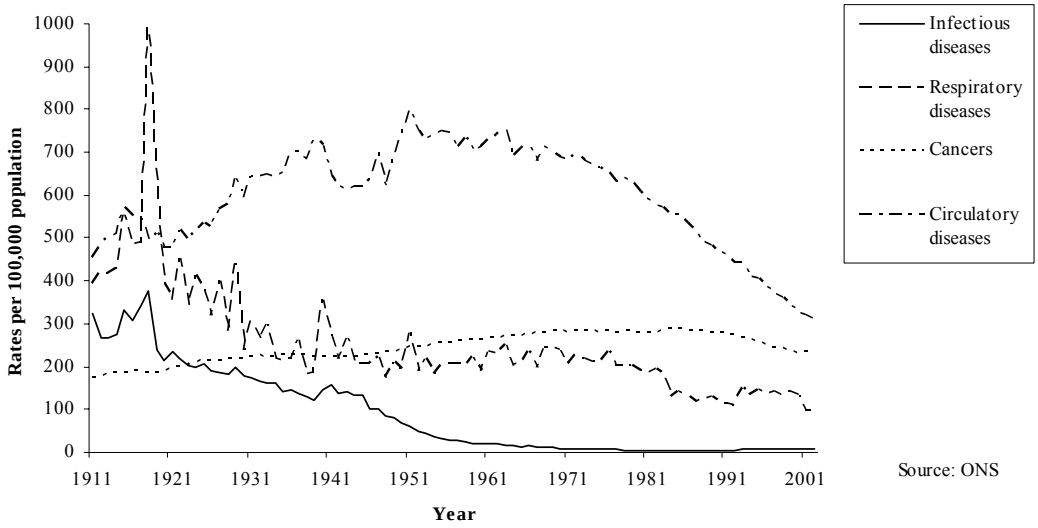
Table 3 indicates the wide variations in mortality improvement for differing age groups over differing periods. It also shows the 'ageing of mortality improvement' in the UK. In the first half of the 20th century, the highest rates of improvement were seen at the younger ages. However, from 1960-2 onwards, excluding children and teenagers, the ages at which the highest rates were seen has gradually been getting older (at ages 40 to 49 over the period 1970-2 to 1980-2, ages 50 to 59 over the period 1980-2 to 1990-2 and ages 60 to 69 over 1990-2 to 2001-3, for both males and females).

Figure 3 shows age standardised mortality rates by selected major causes of death for England and Wales over the period 1911 to 2002, for males and females separately. As can be seen, the rapid improvements in mortality over the last 40 years or so have been largely driven by falls in age standardised mortality rates due to circulatory diseases, of around 55 per cent for males and 60 per cent for females. Mortality from cancer rose gradually over the period for males to a peak in the early 1980s followed by a sharp decline during the 1990s, which may now be starting to tail off. There is a similar pattern for female mortality. There has also been a decline in mortality from respiratory diseases, although the pattern is more difficult to discern because of changes in the ICD coding relating to deaths involving certain respiratory disease such as pneumonia during the 1980s and 1990s. The figures suggest that, allowing for these changes, mortality rates from respiratory diseases have been declining slowly for males and relatively stable for females over the past 20 years or so. It is debatable whether the dramatic decline in mortality from circulatory diseases can continue at its current rate (which, if extrapolated, would mean the eradication of such deaths in the next 25 years or so) or whether it will slow down in the future (as appears to be the case for deaths from respiratory diseases). Even if the decline were to continue, as the proportion of deaths from circulatory disease reduces it would be the results of changes in mortality rates from other causes which would have a greater effect on the rate of future mortality improvement

Table 3: Percentage annual rate of mortality improvement for age-standardised aggregate mortality rates (using mx values from successive English Life Tables and Interim Life Table for England and Wales for 2001-03)

Age group	1910-12 to 1920-22	1920-22 to 1930-32	1930-32 to 1950-52	1950-52 to 1960-62	1960-62 to 1970-72	1970-72 to 1980-82	1980-82 to 1990-92	1990-92 to 2001-03	1910-12 to 2001-03
Males									
0-4	3.1%	2.9%	4.9%	3.0%	2.1%	4.3%	4.2%	3.1%	3.6%
5-9	1.4%	2.2%	6.1%	3.1%	1.5%	4.0%	3.4%	4.8%	3.7%
10-14	0.5%	2.0%	4.9%	3.0%	1.3%	2.6%	2.3%	2.9%	2.7%
15-19	0.1%	0.9%	4.8%	0.2%	0.3%	1.0%	1.9%	2.3%	1.8%
20-24	0.1%	1.3%	4.3%	1.8%	1.3%	1.4%	-0.2%	0.6%	1.7%
25-29	0.5%	2.0%	4.0%	3.5%	1.4%	0.6%	-0.4%	-0.3%	1.7%
30-34	1.0%	2.7%	3.7%	2.7%	1.6%	1.4%	-0.2%	-0.9%	1.7%
35-39	1.4%	2.4%	3.6%	2.2%	1.1%	1.8%	-0.1%	0.2%	1.8%
40-44	1.8%	1.6%	2.9%	2.0%	0.0%	2.2%	1.4%	0.3%	1.7%
45-49	2.3%	0.5%	2.0%	1.8%	-0.4%	2.1%	2.5%	0.7%	1.5%
50-54	2.0%	0.7%	1.0%	1.2%	0.2%	1.6%	3.0%	1.8%	1.4%
55-59	1.9%	0.7%	0.3%	0.6%	0.8%	1.2%	3.1%	2.3%	1.3%
60-64	1.4%	0.6%	0.1%	0.2%	0.8%	1.4%	2.4%	2.8%	1.1%
65-69	0.9%	0.2%	0.2%	0.1%	0.3%	1.7%	1.8%	3.2%	1.0%
70-74	0.6%	-0.1%	0.4%	0.2%	0.1%	1.5%	1.8%	2.7%	0.9%
75-79	0.3%	-0.3%	0.4%	0.5%	0.4%	0.9%	1.8%	2.1%	0.8%
80-84	0.1%	-0.4%	0.2%	0.9%	0.7%	0.5%	1.7%	1.8%	0.7%
85-89	0.1%	-0.7%	0.0%	1.3%	0.8%	0.5%	1.4%	1.0%	0.5%
90-94	0.0%	-0.8%	-0.1%	1.6%	0.6%	0.8%	0.8%	0.7%	0.4%
95-99	-1.7%	-0.8%	0.1%	1.8%	-0.1%	1.2%	-0.2%	0.5%	0.1%
0-99	0.9%	0.3%	0.7%	0.8%	0.5%	1.2%	1.8%	2.0%	1.0%
Females									
0-4	3.4%	3.2%	5.0%	3.0%	2.1%	4.3%	4.2%	2.6%	3.6%
5-9	1.5%	3.3%	7.2%	3.4%	1.5%	3.6%	3.1%	3.0%	3.8%
10-14	0.3%	2.7%	6.5%	4.1%	1.1%	1.7%	2.4%	2.4%	3.1%
15-19	0.2%	1.2%	6.2%	5.4%	-0.4%	1.8%	1.1%	1.5%	2.6%
20-24	-0.4%	1.4%	5.5%	6.4%	0.6%	2.0%	1.1%	0.9%	2.6%
25-29	0.0%	1.8%	4.8%	6.1%	2.0%	1.4%	1.7%	0.3%	2.5%
30-34	0.9%	2.1%	4.3%	4.4%	2.1%	1.6%	1.5%	0.2%	2.4%
35-39	1.8%	2.0%	3.7%	2.9%	1.7%	2.0%	1.3%	0.9%	2.2%
40-44	2.3%	1.7%	3.0%	2.1%	0.7%	2.4%	2.0%	0.6%	2.0%
45-49	2.4%	1.2%	2.5%	1.8%	-0.1%	2.2%	2.3%	0.7%	1.7%
50-54	2.0%	1.2%	2.0%	1.7%	-0.1%	1.3%	2.6%	1.2%	1.6%
55-59	2.1%	0.9%	1.8%	1.6%	0.3%	0.6%	2.3%	1.8%	1.5%
60-64	1.5%	0.8%	1.6%	1.5%	0.8%	0.5%	1.4%	2.4%	1.3%
65-69	1.2%	0.6%	1.3%	1.3%	1.0%	1.0%	0.9%	2.5%	1.3%
70-74	1.0%	0.4%	1.1%	1.3%	1.1%	1.4%	1.1%	1.8%	1.2%
75-79	0.6%	0.1%	0.8%	1.4%	1.2%	1.5%	1.5%	1.2%	1.0%
80-84	0.3%	-0.1%	0.5%	1.4%	1.4%	1.2%	1.9%	0.9%	0.9%
85-89	-0.1%	-0.5%	0.3%	1.2%	1.3%	0.8%	2.1%	0.3%	0.6%
90-94	-0.1%	-0.6%	0.2%	0.8%	1.1%	1.0%	1.5%	-0.2%	0.4%
95-99	-0.4%	-0.6%	0.6%	0.2%	0.2%	2.1%	0.3%	-0.5%	0.3%
0-99	0.8%	0.3%	1.1%	1.4%	1.1%	1.2%	1.6%	0.9%	1.1%

Figure 3: Mortality by major cause and gender – England and Wales, 1911-2002
(a) Males



(b) Females

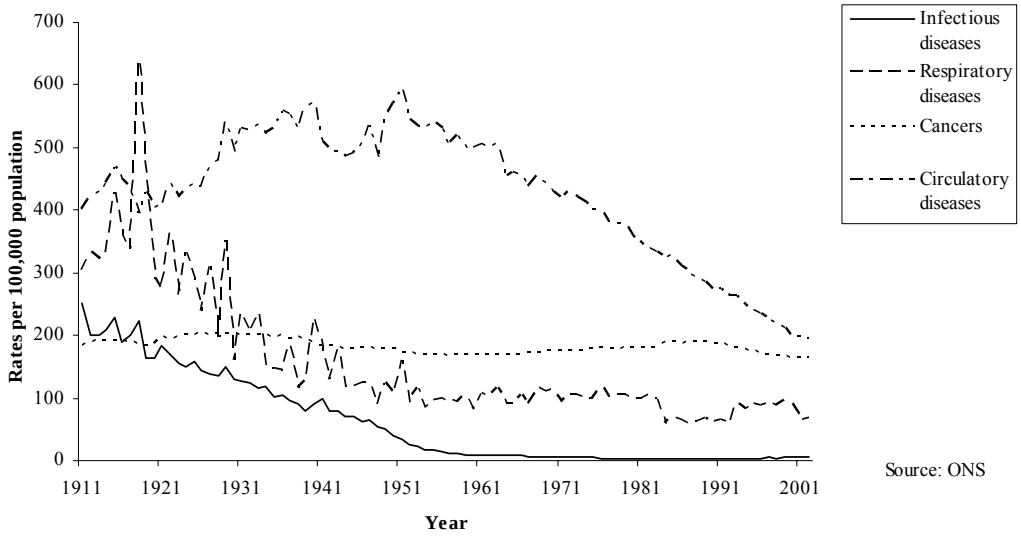


Table 4 gives death rates by selected cause of death for England and Wales in 2002. In general, cancers and circulatory disease are the major causes of death for males aged 45-64. Deaths from circulatory diseases become more dominant at older ages. For those aged 85 and over, deaths from respiratory disease become a major factor so that the

distribution of deaths by cause for men in their 80s is rather different to that for men in their 60s. At these older ages, cancer and heart disease are less significant than strokes and respiratory disorders. Broadly similar patterns exist for females, although circulatory disease is a less important cause than for men at ages 45-64, as is cancer at older ages.

Table 4: Selected causes of death: by sex and age, 2002, England and Wales

Rates per 100,000 population

	0-14	15-29	30-44	45-64	65-84	85 and over
Males						
Infectious diseases	2	1	3	6	30	142
Cancers	4	6	23	245	1,403	3,422
Circulatory diseases	1	4	27	232	1,861	7,982
Respiratory diseases	2	2	5	41	566	3,610
Injury and poisoning	4	41	45	36	59	299
All causes	**28**	**71**	**139**	**654**	**4,427**	**18,806**
Females						
Infectious diseases	1	1	1	4	24	115
Cancers	3	5	32	218	921	1,858
Circulatory diseases	1	3	11	88	1,269	7,016
Respiratory diseases	1	1	4	30	403	2,654
Injury and poisoning	3	10	12	15	45	294
All causes	**21**	**28**	**80**	**416**	**3,155**	**15,983**

Source: Mortality Statistics, Office for National Statistics

Key drivers of future mortality

Willets et al (2004) have identified several key forces likely to drive mortality change in the UK in the 21st century including:

- the 'cohort effect'
- the 'ageing of mortality improvement'
- increased uncertainty at younger ages
- changes in prevalence of cigarette smoking; and
- social class differentials

The cohort effect

Analyses of historical UK mortality rates by GAD have suggested some interesting patterns in past rates of mortality improvement by year of birth. The use of actual age specific mortality rates data provides too much 'noise' which makes it difficult to see any underlying patterns. Thus, the crude mortality rates need to be smoothed in some way in order to detect any potential patterns to the rates of improvement. **Figures 4 and 5** show the annual rates of improvement in smoothed mortality rates by age and year for males and females. The percentage levels of improvement are denoted by the various colours,

with dark red indicating annual rates of mortality improvement of 3.0% and over, whilst blue areas denote ages at which mortality rates have increased over successive years.

The figures exhibit several features. For males, those born in the late 1920s and early 1930s have consistently exhibited, over a very long period, higher rates of mortality improvement than those born in the years either side. There is also evidence that those born around 1945 may be exhibiting a similar pattern of higher rates of mortality improvement than those born either side. These patterns have been termed 'cohort effects'. As will be discussed later, GAD projections of mortality have been strongly linked to trends by year of birth, at least for older ages. There is less evidence of cohort effects in later years of birth. However, **Figure 4** shows that during the 1980s and early 1990s mortality rates for young adult males were worsening. This was mainly due to increasing deaths from AIDS related causes, drink and drug related deaths and suicides outweighing improvements in death rates from other causes. There is evidence that there may be a cohort effect arising for those born in later years of birth, with those born in the early 1950s and in the early 1960s experiencing continuing lower rates of mortality improvement, or even worsening, relative to those born in between. The female data exhibits similar patterns for similar years of birth, although the differentials in mortality are not currently as high as for males. It is possible that these effects may be period specific rather than cohort specific, but future developments will be monitored. As well as the population as a whole, cohort effects have also been found for the subgroup of the UK population who buy life insurance or are in pension schemes run by insurance companies.

Several explanations for these cohort effects have been put forward, including:

- Differences in smoking patterns between generations
- Better diet during and after the second world war
- Benefits from the introduction in the late 1940s of state education and the NHS
- These generations have been the recipients of medical research and advances which have moved on from causes of death affecting children and young adults to those affecting older people.

An analysis of mortality by cause of death for circulatory disorders, cancer and respiratory diseases also displays cohort effects for those born in the 1930s (Willets et al 2004). Willets (2003) suggests that trends in smoking prevalence maybe a major driver for the relatively high improvements for those born in the 1930s, whilst the cohort effect for those born in the early 1940s appears to be driven more by improvements in mortality from heart disease, perhaps caused by the early life experience of those born in or around World War II.

Inevitably, the smoothing process chosen has some effect on the resulting patterns of mortality improvement. However, similar patterns have been observed in UK data by other observers and also in other countries such as Denmark and Japan, and, for males in particular, in France, Italy and Switzerland. The cohorts most affected are not always centred on the same years of birth; for example, in Japan it is those born around 1910 who have been exhibiting the highest rates of improvement.

Figure 4: Annual improvement in smoothed mortality rates – males, UK

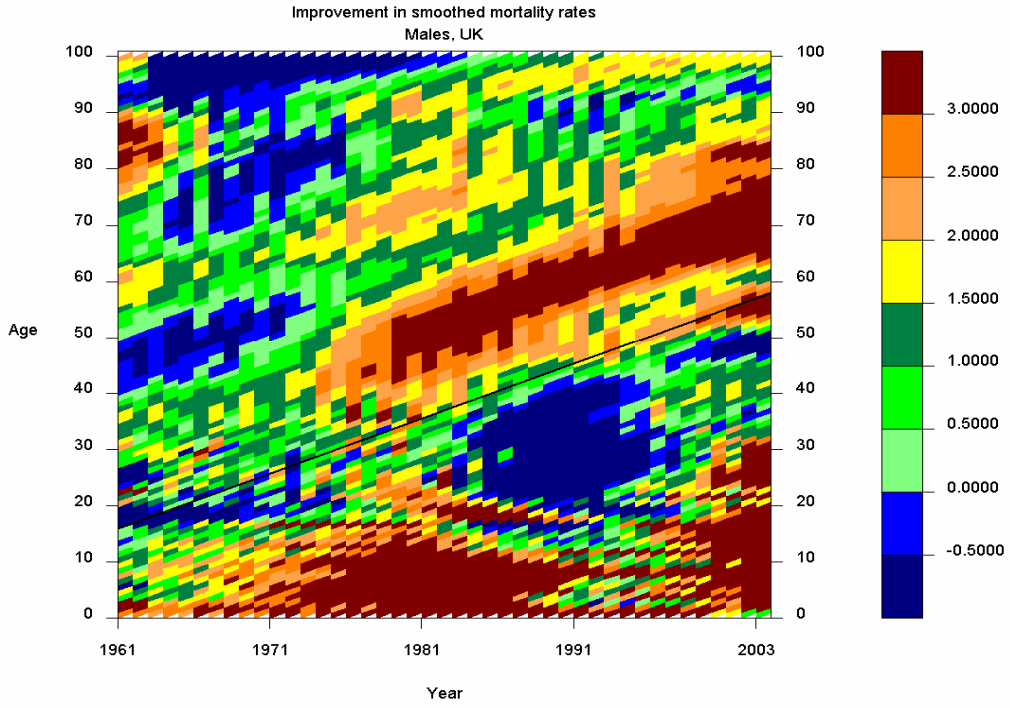
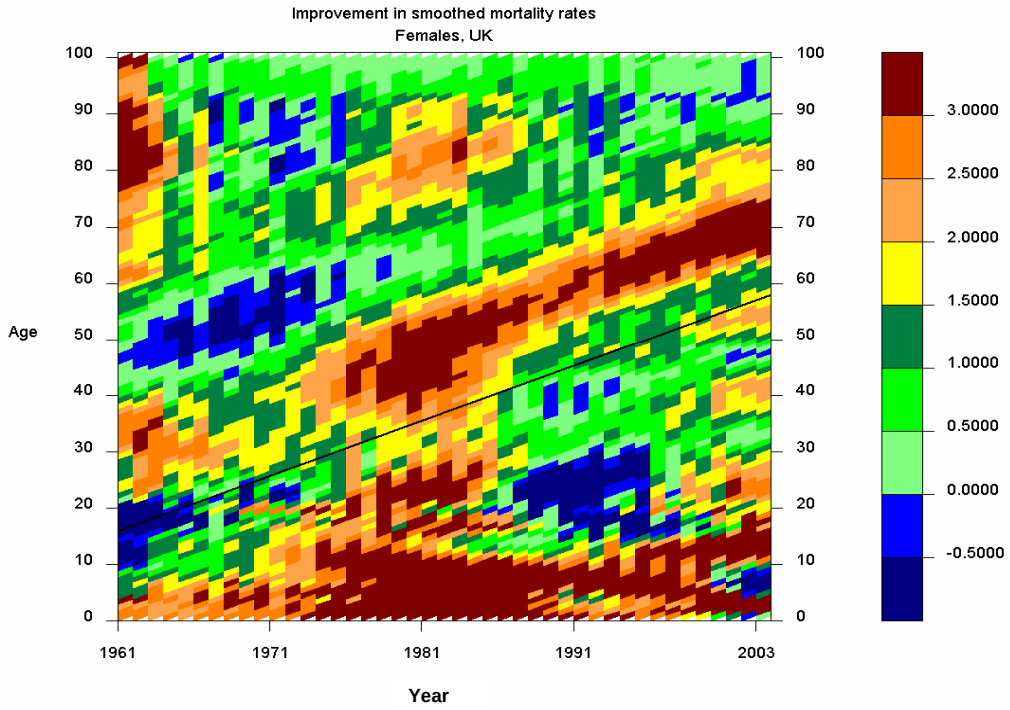


Figure 5: Annual improvement in smoothed mortality rates – females, UK



The ageing of mortality improvement

Table 3 and **Figures 4 and 5** show that for the UK population the ages at which the highest rates of improvement have occurred have been increasing over time. To some extent, this effect is tied up with the cohort effects but it encompasses a wider range of ages and years of birth; it is not necessary that rates of improvement follow a cohort effect for an ageing of mortality improvement to be exhibited. Such patterns can be seen in mortality data for Australia, New Zealand and for Swedish males.

Smoking trends

Various studies have suggested that changes in smoking behaviour in the UK have contributed significantly to the decrease in mortality (e.g. the National Heart Forum (1999) have suggested that the change in cigarette consumption has been responsible for a decrease of between one quarter and one third of the reduction in heart disease mortality). The effects of smoking are dependent not just on overall prevalence but on the duration of smoking and also tend to be correlated with age. For instance, lung cancer rates for men have peaked and are falling, with the peak being later for each successive age, and in general, each time relating to the cohort of men born in the 1900s; for women the peak has been later for each successive age group, each time relating to women born in 1925-30, so that lung cancer mortality rates are still rising for women aged 75 and over (Willets et al, 2004). After a sustained fall in smoking prevalence during the 1980s, levels appear to have stabilised at most ages during the 1990s – thus it may be that there will be lower gains in mortality improvement from the effects of smoking behaviour in future years.

Uncertainty at young ages

As noted earlier, mortality rates in the 1980s and 1990s increased for young ages as deaths related to AIDS, drug and alcohol abuse and violence more than offset improvements in health-related causes of death. This trend appears to have been reversed in more recent years, but is indicative that the future course of mortality rates at young ages is considerably uncertain. However, from the point of view of population projections, the mortality rates at these ages are low and have little overall effect on projected future numbers, unless future mortality rates were to be increased several fold.

Mortality by social class

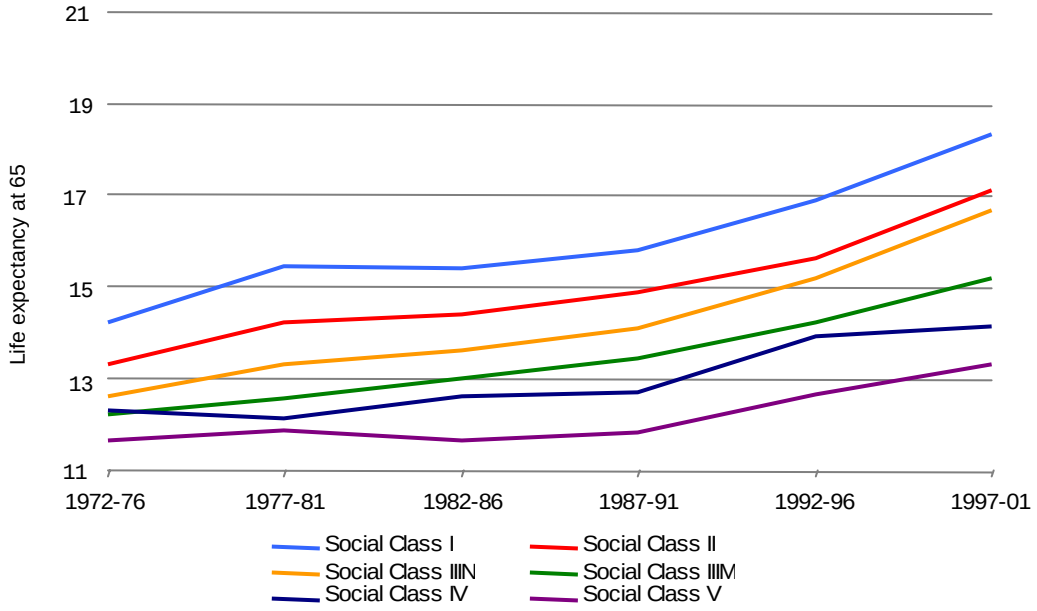
Period life expectancy by social class, calculated from the Office for National Statistics Longitudinal Study, exhibits a gradient both at birth and at older ages, with those in Social Class I living longest and those in Social Class V least, as can be seen from **Table 5**. **Figure 6** shows that there has been a consistent gradient across all social classes of the trends in period life expectancy for males aged 65 for the period 1972-2001.

Table 5: Period life expectancy at birth and at age 65 by gender and social class, England & Wales

	Males		Females	
	1972-76	1997-99	1972-76	1997-99
Period expectation of life at birth				
I	72.0	78.5	79.2	82.8
II	71.7	77.5	77.0	81.5
IIIN	69.5	76.2	78.0	81.2
IIIM	69.8	74.7	75.1	79.2
IV	68.4	72.7	75.0	78.5
V	66.5	71.1	73.9	77.1
Non-manual	71.0	77.3	77.5	81.4
Manual	68.9	73.8	74.9	78.6
Period expectation of life at age 65				
I	14.2	17.5	19.3	20.8
II	13.3	16.8	17.1	19.9
IIIN	12.6	16.3	17.7	19.6
IIIM	12.2	15.1	16.3	17.9
IV	12.3	13.8	16.8	17.4
V	11.6	13.4	16.4	16.3
Non-manual	13.1	16.8	17.4	19.8
Manual	12.3	14.6	16.5	17.4

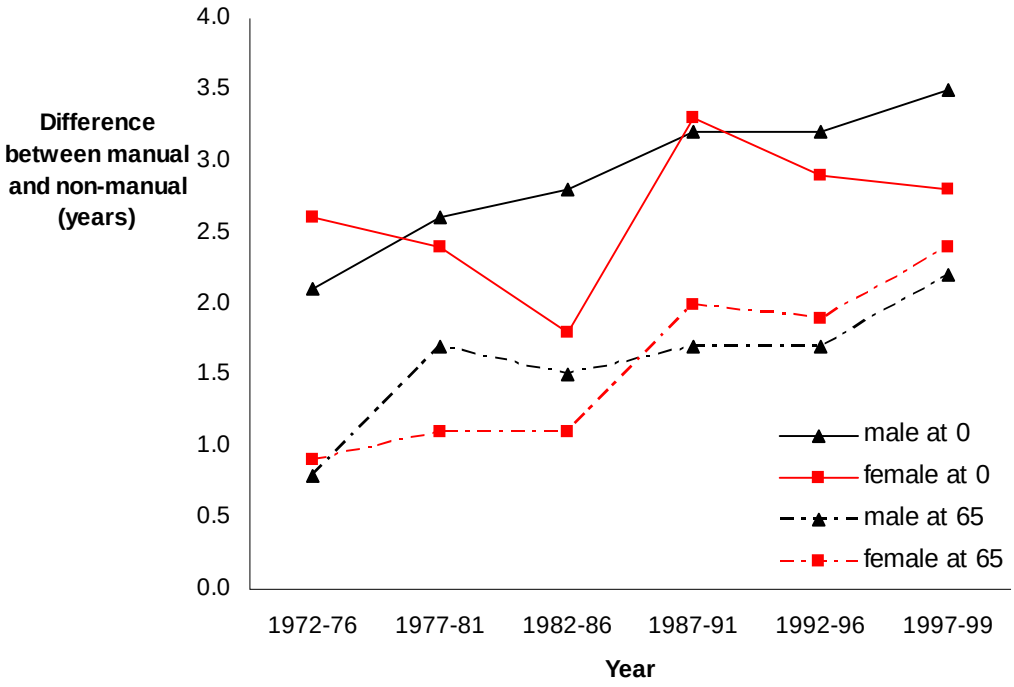
Source: Health Statistics Quarterly No15, Autumn 2002

Figure 6: Trends in male life expectancy at age 65, 1972 – 2001, E&W



Since the proportion of the population in Social Class I is only around 5% and a similar percentage are in Social Class V, the differential between life expectancy for manuals and non-manuals may give a better indication of overall trends. As can be seen from **Figure 7**, this differential has been growing over the past two decades for both males and females at birth and at age 65.

Figure 7: Differential in period life expectancy at age 65 between manual and non-manual classes, England and Wales, 1972-99



One reason for the existence of a mortality gradient by social class is that cigarette smoking varies considerably by social class, although this only explains part of the differentials. Other reasons suggested include selection effects, environmental conditions and cultural/lifestyle differences (Townsend and Davidson, 1982) and differentials in work-related stress (Marmot et al 1997). Valkonen (2001) has concluded that explanations for social differentials are likely to differ for different causes of death and by country and time period.

Medical Advances

A large element of the current improvements in mortality has been driven by medical advances. Mortality from heart disease has been partly reduced by the development of new treatments and surgical procedures. There appears to be ongoing public and political support and availability of funding for continuing medical research which would suggest that medical advances will continue to lead to further mortality decline. For example, the

availability of statins has been described as a potentially major influence on modern medicine.

Ageing and maximal lifespan

There is a wide literature on human ageing. Several recent papers provide comprehensive reviews (e.g. Held (2002)). There are many theories as to why people age. Currently, most weight is given to theories which do not suggest that ageing confers advantages of itself, but arises through the indirect action of natural selection. Two examples of such theories are:

- the 'mutation accumulation' theory which suggests that ageing is explained by the accumulation over many generations of harmful late-acting genes which express their effects after the end of the reproductive period, and
- the 'disposable soma' theory, which considers the allocation of resources between growth, reproduction and bodily maintenance. Optimum allocation strategies give rise to smaller investments in bodily maintenance than would be necessary for indefinite lifespan.

Proponents of a biological maximal length to life discuss the 'Hayflick' limit – in the 1960s, Hayflick found that certain mammal cells could only divide up to a specific limited number of times, which were roughly linked with the typical lifespans of the organisms involved (Hayflick and Moorhead, 1961). Others have argued that lifespan can be viewed as a kind of biological warranty period linked to the reproductive period and physiological decline in the post-reproductive period that produce restraints on the duration of life (Olshansky 2003).

In the more 'optimistic' camp, Oeppen and Vaupel (2002) have observed that past predictions of limits to life expectancy have nearly all been broken shortly afterwards. They have observed that the highest observed life expectancy of any country has increased at a steady pace over the last 160 years or so and suggest that this is likely to continue into the future.

In the 'very optimistic' camp, some scientists have suggested that medical advances could lead to engineered negligible senescence. For instance, de Grey (2003) believes that there are only seven mechanisms for accumulating damage to the human body and that therapies for reducing or reversing all of these types of damage are currently foreseeable. Given sufficient commitment and resources, the possibility of life expectancy of 150 years, or even longer, may be with us in the next 20 to 30 years.

Genes linked to longevity have been isolated in experiments on fruit flies and nematode worms. It is not known how many of these so called 'gerentogenes' may exist or whether such genes, if found in humans, could be successfully manipulated to extend lifespan. Indeed, although these genes may be linked to longevity it does not follow necessarily that they cause ageing.

The possibility of ageing being the result of accumulating wear and tear on the body, for example, from 'free radicals' which are highly reactive atoms created as by-products of

burning oxygen in the body. These may react with other molecules, damaging cells in the process.

It is known that restricting the intake of calories results in increased longevity in laboratory animals. However, it is not clear why this happens and it is unlikely to be a practice followed by many humans.

Infectious diseases

Whilst recent medical advances and other factors have continued to lead to a regime of increasing life expectancy, factors which could work in the opposite direction should not be forgotten. One such area is the threat of infectious diseases.

There has been emergence of new infectious disease, and re-emergence of old ones such as tuberculosis, which may prove resistant to existing antibacterial agents. Increased and rapid travel provides the means for infectious diseases to spread quickly around the globe (eg SARS). Human behaviour has also helped spread certain diseases, for example hepatitis C and HIV.

So far, HIV is the only new example which has had a dramatic impact on mortality globally. In general, medical advances, rapid detection and global cooperation have managed to limit the effects of other newly arrived infectious diseases. The use of highly active antiretroviral treatment in high income countries has postponed HIV-related deaths but the numbers of newly infected individuals has continued to rise. The side and long-term effects of these treatments are also still uncertain.

As deaths from heart disease and cancers reduce in the future, resistance to antibacterials could mean that deaths from infectious diseases become more common at older ages Estimating the effects of an epidemic of an infectious disease is particularly difficult; whilst there would be a short term increase in mortality, the longer-term effects on mortality are more difficult to estimate. The effect may be simply a relatively short-term shock if those affected are mainly the elderly, causing, in large part, an advance of a few years of the deaths of those who would most likely have died in the immediate following years. On the other hand, the effects could be longer term if those of working age are particularly affected, leading to possible decreases in economic output in future years.

Obesity

There has been much discussion recently about the increase in obesity levels, both in the USA and in the UK, and the possible consequential effects on future mortality. Olshansky has suggested that the current levels of obesity in children and young adults in the United States could lead to reductions in future life expectancy over the next 40 years. Whilst increased obesity levels are likely to lead to increases in the levels of heart disease and diabetes and hence to an increase in future morbidity, it is less clear how future mortality will be affected. It may well be that if levels of these diseases increase significantly, more medical research would be focussed to treating these diseases or the causes of death arising from them. There appears to be considerable debate about the likely effects of increasing obesity on mortality. Obesity is likely to lead to increases in

deaths from heart disease but these are the causes of death which are currently experiencing large reductions. It has been suggested that obesity has less impact on mortality than previously thought (Flegal et al. 2004).

Debate about future

As discussed earlier, there is currently considerable debate as to the potential for future human longevity and whether the impact of future technical, medical and environmental changes will have a greater or lesser effect on improvements in mortality in the future than they have had over the 20th century and hence, whether the current high rates of mortality improvement experienced at some ages will continue in the future.

A reduction in the rates of mortality improvement is a common assumption made in official national projections for many countries. This is based partly on the arguments that the large rates of improvement seen over the twentieth century were a result of medical and environmental change which were unlikely to be repeated in the future to such an extent and that it is also likely to be more difficult to sustain this level of improvement in mortality indefinitely. Ageing and death are not genetically programmed, but are a predictable by-product of stable reproductive biologies. Whilst advances in biomedical technology and lifestyle will permit life expectancy to continue to increase over the short-term, a repetition of the gains experienced over the 20th century would require an ability to slow the rate of ageing – a capability which does not currently exist and which would need implementation on a large scale to have a measurable impact.

It is also argued that there is likely to be a slowing down because of potential biological limits, the increase in obesity, the emergence of new diseases and reemergence of drug-resistant older ones and the possibility of it being more difficult to make medical advances which would have as great an effect on mortality as past advances. It should also be noted that, in the UK, whilst there has been considerable improvement in mortality at ages in the sixties and seventies over the last 20 years there has been little improvement in mortality rates for males in their thirties and early forties over the same period.

However, other demographers argue that current rates of mortality improvement might continue into the future indefinitely or at least over a much longer period than often assumed, based on the experience of the recent past and an assumption of continued medical advances, for example in stem cell research. Analysis of large cohorts of data suggests that mortality rates reach a plateau at advanced ages and may even decline (Thatcher et al 1998). This appears to contradict the supposition of increasing mortality after the end of the reproduction period. It is also pointed out that maximum limits proposed on biological grounds in the past for the expectation of life have always been exceeded.

Projection methodologies

Approaches to projecting age specific mortality rates can be classified in various ways – for example, process-based, explanatory, extrapolative or some combination of these.

Process-based methods concentrate on the factors that determine deaths and attempt to model mortality rates from a bio-medical perspective. For example, an assumption that death is caused by the accumulation of defects leads to a mathematical description of mortality. Such methods are not generally used by official bodies to make projections, but they can be used to inform extrapolative methods. These methods are only effective to the extent that the processes causing death are understood and can be mathematically modelled.

Explanatory-based methods employ a causal forecasting approach, for instance using econometric techniques based on variables such as economic or environmental factors. These appear to be rarely used in official projections because the explanatory links are not generally sufficiently understood. Data allowing deaths to be categorised by the risk factors used may not be readily available on death certificates and may need to be obtained from other sources such as medical or longitudinal studies. If the explanatory variables themselves are as difficult to predict as the dependent variables (or indeed more so), then the projection's reliability will not be improved by including them in the model. This is an approach which has been used to model Dutch mortality (Tabeau et al 2000).

A methodology that allows future projected mortality to be derived form the impact of various risk factors on mortality may only be possible if the aggregate mortality projections are built up by analysing the mortality of subgroups. However, disaggregating mortality into these subgroups may be difficult and the composition of the subgroups is likely to change over time.

Although following an explanatory approach may be difficult or impossible, examining past effects of key explanatory variables may provide insight into past trends and the possible future course of mortality.

Extrapolative methods are based on projecting historical trends in mortality into the future. All of the numerous methods for doing this include some element of subjective judgement, for example in the choice of period over which past trends are to be determined. Simple extrapolative methods are only reliable to the extent that the conditions which led to changing mortality rates in the past will continue to have a similar impact in the future. Advances in medicine or the emergence of new diseases could invalidate the results of an extrapolative projection.

Trend methods involve the projection of historical trends in age-specific mortality rates into the future. One problem with these methods is that the relationship between the rates at different ages is often ignored. If mortality rates at different ages are projected forward independently, it is possible that the results will not be plausible. For example, mortality rates at older ages may eventually become lower than those at younger ages.

Parametric methods involve fitting a parameterised curve to data for previous years and then projecting these parameters forward. However, the shape of the curve may not continue to describe mortality satisfactorily in the future.

Targeting methods involve assuming a target or set of targets, which are assumed to hold at a certain future date and to which the population being projected is assumed to approach over time. Targets could involve, for example, a set of age-specific mortality rates, specified rates of mortality improvement or expectations of life for some future year. Assumptions will be required as to the speed of convergence. Targeting can overcome some of the drawbacks of a purely extrapolative approach, since the targets chosen can take into account any evidence of the possible effects of advances in medical practice, changes in the incidence of disease or the recent emergence of new diseases.

The methods used can either be applied deterministically or stochastically; most official national population projections are currently carried out deterministically.

Many of the available methodologies can be applied either to aggregate mortality data or data by cause of death. Projecting mortality by cause of death appears to provide a number of benefits such as providing insights into the ways in which mortality is changing. However, there are problems associated with this approach; for example,

- deaths from specific causes are not always independent,
- the actual cause of death may be difficult to determine or may be misclassified, and
- changes in the diagnosis and classification of causes of deaths can make analysis of trend patterns difficult.

These difficulties apply particularly at older ages, where most deaths occur.

Mortality projections in the United Kingdom

The UK Government Actuary's Department (GAD) has prepared the official national population projections for the United Kingdom and its constituent countries since 1954. The projections are prepared by GAD at the request of the Registrars General of England & Wales, Scotland and Northern Ireland. The assumptions used are agreed in consultation with the statistical offices of the four constituent countries, after input from other government departments who are users of the projections.

A new set of projections is normally made every second year, based on a full-scale review of the trends affecting the underlying assumptions about fertility, mortality and migration. The latest published UK population projections are the 2004-based projections and are available on the GAD website.

A new procedure for the latest projections was the setting up of an advisory panel of experts on fertility, mortality and migration. A meeting was held prior to the setting of

assumptions of the 2004 projections to enable an informed discussion about the range of views on possible future trends. On mortality, opinions were sought on two particular questions – what should the target rate of improvement after 25 years be, and should the tailing off improvements thereafter assumed in previous projections be continued. A questionnaire was also provided; on mortality the questions included asking for respondent's estimates of the average rate of mortality improvement and of expectations of life at birth in 2030, for males and females separately. Minutes of the meeting were made available after publication of the projections.

Review of mortality projection methodology for UK national projections

In 2000/01 GAD undertook a full-scale review of the methodology for projecting mortality for use in the national population projections as part of a programme of quality assurance of UK National Statistics. The main aims of the review were to:

- investigate whether the projected mortality rates fulfil users' needs, including the range of assumptions used in the variant projections.
- assess the adequacy of the current data sources and the possible availability of other relevant data sources.
- assess the suitability and robustness of the current methodology and consider whether an alternative methodology could be found which would overcome the problems identified while still providing at least the same level of performance in terms of reliability and defensibility.

The review addressed the basic *methodology* to be used for projecting mortality rates, but did not consider the precise *assumptions* to be applied in any particular set of projection methodology.

The review (ONS 2001) concluded that:
'Detailed studies conducted as part of the review have confirmed the validity of the existing methodology. In particular, an analysis of different methodologies gave no grounds for believing that any of the alternative methodologies assessed would be likely to outperform the present method in terms of projection accuracy or improve the transparency or defensibility of the projections.'

The review recommended that projections should not be carried out by cause of death but that an analysis of the past trends in causes of death should be carried out to help inform the assumptions made about future rates of mortality improvement. A number of other recommendations were made to strengthen the methodology, to meet the problems identified and in relation to a number of ancillary matters (such as estimating age specific mortality rates for those aged 90 and over), most of which have been incorporated in the latest projections.

Current methodology for projecting mortality in UK national projections

The current methodology used for projecting mortality in the national population projections can be broken down into various steps as follows:

First, estimated mortality rates for the base year of the projections and the rates of improvement in mortality rates by age and gender for the base year are derived by analyzing and extrapolating trends in mortality in recent historic data for the UK (currently the period from 1961 onwards to the year immediately preceding the projection period).

Assumptions are then made of the 'target' rates of mortality improvement in the target year of the projection period (currently the 25th year of the projection period), based on an analysis of past trends and expert opinion.

Assumptions are also made as to the method and speed of convergence from the estimated initial assumed rates of mortality improvement to the target rates of improvement over the first 25 years of the projection period and how the rates of improvement will change thereafter. The rates of improvement by age and gender between the base year and the target year are then obtained by interpolating exponentially between the rates of improvement assumed for the base year and those assumed for the target year. Further assumptions as to how the rates of mortality improvement will change beyond the target year are also required. For those born in earlier years, the interpolations to the target rate and beyond are carried out by year of birth, rather than by year of age, to continue to project forward the cohort effects in the rates of mortality improvement exhibited by those generations in past data, as discussed earlier. The projections at younger ages, where there is little evidence of cohort effects, are carried out by year of age. There is a resulting triangle of rates of improvement by age and year which are not covered by either of these processes; the rates of improvement here for a given age in a given year are obtained by interpolation between the rates for ages at either end of the gap for that year.

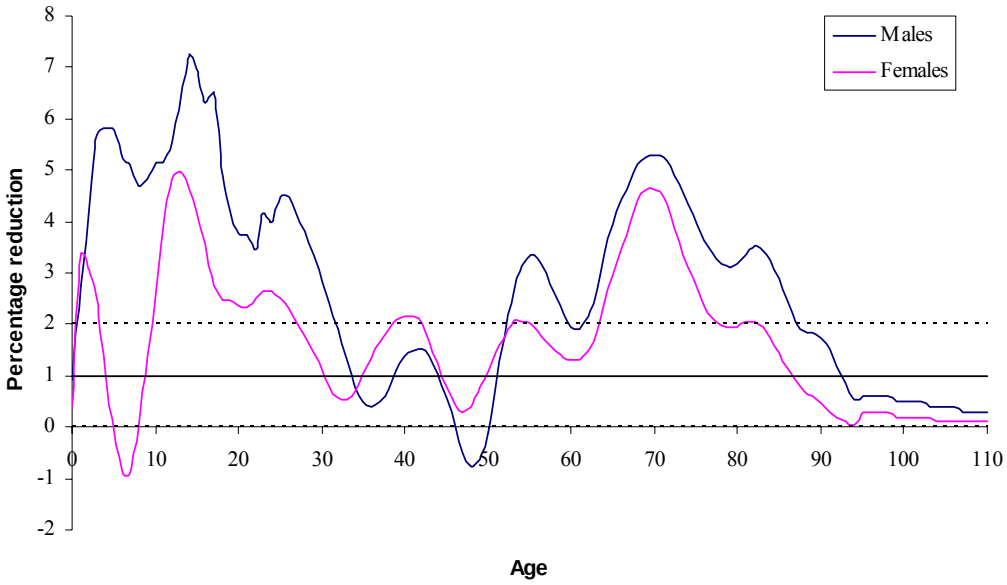
The resulting rates of improvement are then applied sequentially to the assumed trend mortality rates estimated for the base year of the projections to obtain projected mortality rates for each future year in the projection period by age and gender.

Mortality assumptions for 2004-based projections

Trend age specific mortality rates for 2004 and mortality improvements for 2003-04 were estimated from analysing and extrapolating trends in smoothed, graduated mortality rates over the period 1961-2003. **Figure 8** shows the assumed initial rates of mortality improvement for 2004 used in the 2004-based projections. These rates vary from those shown in **Table 3** since they are based on extrapolations of the smoothed historical mortality rates and are partly dependent on the methods of smoothing and extrapolation chosen. They also take into account the size and direction of recent improvements by age. In particular, the high rates for ages in the mid-sixties to mid-seventies reflect recent

high rates of mortality improvement (the annualised rate of improvement for ages 65-69 and for 70-74 over the period 1996-98 to 2001-03 is 4.0% pa compared to the rate over 1990-92 to 2001-03 of 3.2% pa and 2.7% pa respectively shown in **Table 3**.) The mortality rates for the first year of the projection, mid-2004 to mid-2005, were later obtained by adjusting the trend mortality rates so as to obtain the best estimates that could be made in the autumn of 2005 of the numbers of deaths at each age in 2004-05.

Figure 8: Initial smoothed percentage reductions in death rates by age United Kingdom 2003-04



Assumed improvements in mortality rates after 2004-05 are based on trends in mortality rates before 2004. The assumptions used in the 2002-based and 2003-based projections were that the annual rates of mortality improvement would converge to a common reduction of 1.0% at each age in 2027 (the 25th year of the 2002-based projections), halving every 25 years thereafter.

Table 6 shows the average annualised rates of improvement in the smoothed mortality rates for the United Kingdom for the period 1963 to 2003 used as the basis for analysing and projecting trends. The annualised improvements in the standardised mortality rate have been nearly 1.6% pa for males and around 1.3% pa for females. Whilst the annual rate of improvement over this period was relative stable for females, the rate of improvement over the latter half of this period was higher for males than over the first half. As discussed earlier, this appears to be partly due to differential trends in smoking behaviour between males and females. Relatively higher numbers of men have now given up smoking and mortality rates for males at older ages have shown large rates of improvement in recent years.

Table 6: Annual rates of improvement in standardised UK mortality rates

Period	Decrease in standardised UK mortality rate for ages 0 to 99	
	Males	Females
1963-2003	1.57%	1.30%
1963-1983	1.13%	1.38%
1983-2003	1.99%	1.22%

The average annual rate of improvement over the whole of the 20th century was around 1% for both males and females although the improvement rates vary by age. In particular, as discussed earlier, those born during the period 1925-1945 (and centred around 1931) have exhibited greater rates of improvement than those born on either side. As these generations reach older ages, the rates of mortality improvement at these older ages have been increasing, whilst those at younger ages have tended to decline. As these older cohorts reach much more advanced ages over the next 25 years, the contribution of their relatively higher rates of improvement to the overall rate of improvement is likely to lessen. Hence, other things remaining equal, it might be expected that the overall rate of improvement would decline as these cohorts become very old.

Taking into account the above, the levels of improvement over the last 40 and 70 year periods and the current debate as to whether the impact of future technical, medical and environmental changes will have a greater or lesser effect on improvements in mortality in the future than they have had over the 20th century, the target rate of improvement for 2029 (the 25th year of the 2004-based projections) was assumed to be 1.0% at all ages (equivalent to the average rate of improvement over the whole of the 20th century). This was the same target rate of improvement for the 25th year of the projections as used in the 2002-based projections. This compares to an age standardised rate of improvement for ages 0 to 99 using the projected rates of improvement by age for the first year of the projections shown in **Figure 8** of around 3.0% pa for males and around 1.75% pa for females.

The transition from current rates of mortality improvement by age and gender, derived from recent trends, to the target rate of 1.0% in 2029 is not assumed to take place linearly, but more rapidly at first for males and less rapidly for females. This partly reflects the fact that males are currently experiencing rather higher rates of mortality improvement than females. In previous projections, this convergence was projected by cohort for those born before 1947, as there is strong evidence of generational effects in the relative rates of mortality improvement for these cohorts. However, there is now growing evidence of similar generational effects for slightly younger cohorts. Thus, in these projections, convergence to the target rate of 1.0% has been done by cohort for all those born before 1960. For those born in 1960 and later, for whom there is little evidence of generational effects, the changes in the rates of improvement to the target rate are projected by age.

Previous projections have assumed that rates of mortality improvement would gradually diminish in the long-term. So, the 2002-based projection assumed that the rates of

mortality improvement in the 'target' year (2027) would halve every 25 years thereafter. However, expectations of life at birth have continued to rise at relatively constant rates over the last twenty years for both males and females, suggesting that, based on current trends, the previous long-term assumptions have been too pessimistic. The panel of experts also recommended that there should be no tailing off in the rate of reduction after the target year.

Thus, for the 2004-based projections, the rates of improvement after 2029 are assumed to remain constant (at the target rate of 1.0% pa) for all ages for each year thereafter. Taking account of the generally higher rates of improvement assumed prior to 2029, this produces averaged annualised rates of improvement in age standardised mortality of nearly 1.3% pa for both males and females over the whole 70 year projection period, which rates are slightly higher than those experienced over the past 70 years. As **Table 7** shows, the new projections generally assume slightly higher average rates of improvement for the future than experienced over corresponding periods in the past.

Table 7: Actual and assumed overall average annual rates of mortality improvement

	Males		Females	
	Past (actual)	Future (assumed)	Past (actual)	Future (assumed)
Last/next 22 years	2.02%	1.90%	1.34%	1.79%
Last/next 42 years	1.46%	1.47%	1.26%	1.42%
Last/next 72 years	1.17%	1.27%	1.22%	1.25%

Note: Analysis relates to England & Wales. Historic estimates are based on comparison of latest (2002-04) interim life tables with English Life Tables for 1930-32, 1960-62 and 1980-82. See GAD website[i] for further details.

Figures 9 and 10 show the actual and projected annual rates of mortality improvement using and same colour patterns as for **Figures 4 and 5**. The figures show the prolongation of the rates of improvement by cohort for those born before 1960 and by age for those born later. It might be argued that it would have been more desirable to use target rates that were somewhat higher than 1% for those born around the early 1930s, especially for males. However, there are concerns as to whether very high rates of mortality improvement would carry on into ages 90 and over and table 7 shows that, even with the current assumptions, in general mortality improvements over the future will be similar to, or higher than, those experienced over the past, except for males over the shorter term.

Figure 9: Actual and projected annual improvement in smoothed mortality rates – females, UK

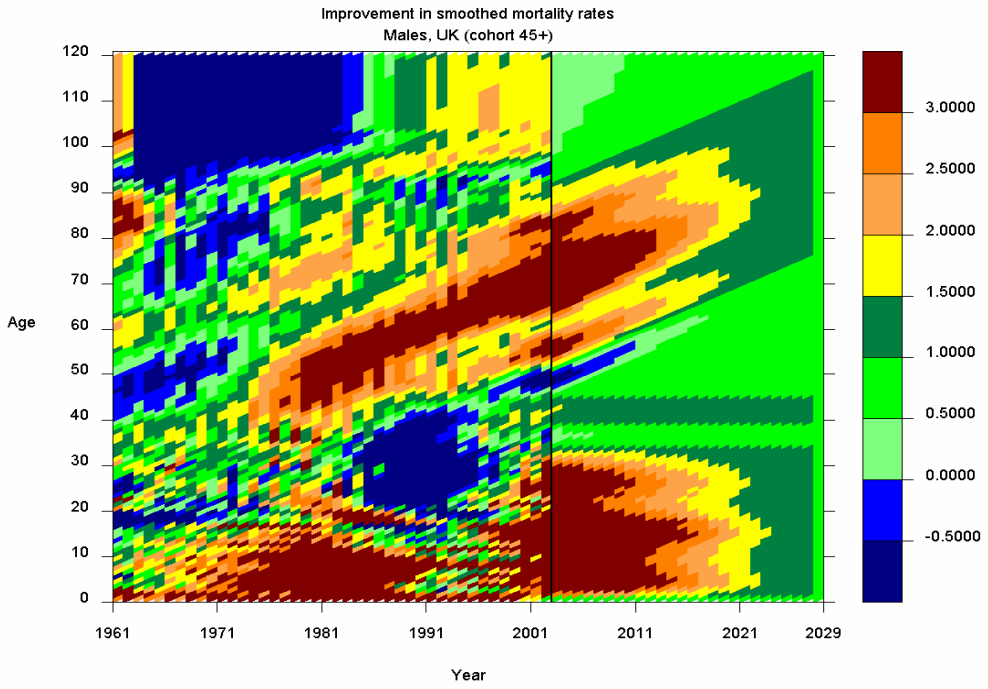


Figure 10: Actual and projected annual improvement in smoothed mortality rates – females, UK

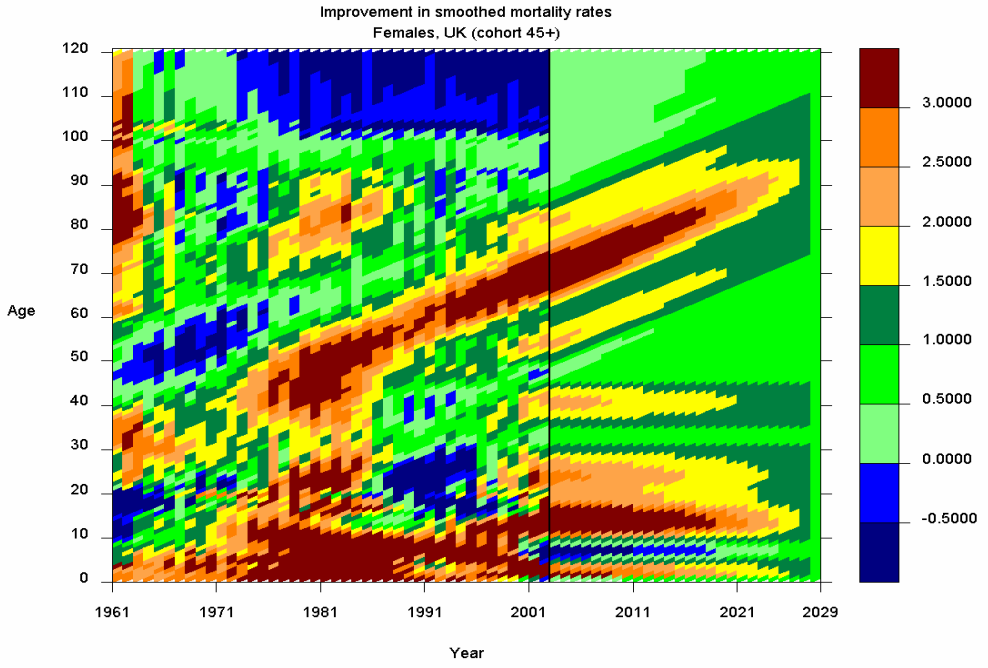


Table 8 shows actual and projected period life expectancies at birth for the UK for selected years. As a comparison, Japan currently has one of the highest period life expectancies at birth for both males and females. Under the UK 2004-based projections, period life expectancy at birth would not reach those experienced in 2003 in Japan (of 78.4 years for males and 85.3 years for females) until 2011 for males and 2034 for females.

Table 8: Actual and projected period expectations of life, United Kingdom 2004-based projections

Year	Males		Females	
	Age 0	Age 65	Age 0	Age 65
1981	70.9*	13.0*	76.9*	16.9*
1991	73.1*	14.1*	78.6*	17.8*
2001	75.8*	16.0*	80.5*	19.1*
2011	78.5	18.2	82.2	20.6
2021	80.2	19.7	83.9	22.0
2031	81.4	20.6	85.0	22.9
2051	83.6	22.2	87.0	24.5

* Actual data

Table 9 gives an indication of the differences in period and cohort life expectancies at birth and at age 65 for 2004 and those projected for 2054.

Table 9: Period and cohort life expectancies, UK

	2004		2054	
	Period	Cohort	Period	Cohort
Life expectancy at birth				
Males	76.7	86.2	83.9	92.4
Females	81.1	89.8	87.3	95.3
Life expectancy at age 65				
Males	16.7	19.2	22.4	23.9
Females	19.6	21.9	24.7	26.3

Projections for constituent countries of the UK

The initial analysis of past trends is carried out at the UK level. A comparison of the mortality experience of each country of the UK to that for the UK as a whole is then carried out to ascertain whether there should be any changes to the UK assumptions for future rates of mortality improvement when applied to the constituent countries. In practice, the same rates of mortality improvement have been used for each country as projected for the UK as a whole, except for Scottish males, where lower rates of improvement are assumed for certain ages over the first 25 years of the projections. The trend base mortality rates assumed for each country are derived by comparing recent mortality experience for that country with the UK as a whole.

The projections are carried out at a country specific level. Projected mortality rates for combinations of countries such as England and Wales, Great Britain and United Kingdom are obtained by back calculation from the appropriate projected aggregated deaths and midyear population estimates.

Variant projections

The inherent uncertainty of demographic behaviour means that any set of projections is likely to be proved wrong. To help users take into account the consequences of future experience differing from the assumptions made and to give some idea of the sensitivity of the results to changes in the assumptions, variant projections are also carried out based on alternative assumptions of mortality (and also fertility and migration). Two standard variant mortality assumptions (labelled high life expectancy and low life expectancy variants) are provided for each set of projections. These are intended to be plausible alternatives to the principal assumptions but not to represent upper and lower limits to future demographic behaviour. Other variants have also been published for recent projections as special scenarios; e.g. one in which mortality rates are assumed to remain constant at the levels assumed for the first year of the projections and a constant mortality improvement scenario in which mortality rates were assumed to continue to increase in line with recent trends prior to the projection period.

At present it is not possible to provide probabilistic interpretations for these variants. However, work on the possible ways of attaching probability levels to mortality variants is being taken forward.

For the 2004-based projections the high life expectancy variant assumes target rates of improvement in 2029 of 2.0% a year and the low life expectancy variant assumes target rates in 2029 of 0% a year for all ages. A 'no mortality improvement' special scenario variant was also produced, where it was assumed that future mortality rates will remain constant at the values assumed for the first year of the projections. The 'constant mortality improvement' scenario variant, where it was assumed that future overall mortality would continue to improve indefinitely at around 2.0% a year (the same rate at which overall mortality was improving in the years immediately prior to 2004), was not produced as this would essentially have provided results very close to that of the standard high life expectancy variant.

Table 10 shows the resulting expectations of life at birth in 2040 under the principal projection and each of these variants projections.

Table 10: Principal and variant projections: assumed period expectations of life at birth and at age 65 in 2050 for the United Kingdom

	Standard variants			Special case scenario
	High variant	Principal projection	Low variant	No improvement
Males				
At birth	87.7	83.5	79.2	76.8
At age 65	25.4	22.1	19.1	16.8
Females				
At birth	90.2	86.9	83.6	81.1
At age 65	27.1	24.4	21.9	19.6

Other projections of mortality in the UK

Continuous Mortality Investigation

The Continuous Mortality Investigation (CMI) is a body funded by the UK life insurance industry, and run by the Faculty of Actuaries and Institute of Actuaries, which collects deaths and in force data by age and gender from participating UK life offices for various population subgroups who have taken out insurance contracts, including annuities, and publishes graduated mortality rates derived from these data, together with projections of future mortality rates by year and age.

Data are collected of numbers of claims (or annuities ceasing payment by death) during the preceding calendar year, and numbers of policies in force at the end of each calendar year; in the case of some classes of pension and annuity business, total amounts of annuity are collected as well. Thus, the investigation is not of deaths, but claims, and various crude adjustments are needed to allow for persons with duplicate policies. Data are always subdivided by individual age and sex, and then by other categories determined by the evolving nature of the business; for example data in respect of assurances are now split by smoker/non-smoker status whenever possible.

An important duty of the CMI is to produce the standard tables for use by actuaries in life insurance companies. New standard tables have been produced every 10 years or so; at the time of writing, new "00" Series tables are being prepared based on the experience of 1999-2002 to replace the current "92" Series tables. Tables for pensioners and annuitants have, and continue to be, produced in two stages. First, base tables are prepared, which are straightforward graduations of the data from the quadrennium. Second, the base tables are projected forward to allow for future improvements in longevity.

The methodology used for graduating the base tables has for some time been based on maximum likelihood fitting of a Gompertz-Makeham family of functions (of the general form "polynomial + exp(polynomial)" to the force of mortality. It is described in detail in Forfar, McCutcheon & Wilkie (1988).

Currently, the projection methodology is attracting more interest, because improving longevity is recognised as a significant factor in capitalising annuity business. Allowance for improvements has been made in past tables, latterly explicit projection formulae were used, which, in the form of reduction factors applied to the base table, resulted in a two-dimensional table indexed by age and calendar year. The "92" Series reduction factors were based on rates of mortality declining exponentially to asymptotic values, the latter chosen to produce greater improvements at younger ages than at older ages.

The methodology and assumptions can be expressed as follows.

Let $q_{x,0}$ be the probability of someone aged x in the base year dying before reaching age $x+1$,and

$q_{x,t}$ be the probability of someone aged x in year t dying before reaching age $x+1$.

(i) The long term mortality rate at age x is taken to be $\alpha(x).q_{x,0}$.

(ii) The mortality rate declines exponentially to its long term value.

(iii) For some period integer (n = 20, for example) a proportion $f(x)$ of the total long-term reduction in mortality at age x has occurred by time n

that is $[q_{x,0} - q_{x,n}] = f(x).[q_{x,0} - q_{x,\infty}]$.

These assumptions imply that

$$q_{x,t} = q_{x,0} . \{\alpha(x) + [1-\alpha(x)].[1-f(x)]^{t/20}\}.$$

Thus, having chosen n, the improvement is modelled by the two functions $\alpha(x)$ and $f(x)$, which are taken to be linear over the age range 60 to 110. The values of $\alpha(x)$ at age 60 and of $f(x)$ at ages 60 and 110 are chosen to obtain a best fit to the observed mortality improvements over a recent 20-year period. The latest projections assume that $\alpha(60)$ = 0.13, $\alpha(110)$ = 1.0, $f(60)$ = 0.55 and $f(110)$ = 0.29 with linear interpolation for intermediate ages. These rates of improvement were applied to base mortality rates derived from analysing the mortality experience for 1991-94 to obtain projected mortality rates by age and gender for future years.

The method has certain similarities in approach to that of the GAD projection methodology in the use of targets together with a form of exponential interpolation from current levels to the target level. However, the parameters are derived from observed trends in a subset of the total population, namely those receiving insured occupational pensions. In general, these people tend to be in the higher socio-economic classes, which have exhibited lower mortality than the population as a whole.

Mortality tables are produced both for lives and amounts of pension. In general, mortality rates per unit of pension are lower than those calculated on a lives basis reflecting the fact that mortality appears to be lower for those with larger amounts of pension (again this is probably an indicator of a correlation with socio-economic class).

The experience of the 1990s suggested that even these most recent projections underestimated actual improvements in mortality, and further investigation focussed on birth cohorts. The CMI Assured Lives data for males was found to show cohort effects similar to those in the general population, but based around an earlier year of birth of 1926.

New interim projections were issued in 2002 (CMI Working Paper No.1) in which the existing reduction factors, based on exponential decline, were adjusted in an ad hoc manner to allow for the main cohort effect. Three possible scenarios were put forward, called short, medium and long cohorts, depending on the period during which the excess rate of improvement enjoyed by the main cohort were supposed to wear off. Previous CMI projections had presented a single scenario.

The Financial Services Authority (the UK insurance regulator) is introducing new rules for capital adequacy based on stochastic evaluations of risk. While the initial impetus may have come from asset risk, the same philosophy applies to all forms of risk that may reasonably be modelled, including mortality risk. At the time of writing, a working party of the CMI is evaluating recent advances in projection methodologies, with a view to proposing methods suitable for use with the "00" Series tables, and adequate to meet the needs of life insurers under the new regulatory regime being introduced in the UK. Thus, the working party is examining projection methodologies capable of producing quantitative measures of risk as well as sample or central projections. CMI Working Paper No. 3, issued in March 2004; discusses, inter alia, contrasting methodologies such as time-series approaches (typified by the Lee-Carter model in much of the literature) and extrapolation of smoothed regression models; model, parameter and stochastic risk, and the problems of quantifying them; and the extent to which measures of uncertainty based on large populations could be applied to different, smaller populations such as an insurer's annuitant portfolio.

The two methods actively being researched are the use of a P-spline model and a Lee-Carter model (CMI Working paper No 15). The P-spline model fits a surface of mortality rates to historical data and in the region of the projections and provides estimates of the standard deviation of the log mean values of the rate of mortality. These can then be used to generate future scenarios together with percentile measures. The Lee-Carter methodology is being developed to provide sample paths of future mortality. One of the difficulties in adapting Lee-Carter methods to UK data is the existence of the cohort effects discussed earlier. These are not readily picked up by the original Lee-Carter methods, either in fitting past data or in projecting these effects forward, but research on this area is currently being undertaken.

Eurostat, United Nations and other projections

Figures 11 and **12** compare projected period expectations of life at birth for the UK using the proposed assumptions for the principal 2004-based projection and those suggested for the high and low life expectancy variants (discussed in section 10), with those from the projections published this year by the United nations and Eurostat.

As can be seen, the proposed assumptions for the 2004-based principal projection would produce projected period expectations of life at birth which are higher than those in the most recent Eurostat and United Nations projections for the UK in 2050 and for most years before then. The UK national projections are slightly more optimistic than the Eurostat projections for males, and broadly similar for females.

Figure 11: Projected period life expectancy at birth, Males, United Kingdom, 2004 to 2050

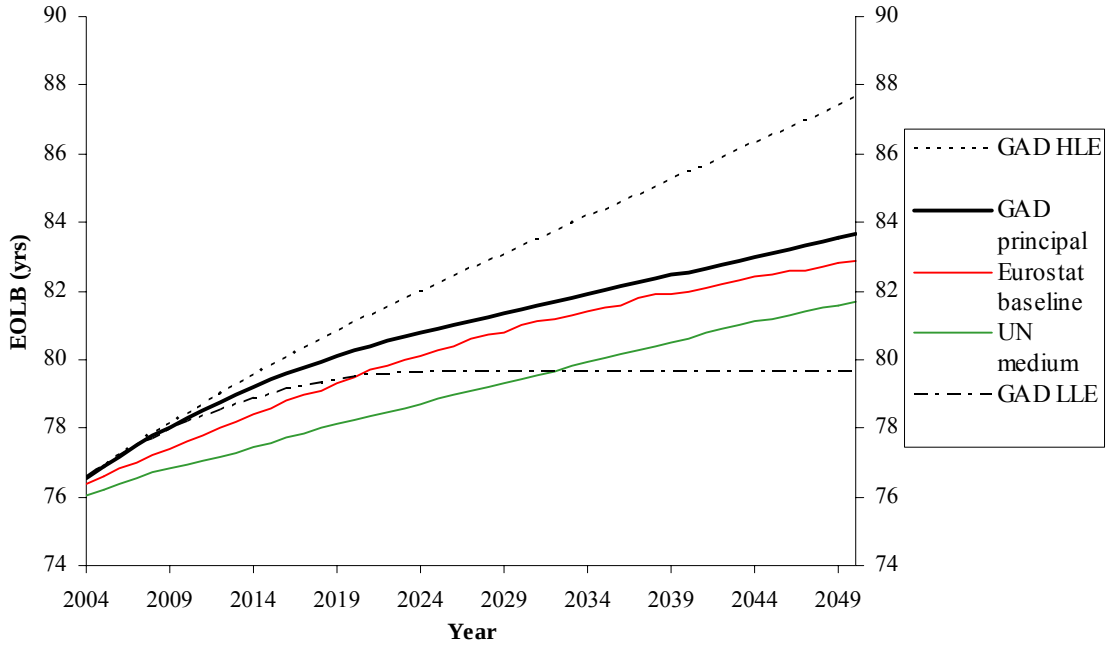


Figure 12: Projected period life expectancy at birth, Females, United Kingdom, 2004 to 2050

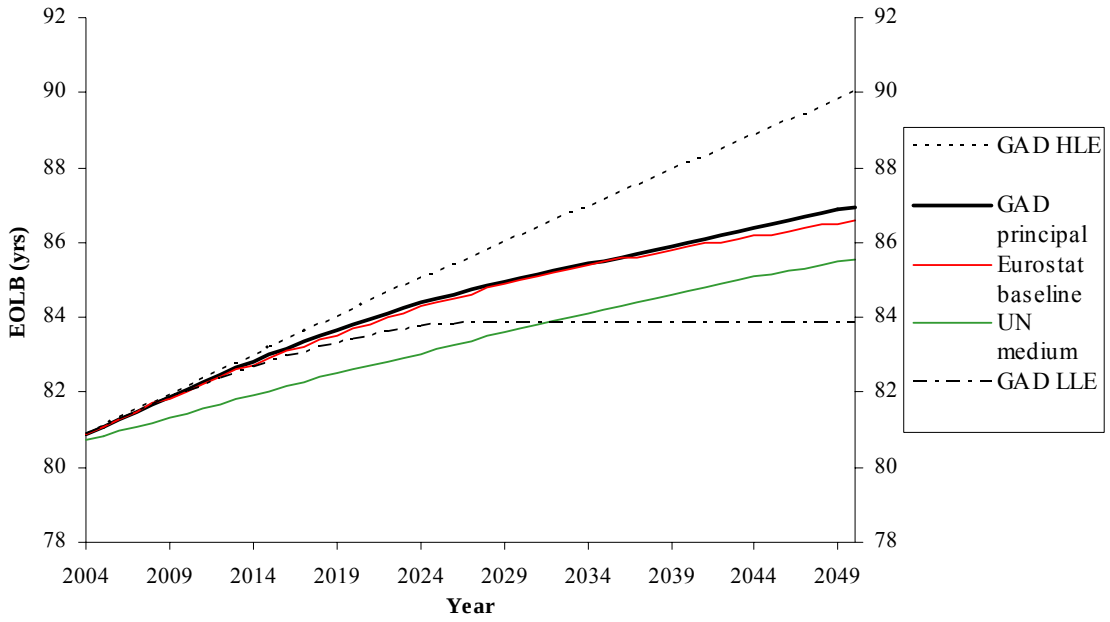


Table 11 provides a comparison of the projected period expectation of life at birth in 2050 from the latest official projections for a selection of countries for which these data are readily available with those proposed for the principal 2004-based UK projections.

Table 11 Projected period expectations of life (eol) at birth in 2050 – latest official projections for selected countries

Country	Projected period expectation of life at birth in 2050	
	Males	Females
United Kingdom	83.6	87.0
The Netherlands	79.6	82.6
Japan	81.0	89.2
USA	81.2	86.7
Canada[1]	82.0	85.3
Australia		
(declining improvement in eol at birth)	84.1	87.6
(constant improvement in eol at birth)	92.3	95.2

[1] Figures from Actuarial Study No4, National Population Projections, Office of the Chief Actuary

The Netherlands are maintaining a pessimistic stance as to the course of future life expectancy. Surprisingly, the Japanese projections assume relatively little improvement in life expectancy at birth for males. On the other hand the projections for Australia are more optimistic than the proposed UK projections, albeit the life expectancy at birth is currently around 2 years higher for both males and females.

Comparison of UK and Canadian mortality

Tables 12 and 13 show period expectations of life for selected ages taken from the official life tables for Canada and England and Wales (E&W Interim Life Tables for 1986 and 1996).

For males, period expectations of life for males at all ages before the Second World War were substantially higher in Canada than in England and Wales. In 1951, the expectation of life at birth in Canada was the same as E&W but remained higher at older ages. After 1951, expectations of life at birth began to increase faster in Canada than in E&W; however, at older ages there was further convergence until around 1971, after which expectations of life began to increase faster in Canada. Although this appears to still be the trend at younger ages, for adults there appears to be convergence again after 1986. This suggests that, over recent years, mortality improvements for older men have been greater in E&W than in Canada. However, Canadian expectations of life are still higher than in E&W by around 1.2-1.3 years for ages up to 60.

The pattern for females is not quite the same. The Canadian advantage before 1951 is not so marked and rather than the convergence seen for males at most ages between 1951 and 1971, there was a divergence for females with Canadian expectations of life increasing more rapidly than in E&W for most ages. From 1971, there was divergence for both males and females with similar falls in the differentials from 1986 onwards, although this also occurs for female infants and children. This suggests that improvements in female mortality have been higher in E&W than in Canada since 1986, for all ages. However, as for males Canadian expectations of life are still higher than in E&W by around 1.8 years for ages up to 60.

Table 12: Expectations of life for selected ages and calendar years, Canada and England and Wales, males

Males	1921	1931	1951	1961	1971	1981	1986	1991	1996
Canada Life Tables									
0	56.87	60.02	66.35	68.36	69.35	71.88	73.05	74.56	75.42
15	53.42	53.41	55.39	56.20	56.33	58.04	58.98	60.33	61.09
45	28.24	27.79	28.05	28.49	28.77	30.16	30.91	32.14	32.79
60	16.66	16.29	16.49	16.73	16.95	17.96	18.41	19.35	19.81
80	5.95	5.61	5.84	6.14	6.41	6.85	6.91	7.24	7.24
EW/ILT									
0	55.62	58.74	66.42	68.09	69.00	71.04	71.91	73.41	74.25
15	50.12	51.19	54.40	55.33	55.84	57.27	57.95	59.26	59.95
45	25.22	25.51	26.49	27.05	27.44	28.70	29.36	30.68	31.46
60	14.36	14.43	14.79	15.06	15.41	16.38	16.83	17.85	18.52
80	4.93	4.74	4.87	5.26	5.55	5.79	6.04	6.45	6.57
Canada - EW/ILT									
0	1.25	1.28	-0.07	0.27	0.35	0.84	1.14	1.15	1.17
15	3.30	2.22	0.99	0.87	0.49	0.77	1.03	1.07	1.14
45	3.02	2.28	1.56	1.44	1.33	1.47	1.55	1.46	1.33
60	2.30	1.86	1.70	1.66	1.54	1.58	1.58	1.50	1.29
80	1.02	0.87	0.97	0.88	0.86	1.05	0.87	0.79	0.67

Table 13: Expectations of life for selected ages and calendar years, Canada and England and Wales, females

Females	1921	1931	1951	1961	1971	1981	1986	1991	1996
Canada Life Tables									
0	58.29	62.12	70.84	74.18	76.37	78.94	79.74	80.90	81.16
15	53.66	54.15	59.19	61.51	63.02	64.90	65.53	66.56	66.76
45	28.84	28.87	31.14	32.82	34.37	35.99	36.48	37.44	37.60
60	17.22	17.15	18.64	19.90	21.39	22.80	23.17	23.99	24.05
80	6.15	5.92	6.38	6.90	7.88	8.76	8.94	9.42	9.28
EW/ILT									
0	59.58	62.88	71.54	74.00	75.25	77.00	77.68	78.96	79.39
15	53.06	54.28	58.99	60.85	61.78	63.03	63.55	64.66	64.98
45	27.73	28.30	30.76	32.06	32.88	33.95	34.41	35.48	35.81
60	16.22	16.50	18.07	19.11	19.99	20.89	21.21	22.08	22.34
80	5.56	5.46	5.84	6.40	6.99	7.50	7.83	8.42	8.34
Canada – EW/ILT									
0	-1.29	-0.76	-0.70	0.18	1.11	1.94	2.06	1.94	1.77
15	0.60	-0.13	0.20	0.66	1.24	1.87	1.98	1.90	1.78
45	1.12	0.57	0.38	0.75	1.49	2.04	2.07	1.96	1.79
60	0.99	0.65	0.56	0.80	1.40	1.91	1.96	1.91	1.71
80	0.59	0.45	0.53	0.50	0.89	1.26	1.11	1.00	0.94

As well as comparing expectations of life, it is helpful to look at the patterns of mortality improvement for Canada. **Tables 14 and 15** show the average annualised rates of improvement in age standardised mortality rates for 5-year age groups between selected Canadian life Tables (the figures for 2000 use an estimated life table for 1999-2001 derived by the author). A comparison with **Table 3** shows that the patterns of mortality improvement in Canada were rather different than those for E&W. There is some evidence of an 'ageing of mortality improvement' for males in the 1970s and 1980s but in more recent years, mortality at younger ages has shown large rates of improvement after a period of relatively low improvement. There is also some evidence of a possible cohort effect for those born in the 1930s, but this is not as pronounced as that for E&W. For females, the patterns are even less clear cut with only weak evidence of an ageing of mortality improvements or any cohort effects.

Mortality rates for each calendar year have been calculated for the period 1962 to 2001 from deaths data and mid-year population estimates for ages up to 89 (data by single year of age at ages 90 and over were not immediately available for some years). These were then graduated by year, and then smoothed across a year of age using the methodologies applied to the UK data in obtaining **Figures 4 and 5**, as far as possible (some different weights were used at some ages because the originals results suggested implausibly high rates of improvements at these ages). After further smoothing the resulting annual rates of improvement in smoothed mortality rates for Canada are shown in **Figures 13 and 14**. As for the figures for E&W, the patterns in these data are based on smoothed mortality rates and improvements in those rates and hence are not directly comparable with the figures in **Tables 14 and 15** which are based on actual data. However, overall the patterns are very similar, with weak evidence for both the 'ageing of mortality improvement' and for any cohort effects. The patterns suggest rather more of series of separate periods of change with mortality rates at most ages improving little or even worsening during the 1960s and early 1970s followed by quite large improvements at most ages in the late 1970s and early 1980s. Improvements carried on into more recent years, although at lower rates at some ages little improvement or worsening was exhibited for both males and females in their late twenties and thirties during the late 1980s and early 1990s which has been reversed in more recent years.

Table 14: Percentage annual rate of mortality improvement for age-standardised aggregate mortality rates (using mx values from Canadian Life Tables), males

Age	1881 - 1921	1921 - 1931	1931 - 1951	1951 - 1961	1961 - 1971	1971 - 1981	1981 - 1991	1991 - 1996	1921 - 1996	1991 - 2000[1]	1921 - 2000[1]
0-4	2.3%	3.5%	3.9%	3.7%	3.9%	5.7%	4.3%	2.9%	4.1%	2.7%	4.0%
5-9	2.2%	3.1%	4.2%	4.1%	2.4%	5.9%	5.0%	4.2%	4.1%	0.8%	3.8%
10-14	1.7%	2.4%	3.2%	3.5%	0.7%	3.0%	4.0%	3.2%	2.9%	4.4%	3.0%
15-19	0.5%	1.6%	3.0%	1.7%	-2.0%	1.3%	3.4%	3.2%	1.8%	3.0%	1.9%
20-24	1.1%	1.3%	2.9%	1.2%	-1.1%	1.5%	3.2%	2.3%	1.7%	2.4%	1.8%
25-29	1.4%	1.2%	3.1%	1.8%	-0.2%	0.9%	1.9%	2.6%	1.8%	3.3%	1.9%
30-34	1.1%	0.6%	2.8%	2.2%	-0.1%	1.8%	0.4%	1.2%	1.5%	2.9%	1.7%
35-39	0.7%	0.4%	2.6%	1.4%	0.2%	2.2%	0.8%	0.8%	1.4%	2.6%	1.6%
40-44	0.6%	0.2%	1.6%	1.4%	-0.3%	2.6%	2.5%	0.1%	1.3%	1.5%	1.4%
45-49	0.2%	-0.3%	0.6%	1.1%	0.2%	2.0%	3.1%	2.1%	1.1%	1.9%	1.1%
50-54	-0.1%	-0.6%	0.1%	0.9%	0.2%	1.8%	3.2%	1.9%	0.9%	2.5%	1.0%
55-59	-0.2%	-0.4%	-0.2%	0.5%	0.5%	1.6%	2.8%	2.5%	0.8%	2.6%	0.9%
60-64	-0.1%	-0.7%	-0.3%	0.3%	0.3%	1.6%	2.3%	2.6%	0.6%	2.6%	0.7%
65-69	-0.3%	-0.4%	0.1%	0.0%	0.0%	1.4%	2.2%	1.6%	0.6%	2.3%	0.7%
70-74	-0.7%	-0.1%	0.3%	0.0%	0.2%	1.2%	1.9%	1.2%	0.6%	1.9%	0.7%
75-79	-0.9%	-0.4%	0.3%	0.5%	0.3%	0.9%	1.4%	1.0%	0.5%	1.6%	0.6%
80-84	-0.8%	-0.5%	0.3%	0.8%	0.5%	0.9%	1.0%	0.5%	0.5%	1.1%	0.5%
85-89	-0.1%	-0.7%	0.3%	0.7%	0.7%	0.9%	0.7%	-0.2%	0.4%	0.4%	0.4%
90-94	1.3%	-2.2%	0.2%	0.3%	1.0%	1.2%	0.5%	-0.9%	0.1%	0.3%	0.2%
95-99	2.3%	-4.5%	0.3%	-0.2%	1.2%	1.6%	0.3%	-2.1%	-0.3%	-2.6%	-0.4%
0-99	0.4%	0.1%	0.7%	0.7%	0.4%	1.4%	1.7%	1.1%	0.8%	1.6%	0.9%

[1] Own estimate

Table 15: Percentage annual rate of mortality improvement for age-standardised aggregate mortality rates (using mx values from Canadian Life Tables), females

Age	1881 - 1921	1921 - 1931	1931 - 1951	1951 - 1961	1961 - 1971	1971 - 1981	1981 - 1991	1991 - 1996	1921 - 1996	1991 - 2000[1]	1921 - 2000[1]
0-4	2.8%	4.3%	4.1%	3.8%	4.0%	5.7%	3.9%	2.2%	4.1%	2.6%	4.1%
5-9	2.5%	3.6%	4.8%	4.9%	1.0%	5.2%	5.5%	-0.3%	4.0%	1.0%	3.9%
10-14	2.0%	1.9%	5.0%	5.7%	-0.5%	3.3%	3.3%	0.8%	3.2%	2.9%	3.3%
15-19	1.3%	1.2%	5.4%	4.8%	-1.2%	2.2%	2.4%	1.0%	2.8%	0.6%	2.6%
20-24	1.3%	1.0%	5.8%	5.1%	0.1%	1.9%	2.6%	2.2%	3.2%	1.2%	3.0%
25-29	1.5%	0.8%	5.9%	4.8%	0.7%	2.0%	2.4%	1.8%	3.1%	1.8%	3.1%
30-34	1.2%	1.2%	5.1%	4.7%	0.1%	3.2%	1.9%	1.1%	2.9%	1.7%	2.9%
35-39	0.8%	1.2%	4.1%	4.0%	0.3%	2.8%	2.2%	1.2%	2.6%	1.0%	2.5%
40-44	0.6%	0.6%	2.9%	3.6%	0.1%	2.5%	2.8%	-0.1%	2.1%	0.5%	2.0%
45-49	0.1%	0.7%	2.0%	3.0%	0.8%	1.9%	2.1%	1.5%	1.8%	1.8%	1.8%
50-54	-0.3%	0.5%	1.7%	2.3%	0.8%	1.7%	2.1%	1.5%	1.5%	1.6%	1.5%
55-59	-0.1%	-0.2%	1.5%	2.1%	1.0%	1.5%	1.9%	1.0%	1.3%	1.6%	1.4%
60-64	-0.1%	0.0%	1.3%	2.0%	1.5%	1.5%	1.6%	1.1%	1.3%	1.5%	1.3%
65-69	-0.4%	0.5%	1.2%	1.7%	1.7%	1.5%	1.7%	0.7%	1.3%	1.2%	1.3%
70-74	-0.8%	0.1%	1.0%	1.8%	1.8%	1.8%	1.6%	0.6%	1.2%	1.1%	1.3%
75-79	-0.8%	-0.7%	0.9%	1.7%	2.0%	1.9%	1.4%	0.5%	1.1%	1.1%	1.2%
80-84	-0.7%	-0.6%	0.7%	1.4%	2.1%	1.9%	1.3%	0.0%	1.0%	0.8%	1.0%
85-89	-0.4%	-0.2%	0.4%	1.0%	2.1%	1.7%	1.2%	-0.6%	0.8%	0.0%	0.8%
90-94	0.5%	-0.7%	0.0%	0.6%	2.1%	1.5%	1.2%	-1.2%	0.6%	-0.4%	0.6%
95-99	1.3%	-1.8%	-0.3%	0.3%	2.1%	1.5%	1.0%	-1.1%	0.2%	-1.3%	0.2%
0-99	0.3%	0.2%	1.2%	1.6%	1.8%	1.8%	1.5%	0.1%	1.2%	0.6%	1.2%

[1] Own estimate

Figure 13: Annual improvement in smoothed mortality rates – males, Canada

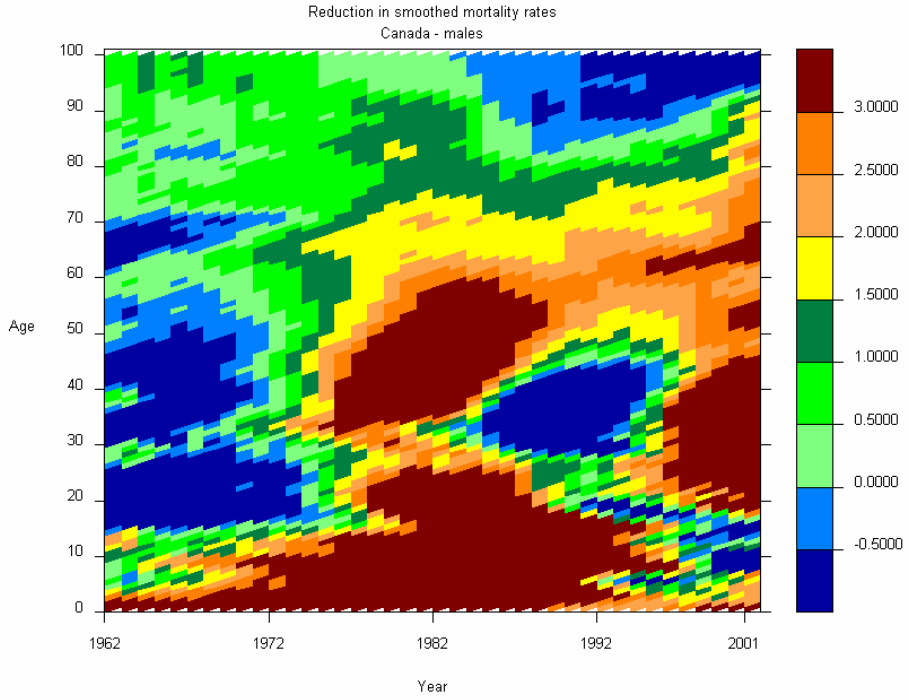
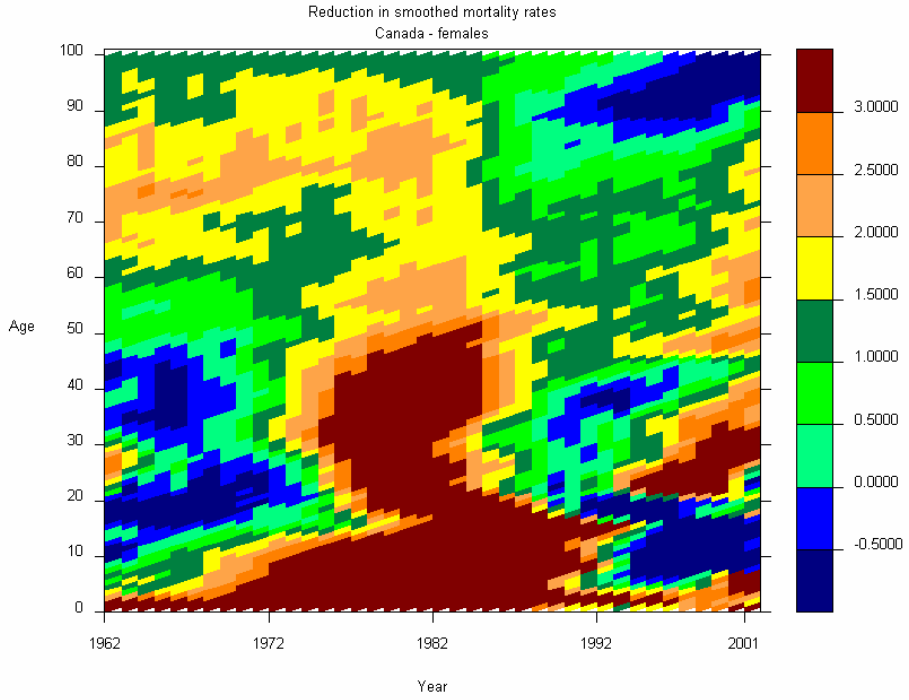


Figure 14: Annual improvement in smoothed mortality rates – females, Canada



Comparison of UK and Canadian mortality with other countries

Tables 16 and **17** give an indication of mortality in the United Kingdom and of Canada relative to selected European countries, the USA, Australia and Japan. Comparisons with other countries can indicate those countries where mortality patterns may be similar and which may repay closer investigation. A comparison against the highest expectations of life recorded gives an indication of the potential achievable gains in life expectancy.

Male life expectancy in the UK at birth and at age 60 is now very similar to the levels in the rest of Western Europe, with the exception of Sweden and Switzerland but is lower than Canada, Australia and Japan. Canadian male life expectancy is generally higher than in Western Europe, except for Sweden and Switzerland, is broadly equivalent to that in Australia but below that for Japan. More noticeable is that in the recent past female life expectancy in the UK has lagged behind all the countries shown other than the USA and Denmark. Similarly, life expectancy at birth and at age 60 for Canadian females has a somewhat lower ranking than for males, being a little higher than for the EU as a whole, ahead of the UK and USA but behind Australia and Japan.

A comparison of the size and trends in the differentials in life expectancy at given ages between Canada and other countries may suggest countries whose historical mortality patterns may have been similar to that of Canada and which may be worth further investigation. For example, looking at the figures for life expectancy at birth for males in Table 16 for 1970, 1980, 1990, 1995, 2000, 2001 and 2002, the differentials with Canada have varied by 1.0 years or less for France, Italy, the UK and the USA. For female life expectancy at birth, the range of differentials with Canada over the same period are 1.0 or less for Switzerland, the UK and the USA. A shorter period would increase the number of countries lying within these criteria. Looking at the differentials with Canada at birth and at age 60 over the period 1970 to 2002 suggests that, for males, mortality in France, UK, USA and possibly Italy and Sweden would be worth further investigations as to whether there were similarities in past mortality patterns, and, for females, Sweden, Switzerland, UK and USA.

Table 16: Period life expectancies at birth for selected countries and years

Males	1950	1960	1970	1980	1990	1995	2000	2001	2002	2003
Denmark	69.1	70.4	70.7	71.2	72.0	72.7	74.5	74.7	74.8	75.1
France	62.9	66.9	68.4	70.2	72.8	73.9	75.3	75.5	75.8 p	75.9 p
Italy	63.7	67.2	69.0	70.6	73.6	74.9	76.6	76.7 e	76.8 e	76.8 e
Netherlands	70.3	71.5	70.7	72.7	73.8	74.6	75.5	75.8	76.0	76.2 p
Spain	59.8	67.4	69.2	72.5	73.3	74.3	75.8	76.1 e	76.2 e	76.9 e
Sweden	69.1	71.2	72.2	72.8	74.8	76.2	77.4	77.6	77.7	77.9
Switzerland	66.6	68.7	70.7	72.8	74.0	75.3	76.9	77.4	77.8	78.0
United Kingdom	**66.0**	**67.8**	**68.7**	**70.5**	**72.9**	**74.0**	**75.4**	**75.8**	**75.9**	**76.2**
EU-15		67.4	68.4	70.5	72.8	73.9	75.4 e	75.7 e	75.9 e	76.0 e
Canada	**66.4**	**68.5**	**69.5**	**71.7**	**74.4**	**75.1**	**76.7**	**77.0**	**77.2**	**77.4**
Australia		67.9	67.8	71.2	74.3	75.2	77.0	77.4	77.8	
USA	65.6	66.6	67.1	70.0	71.8	72.5	74.3	74.4	74.5	
Japan	59.6	65.3	69.3	73.4	75.9	76.4	77.7	78.1	78.3	78.4

Females	1950	1960	1970	1980	1990	1995	2000	2001	2002	2003
Denmark	71.5	74.4	75.9	77.3	77.7	77.8	79.3	79.3	79.5	79.9
France	68.5	73.6	75.9	78.4	80.9	81.8	82.7	82.9	83.0 p	82.9 p
Italy	67.2	72.3	74.9	77.4	80.1	81.3	82.5	82.8 e	82.9 e	82.5 e
Netherlands	72.5	75.3	76.5	79.3	80.9	80.4	80.5	80.7	80.7	80.9 p
Spain	64.3	72.2	74.8	78.6	80.3	81.5	82.5	82.8 e	82.9 e	83.6 e
Sweden	72.3	74.9	77.1	78.8	80.4	81.4	82.0	82.1	82.1	82.5
Switzerland	71.1	74.5	76.9	79.6	80.7	81.7	82.6	83.0	83.0	83.1
United Kingdom	**70.4**	**73.5**	**75.0**	**76.6**	**78.5**	**79.2**	**80.2**	**80.5**	**80.6**	**80.5**
EU-15		72.9	74.7	77.2	79.4	80.4	81.4 e	81.7 e	81.7 e	81.7 e
Canada	**70.6**	**74.1**	**76.3**	**78.9**	**80.8**	**81.1**	**81.9**	**82.1**	**82.1**	**82.4**
Australia		74.2	74.5	78.3	80.4	81.1	82.4	82.6	82.8	
USA	71.1	73.1	74.7	77.4	78.8	78.9	79.7	79.8	79.9	
Japan	63.0	70.2	74.7	78.8	81.9	82.9	84.6	84.9	85.2	85.3

Sources: Eurostat Population Statistics, Human Life Table database, Australian Bureau of Statistics, National Center for Health Statistics (USA), Ministry of Health, Labour & Welfare (Japan), GAD (UK)
e Eurostat estimate
p provisional

Table 17: Period life expectancies at age 60 for selected countries and years

Males	1950	1960	1970	1980	1990	1995	2000	2001	2002	2003
Denmark		17.1	17.1	17.0	17.4	17.6	18.9	19.0	19.1	19.3
France	15.4	15.6	16.2	17.3	19.0	19.7	20.4	20.6	20.8	
Italy	16.0	16.7	16.7	16.8	18.6	19.5	20.4			
Netherlands		17.7	16.8	17.5	18.1	18.5	19.1	19.4	19.5	19.7
Spain	14.9	16.5	16.8	18.4	19.1	19.7	20.4	20.6	20.6	
Sweden		17.3	17.8	17.9	19.1	19.8	20.7	20.9	20.9	21.0
Switzerland					19.0	19.9	20.9	21.2	21.5	21.5
United Kingdom	**14.8**	**15.2**	**15.3**	**16.2**	**17.6**	**18.3**	**19.5**	**19.8**	**20.0**	**20.1**
EU-15		15.9	15.9	16.8	18.2	18.9	19.9 e	20.1 e	20.2 e	20.3 e
Canada	**16.6**	**16.8**	**17.1**	**17.9**	**19.2**	**19.7**	**20.8**	**21.0**	**21.2**	**21.3**
USA	15.7	15.9	16.1	17.4	18.5	19.1	19.9	20.1	20.2	
Japan	14.4	14.8	15.9	18.3	20.0	20.3	21.4	21.8	21.9	22.0

Females	1950	1960	1970	1980	1990	1995	2000	2001	2002	2003
Denmark		19.3	20.6	21.4	21.6	21.3	22.3	22.4	22.4	22.7
France	18.4	19.5	20.8	22.4	24.1	24.9	25.5	25.7	25.7	
Italy	17.5	19.3	20.2	21.2	23.0	24.0	24.8			
Netherlands		19.7	20.5	22.6	23.1	23.2	23.4	23.5	23.5	23.7
Spain	17.1	19.2	20.0	22.1	23.3	24.2	24.8	25.1	25.2	
Sweden		19.3	20.9	22.1	23.2	23.9	24.3	24.3	24.3	24.6
Switzerland					23.7	24.5	25.0	25.4	25.4	25.3
United Kingdom	**17.9**	**19.0**	**19.9**	**20.7**	**21.8**	**22.2**	**23.1**	**23.2**	**23.3**	**23.3**
EU-15		19.0	19.8	21.2	22.5	23.3	24.0 e	24.3 e	24.3 e	24.3 e
Canada	**18.6**	**19.8**	**21.3**	**22.7**	**23.9**	**24.0**	**24.7**	**24.8**	**24.9**	**25.0**
USA	18.5	19.5	20.8	22.2	22.8	22.9	23.1	23.4	23.5	
Japan	16.8	17.8	19.3	21.9	24.4	25.3	26.9	27.1	27.4	27.5

Sources: Eurostat Population Statistics 2004, Human Life Table database, National Center for Health Statistics (USA), Ministry of Health, Labour & Welfare (Japan), GAD (UK)
e Eurostat estimate
p provisional

Projections of Canadian mortality using GAD methodology

The basic methodological approach used in the UK national population projections has been applied to Canadian data for the period 1962 to 2001 to produce projections of mortality rates for the period 2002-2075. Age specific mortality rates for ages 0 to 89 for the period 1961 to 2001 were derived from data on calendar year deaths and mid-year population estimates for Canada. The rates obtained for each year were then graduated and extended to age 120 using the methods adopted for the UK projections. These rates were then further smoothed by age and extrapolated forward one year to obtain age specific trend mortality rates for the year 2002 and estimated rates of mortality

improvement for 2002 were calculated using these mortality rates and further smoothed to obtain the estimated age specific rates of mortality improvement for 2001-2002. The estimated initial smoothed percentage reductions in death rates by age thus obtained are shown in **Figure 15**. The very high rates shown for ages in the thirties reflect what appear to be rapidly improvements in the smoothed mortality rates at these ages in the years immediately prior to 2002, but this would need further investigation. The rates of improvement at ages 90 and over derived from rough estimates of age specific mortality rates at these ages were often negative; these have been set to be 0%. Amendments are also made to rates of improvement at ages 90 and over in the UK projections. It is not possible to obtain age specific mortality rates directly at ages 90 and over from UK data since population estimates are only available as an aggregate figure. Population estimates are obtained using a survivor ratio methodology to calculate these. Rates at the very oldest ages are then obtained by extrapolation. These procedures can result in fluctuating rates at the oldest ages for which it is difficult, if not impossible, to assess rates of improvement.

Figure 15: Initial smoothed percentage reductions in death rates by age, Canada 2001-02

The target year was taken as 2027, the 25th year of the projection period. The target rates of mortality improvement in the target year was taken to be 1% pa at all ages for males and females, as used in the UK projections. (Given annualised rates of improvement in standardised mortality rates for Canada over the period 1921 to 2000 of around 0.9% pa for males and 1.2% pa for females, this assumption does not seem unreasonable). Rates of improvement between 2002 and 2027 were then obtained by interpolation using the same parameters as for the UK projections. Two approaches were used; one carrying out the interpolation by cohort for those born before 1947 and by age for those born later (as

was done in the corresponding 2002-based UK population projections), and a second in which interpolation was carried out by age alone. Mortality rates after 2027 were assumed to remain at 1% pa for all years and ages for both males and females.

Table 18 shows period expectations of life at birth and at age 60 for selected years taken from

(i) the latest best estimate CPP mortality projections (from Actuarial Study No 4, National Population Projections, Office of the Chief Actuary),
(ii) from projections of Canadian mortality using the UK methodology and parameters with projections by cohort for those born before 1947,
(iii) from projections of Canadian mortality using the UK methodology and parameters with projections by age, and
(iv) from the latest 2004-based UK principal projections, for comparison.

Table 18: Period life expectancies from various projections of Canadian and UK mortality data

		CPP projection	Canadian data UK cohort	Canadian data UK age	UK data UK projns
Males					
2003	At birth	77.5	77.2	77.2	76.2
	At age 60	21.3	21.0	21.0	20.1
2025	At birth	80.7	81.3	81.0	80.7
	At age 60	23.3	24.0	23.7	24.1
2050	At birth	82.0	83.9	83.5	83.5
	At age 60	24.3	26.1	25.7	26.3
2075	At birth	83.4	86.4	86.0	86.2
	At age 60	25.3	28.2	27.8	28.5
Females					
2003	At birth	82.4	82.1	82.1	80.6
	At age 60	25.0	24.7	24.7	23.3
2025	At birth	84.1	85.5	85.0	84.4
	At age 60	26.1	27.4	26.8	26.7
2050	At birth	85.3	87.8	87.2	86.9
	At age 60	27.1	29.4	28.7	28.8
2075	At birth	86.5	90.1	89.4	89.3
	At age 60	28.0	31.4	30.7	30.9

The results suggest that applying the UK methodology and parameters to Canadian data would result in higher expectations of life after the first few years of the projection period, with the 'cohort' approach producing slightly higher period expectations of life than the age approach. The latest UK projections of UK mortality also show higher period expectations of life than the CPP projections from the mid-2020s for both males and females, even though the starting figures are lower. This is largely due to the rather higher initial starting rates of mortality improvements and effectively higher target rates at older ages than are assumed in the CPP projections. There is little difference in the

expectations of life for projecting Canadian mortality for males, whether a 'cohort' or 'age' projection interpolation is used. The results give generally slightly higher expectations of life at birth and lower expectations of life at age 60 than for the UK projections.

The difference between the two methods is more marked for females and both methods generally produce higher expectations of life than in the UK projections.

The projections of Canadian mortality using the UK methodology are only illustrative. There would need to be a more thorough investigation as to whether the various assumptions and parameters used for projecting UK mortality were appropriate for projecting Canadian mortality and, if not, as to what would be more appropriate ones.

Conclusions and discussion

The paper provides some brief background into past mortality experience of the United Kingdom and what may be the key drivers which will shape future mortality there, particularly in the shorter term. The extent to which these past and future drivers are appropriate in a Canadian context might be explored further. In particularly, further examination of the historical patterns of mortality improvements by age, period and year of birth should provide further insight into how mortality has changed in the past and how it might be expected to change in the future. For example, there appears to be weaker evidence for both the 'ageing of mortality improvements' and for the existence of 'cohort effects' in historical Canadian mortality data. A comparison with the mortality experience of other countries may also prove useful.

The paper also discusses some of the considerations that might be taken into account in determining how to project forward mortality and gives a brief description of how recent projections of mortality for the UK national population projections are carried out. The results of the latest 2004-based UK population projections assume higher expectations of life than the latest Canadian Pension Plan projections after the first few years of the projection period. The CPP approach is not dissimilar to the UK methodology, but the application of the UK methodology to Canadian data together with the various parameters and assumptions used in recent UK projections produces higher projected expectations of life than the CPP projections. Further investigation would be needed as to whether the various assumptions and parameters used would be appropriate for Canada.

Expert views on the likely course of future mortality are probably wider now than they were, say, twenty years ago. There are potential advances which could lead to large increases in life expectancy if the processes by which people age can be understood and slow down. On the other hand the rise in levels of obesity and the potential occurrence of an influenza epidemic could lead to smaller increases in life expectancy or even a decline. Any projections are likely to be proved inaccurate, possibly within only a few years. Uncertainty can arise through a variety of sources; in particular, where statistical models

are used there is model uncertainty, parameter uncertainty and stochastic uncertainty. Consequently there is an increasing drive to emphasise the uncertainty in any projections, through providing measures of the uncertainty and by educating users to take uncertainty into account. For example the recent Pensions Commission report (2005) which reviewed the regime for UK private pensions and long-term savings had a recommendation that:

'Official publications which set out estimates of projected life expectancy should ideally provide not only the best mean estimate, but also the range of possible results which could arise from alternative reasonable assumptions. The GAD publications already include high and low variants: these should be given wider publicity.'

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Longevity in the 21st century (Willets et al, 2004) and
Mortality at advanced ages in the United Kingdom (Gallop and Macdonald, SoA 2005)

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