MORTALITY RESEARCH WORKING GROUP REPORT

This report represents the work of the Mortality Research Working Group of the Board for Actuarial Standards.

The Group was established to assist the BAS to consider matters from the research community relevant to the mortality assumptions used in actuarial calculations. Details of the Group's membership are given in Appendix C.

March 2008

CONTENTS

Section		*Page*
1	Introduction & Summary	3
2	Mortality assumptions	5
3	Factors that correlate with mortality	8
4	Modelling future mortality	18
5	Difficulties with models	22
6	Uncertainty	25
7	References and bibliography	30

Appendix		*Page*
A	Population mortality trends in the United Kingdom	35
B	CMI Mortality Data	40
C	Members of the Working Group	43

1 INTRODUCTION & SUMMARY

INTRODUCTION

1.1 Many actuarial calculations require assumptions to be made about future rates of mortality. These assumptions are used to estimate the number of people in respect of whom pension, annuity, or life assurance payments or other benefits will be paid, or pension contributions or premium payments received.

1.2 The Mortality Research Working Group has considered how actuaries can draw on information and techniques from a number of different research areas. This report does not claim to be comprehensive, but reflects the opinions of the group members. There are some differences of opinion among the members of the group, reflecting the lack of consensus in the wider research community over a number of issues, so not every member of the group agrees with every opinion that is expressed.

1.3 This report inevitably has a UK bias, especially where it discusses the availability of data and the pattern of recent trends, but many of the principles are more generally applicable. In addition, the group believes that much can be learned from analysing the experience of other countries. Countries with significantly higher levels of life expectancy at all ages for both men and women than the UK include Japan, some Scandinavian countries, Switzerland, Italy, Australia and Canada. Looking at the reasons for the declines in mortality that led to the lower levels in those countries might prove to be a useful guide to what may happen in the UK in the future. Similarly, there are important lessons still to be learnt from the continuing differences in mortality patterns between UK regions.

SUMMARY

1.4 The group believes that assumptions about future mortality should have two components: an estimate of past mortality rates, combined with an assumption about future changes in mortality (section 2).

1.5 There are a number of factors that are correlated with mortality rates and with changes in mortality rates. The group has considered the quantitative information that is available for these factors, and has summarised some of the issues surrounding their use (section 3).

1.6 Modelling future mortality changes is an enterprise that is fraught with difficulty. The group believes that there is currently no single model, or type of model, that has clear advantages over all other models (sections 4 and 5).

1.7 It is, of course, impossible to tell exactly what the future will hold. Mortality rates have undergone significant changes in the past, and all the evidence is that they will continue to change in the future. Furthermore, there is no consensus about the overall long-term trend. Whatever the assumptions used, they are unlikely to be borne out in practice. There is necessarily considerable uncertainty about the course of future mortality rates, and this uncertainty will affect all calculations that use assumptions about them. The group believes that it is important that the users of actuarial information recognise the extent of this uncertainty, as well as that of the other sources of uncertainty surrounding mortality (section 6).

Data sources

1.8 The principal sources of data on mortality in the UK are the Office for National Statistics (ONS) and the Continuous Mortality Investigation of the Actuarial Profession (CMI). The ONS produces a wide range of statistics and datasets based on the population of the UK, a number of which are discussed throughout this report. The CMI has, until recently, concentrated on data from life insurance companies, but is now also conducting an investigation of the mortality among members of self-administered pension schemes.

1.9 The World Health Organisation (WHO) has by far the most comprehensive database of international data, both worldwide and for Europe (see [34], [36]). Mortality data for many countries is available from the Human Mortality Database (see [14]).

1.10 LifeMetrics publishes mortality tables as part of its toolkit for measuring and managing longevity and mortality risk (see [20]). The current range includes mortality tables for males and females in England and Wales for all years from 1961 to 2005, for the Netherlands from 1951 to 2006, and for the United States from 1968 to 2005. The tables for England and Wales are based on death and population data from the ONS.

Life expectancies

1.11 Life expectancy is the average number of years before death, and can be calculated at any age, from mortality rates for that age and all older ages. There are two commonly used variants, *period life expectancy* and *cohort life expectancy*.

1.12 Period life expectancy is based on mortality rates at a specific date (or period). So, for example, the period life expectancy of a man aged 65 in, say, 2008, uses the mortality rates for all ages from 65 upwards as they are expected to be in 2008. In other words, period life expectancy takes the mortality rates at a specific date and assumes that they do not change.

1.13 In spite of the name, period life expectancy does not necessarily provide an estimate of anyone's expected remaining lifetime. The combination of mortality rates that are used – in our example the mortality rates for 65 year olds in 2008, 66 year olds in 2008, 67 year olds in 2008, and so on – will only apply to a single person if mortality rates do not change in the future.

1.14 Cohort life expectancy, on the other hand, is based on the mortality rates that are expected to be experienced by the lives in question, using assumptions about future changes in mortality rates. The cohort life expectancy of a man aged 65 in 2008 uses the mortality rates for 65 year olds in 2008, the expected rates for the same group of people (66 year olds) in 2009, for 67 year olds in 2010, and so on.

1.15 In this report the terms *period life expectancy* and *cohort life expectancy* are often used with no further qualification, with the meanings described in the previous three paragraphs.

2 MORTALITY ASSUMPTIONS

2.1 When addressing assumptions about future mortality rates, the first step is to investigate the starting point – ie, what is known about past and current mortality rates. It is clearly desirable for assumptions about future mortality rates to be consistent with what is known about the past.

2.2 There are very different issues surrounding past and future mortality rates. In theory at least, it is possible to estimate past mortality rates with some accuracy, whereas it is not possible to know exactly what the future will hold. There is a great deal of information available about what has happened in the past (see section 3 and Appendix A for some examples).

2.3 It is therefore sensible to derive assumptions for future mortality rates by starting with past rates, and applying the rates of change that may occur in the future. This approach thus splits the assumptions into two components: the *base mortality rates*, which are assumed to prevail at a specified time in the recent past, and the *future changes*, which are assumed to prevail at later times.

2.4 It is often desirable to use mortality assumptions for base mortality rates that are very specific to the particular group of lives under consideration. Separating the assumptions into base mortality rates and future changes means that specificity can be achieved for base mortality rates when it is feasible to do so, while using more generally applicable assumptions for future changes, for which specificity is often infeasible.

2.5 The setting and justification of mortality assumptions for a group of lives depend on many factors, including the purpose for which the assumptions are needed, the amount of past data that is available for the group of people under consideration and the availability of data on the individuals concerned.

BASE MORTALITY

2.6 As discussed in section 3, mortality rates are affected by a number of factors including state of health, socio-economic group, and whether the people in question smoke or not. The mortality of a specific group of lives is unlikely to reflect that of the national population, as the mix of people will be different. In most cases, therefore, general population statistics cannot be used directly.

2.7 Taking pension schemes as an example, mortality analyses of general population data include people such as those in ill-health who are excluded from the work force. Pensioners of final salary pension schemes are people who had been fit enough to be employable, and hence can be expected to be healthier than the general population on average. Furthermore, pensioners with final salary pensions are more likely to have been in more stable and secure jobs, which are potentially beneficial to health, than pensioners who do not have a final salary pension.

2.8 For protection insurance, medical underwriting results in healthier people, with lower mortality rates, being accepted for insurance. Other insurance products appeal to different segments of the population, who might have potentially lower mortality (such as those in a higher socio-economic group) or higher mortality (such as those working in a hazardous environment).

2.9 If there is sufficient data, the past mortality experience of the group over recent years can be used. Whether this is possible depends both on the quantity of data, in terms of the numbers of lives under consideration and the period for which data is available, and on its suitability. If the composition of the group has changed over the period, for example, the mortality experience of the current members of the group may not reflect the past experience.

2.10 If past mortality experience is available, it can be compared to published rates, such as those from one of the mortality tables published by the CMI or ONS. Depending on the amount of data available, it may be possible to use the experience to determine the most appropriate published table; otherwise, a published table can be chosen based on a judgement as to the similarity of the lives on which it is based to those for which mortality assumptions are being set. Once a published table has been selected, the rates that it contains can be adjusted to reflect the actual experience, for example by taking a proportion of the rates, or by adjusting the ages to which they apply.

2.11 If past experience cannot be used in setting the mortality rates, it may be possible to use factors such as those described in section 3 to adjust published tables.

2.12 The extent to which it is possible to take specific factors into account depends crucially on the data that is available. Life offices often have quite detailed information for current policyholders, including addresses, some details of medical history, smoking and other lifestyle factors. Pension schemes tend to have less detailed information. Obviously, when deriving mortality assumptions for pricing purposes, no details of specific lives are available.

2.13 These factors should also be considered for populations that have experienced changes in their composition, so that past experience is no longer relevant for current members.

2.14 Some CMI mortality tables for pensioners and annuitants are produced both for lives and for amounts of pension. The 'lives' tables provide mortality rates based on deaths of persons (perhaps subject to adjustment to allow for those with more than one pension). 'Amounts' tables provide mortality rates per unit of pension; these are applied to amounts of pension by age to estimate amounts of pension ceasing to be paid during a year. In general, mortality rates per unit of pension are lower than those calculated on a lives basis. This reflects the fact that mortality appears to be lower for those with larger amounts of pension. This suggests a correlation between wealth (using higher pension as a proxy for wealth) and higher life expectancy and is one of the factors explaining the mortality gradient by social class.

FUTURE CHANGES

2.15 It is much less likely that an individual pension scheme or life office will have sufficient data to derive meaningful information about past rates of change in mortality rates. However, assumptions about future changes should be consistent with what is known about the past. For instance, there should be no discontinuity between past rates of change and those assumed in the future.

2.16 In particular, the estimates of changes in mortality rates between the effective date of the base table and the present may be different from the assumptions about future changes. For example, base rates based on the CMI's "00" series of tables might be used for a valuation as at 31st December 2007 (see [60], [61]). These rates apply to the year 2000. At the time that the valuation is being prepared, information about actual changes in mortality rates between 2000 and, say, 2006 would probably be available, and should be used to bring the base table rates up to rates applying in 2006. Projections could then be used for the period after 2006.

2.17 Information that would enable reasonable assumptions to be made about recent rates of change in mortality rates is published by the ONS, CMI, and LifeMetrics. Actual changes can be calculated from any of the mortality tables that are published at regular intervals, such as the LifeMetrics indexes and the interim life tables from the ONS. However, these do not give smoothed rates of improvement. From time to time the CMI publishes comparisons of observed mortality rates compared to those expected on the basis of published tables. And some of the projections in the CMI library include smoothed actual rates of improvement for past years, as well as projected future rates of improvement.

3 FACTORS THAT CORRELATE WITH MORTALITY

3.1 This section describes a number of factors that correlate with mortality rates and changes in mortality rates, and discusses their suitability for use in deriving assumptions for mortality rates and changes in the UK.

3.2 Some factors have a very significant direct impact on mortality rates, but are little used in practice by actuaries working in life assurance or pensions. On the other hand, some factors have very little direct influence, but are extremely useful in practice. A classic example is postcode. Although moving house from one postcode to another does not generally have a direct effect on anyone's life expectancy, mortality rates and postcode are highly correlated. This is because postcode is in turn correlated with other factors such as lifestyle and wealth that do influence mortality rates. Postcode is therefore a useful proxy for these other factors.

3.3 Table 3-1 lists a number of factors that may correlate with mortality rates. The table gives one view of the level of impact of the factors on mortality rates and their possible utility in actuarial work, based mostly on the availability of reliable data. Any such characterisation can only be approximate, as different data is available under different circumstances. Within the broad category of life insurance, for example, practice varies greatly between, say, pricing impaired annuities and reserving for term insurance. Factors that are of little interest to actuaries have not been included, and the list is by no means comprehensive; there are other variables that have more influence on mortality rates than those given here.

Table 3-1: Factors correlating with mortality rates

Factor	**Direct influence on mortality rates**	**Usefulness as a proxy variable in life assurance**	**pensions**
Age	Very high	Very high	Very high
Gender	Very high	Very high	Very high
Medical history	Very high	Very high	Very low
Genetics	High	Very low	Very low
Smoking status	High	Very high	Very low
Diet	High	Very low	Very low
Obesity	High	Moderate	Very low
Occupation/socio-economic class	High	Low	Moderate
Alcohol consumption	Moderate	Moderate	Very low
Regular exercise	Moderate	Very low	Very low
Exposure to stress	Moderate	Very low	Very low
Wealth	Moderate	Very low	Very low
Marital status	Moderate	Very low	Moderate
Education	Moderate	Low	Low
Degree and method of medical underwriting	Low	High	Very low
Family medical history	Low	High	Very low
Geographical location	Low	Low	Low
Postcode	Low	Moderate	High
Benefit amount	Low	High	High

3.4 Most proxy variables correlate with more than one factor directly linked to mortality, and there is considerable overlap among them. It is therefore important to allow for the interactions between factors.

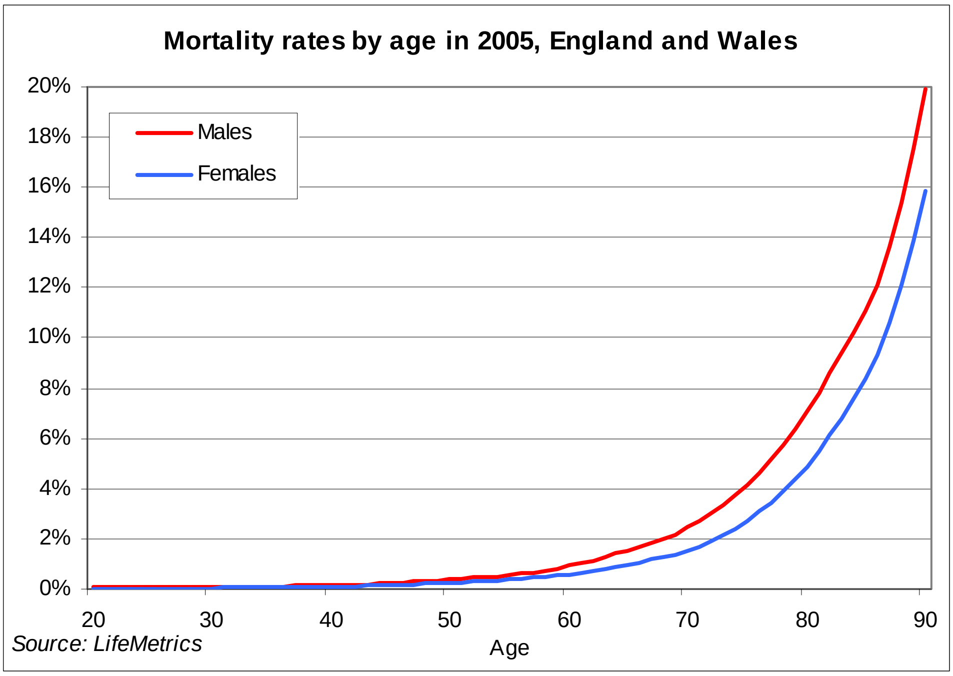
3.5 The utility of a factor depends on whether information about that factor is available for the members of the group under consideration, and on the availability of quantitative information about its effect on mortality rates.

AGE AND GENDER

3.6 Age and gender are well-recognised factors that affect mortality. Indeed, they have been used by actuaries for hundreds of years, and nearly all published mortality tables used by actuaries give separate mortality rates by age and gender.

3.7 As shown in Figure 3-1, women of a given age are less likely to die within a year than men of the same age, and mortality rates for adults increase sharply after age 60. However, male mortality has been improving faster than that for females over recent years, so the differential between males and females may reduce in the future.

Figure 3-1: Mortality rates by age and sex



SOCIO-ECONOMIC GROUPS

3.8 People in higher socio-economic groups have been shown to have lower mortality than those in lower socio-economic groups. The ONS has published a series of notes on trends in period life expectancy for England and Wales by social class, the latest of which covers the period to 2005 (see [37]). Articles are also published from time to time in *Health Statistics Quarterly* (see [38]). Up to date information is published in spreadsheets on the ONS website.

3.9 In the absence of data that would allow the direct assignment of socio-economic group, there are a number of proxies that can be used. These include industry, postcode, and pension amount. However, differences in mortality by socio-economic group are by no means the only explanations for the correlations of these factors with mortality rates.

3.10 It has become increasingly common for actuaries to derive the socio-economic status of individuals via postcode using various proprietary databases, such as consumer segmentation tools. Using postcode information for mortality modelling has become widespread among actuaries working for insurance companies writing annuity business and similar techniques are also now being utilised by some actuaries in their advice to the trustees and sponsors of pension schemes.

3.11 On a related note, Richards & Jones describe the significance of lifestyle as an explanatory factor, over and above other factors (such as annuity amount), in a Generalised Linear Model fitted to annuitant mortality data (see [27]).

ONS data

3.12 Period life expectancy figures by social class are estimated using data from the ONS Longitudinal Study (see [39]). The Longitudinal Study is a one per cent representative sample of the population of England and Wales which links census data from 1971 onwards with death registrations and other data. Social class is allocated at entry to the Study and is based on data from the last valid census relating to the individual, their spouse or parents, according to a set of priority rules. The basic methodology is described further in *Health Statistics Quarterly No 2*; recent methodological refinements are described in *Health Statistics Quarterly No 35* (see [38]).

3.13 Figure 3-2 and Figure 3-3 show a mortality gradient by social class with those in Social class I exhibiting the lowest rates of mortality and those in Social class V the highest. There is no clear overall trend in the differentials between the social classes.

Figure 3-2: Trends in male period life expectancy at age 65, 1972-2005, England & Wales (Source: ONS)

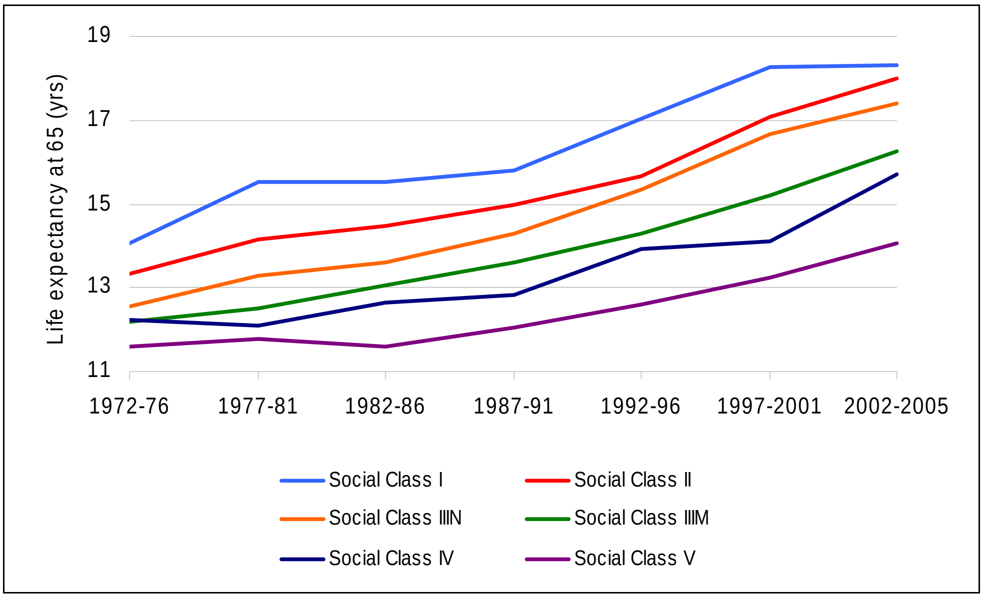
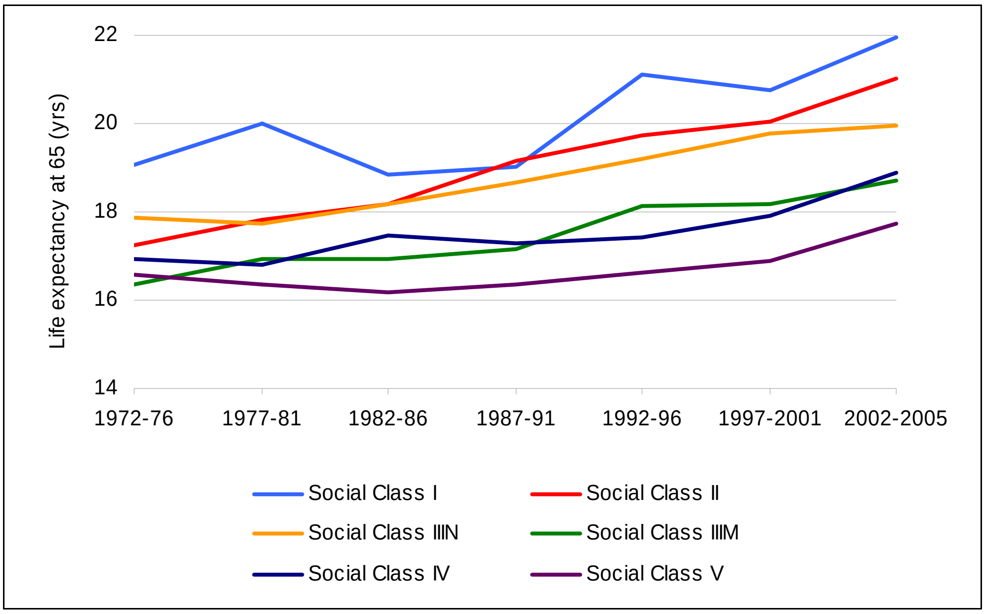


Figure 3-3: Trends in female period life expectancy at age 65, 1972-2005, England & Wales (Source: ONS)



3.14 Definitions of the broad social classes used are:

Social class I:	Professional eg doctors, accountants
Social class II:	Managerial and technical eg managers, journalists, teachers
Social class IIIN:	Skilled non-manual eg clerks, retail staff
Social class IIIM:	Skilled manual eg plumbers, electricians
Social class IV:	Partly skilled eg security guards, waiters, care assistants
Social class V:	Unskilled eg labourers, cleaners, messengers

3.15 As the percentages of the population in Social classes I and V are relatively small, the differential between manual and non-manual classes provides a more reliable estimate of the trends in inequality.

3.16 Over the 30 years to 2002-05, mortality improved faster for non-manual males than for manual males, as shown in Table 3-2. However, over the 4 years to 2001-05 the opposite was true. This does not necessarily mean that the trend in inequalities is changing, as some short term variation is to be expected as a result of sampling and the method of assigning social class.

Table 3-2: Recent changes in mortality for males by socio-economic group (source: ONS)

	Increase in period life expectancy at birth (years)		**Increase in period life expectancy at age 65 (years)**	
Period of change	**Manual**	**Non-manual**	**Manual**	**Non-manual**
1972-76 to 2002-05	6.8	8.0	3.8	4.8
1997-2001 to 2001-05	1.8	1.3	1.2	0.8

3.17 The National Statistics Socio-economic Classification (NS-SEC) was adopted as the official socio-economic classification at the 2001 census (see [40]). The NS-SEC classes are defined by occupational characteristics such as job control and security of employment, not by income or broader concepts of social position. However, there is a historical relationship between all these factors, and between material disadvantage and health. Mortality rates for males aged 25-64 for the period 2001-03 have been published in *Health Statistics Quarterly No 37* (see [38]). Work is in progress to consider the feasibility of providing life expectancies by NS-SEC in future.

3.18 Further historical information on mortality differentials by social class is available in the *Health Inequalities Decennial Supplement* and the *Health of Adult Britain Decennial Supplement* (see [41], [42]).

CMI data

3.19 CMI mortality data says nothing directly about socio-economic profile (see Appendix B for an overview of the mortality data captured by the CMI).

3.20 CMI data tends to show lower mortality than overall population data, and the different composition of the CMI data, by socio-economic group, is probably one of the factors that contribute to this. Such differences may also partially explain the differences in mortality between certain of the product categories within which CMI life office mortality data has traditionally been analysed (eg, differences in mortality between different annuity products). However, other differences make such comparisons difficult; for example, different groups of life offices may be represented within the different product categories.

GEOGRAPHICAL LOCATION

3.21 Many studies show that mortality rates are higher in more deprived areas. An article "Mortality by deprivation and cause of death in England and Wales, 1999-2003", in *Health Statistics Quarterly No 32* shows that mortality rates in England and Wales increase with deprivation for both sexes, but the relationship is stronger for males (see [38]). Standardised death rates are 1.7 times higher for males in the most deprived wards compared to the least deprived wards and 1.5 times higher for females. The differentials were more pronounced for younger ages than for all ages. The strongest positive correlations with deprivation were mostly found for smoking-related causes. Those living in the least deprived areas had similar levels of mortality, independent of region. There was more geographical variation in mortality for those in the most deprived areas, with the highest rates generally in the north.

3.22 The Interim Life Tables published by the ONS can be used to look at changes in mortality rates for England, Scotland, Wales and Northern Ireland (see [48]). As described below, the ONS publishes data giving mortality rates for broad sub-national regions by age group and life expectancy at birth for sub-national areas such as local authorities, but the data are likely to be insufficient to draw any detailed conclusions on any variation in mortality improvements by geographic location.

ONS data

3.23 The annual publications of ONS on regional mortality reveal that there are large differences in mortality rates between regions and local authority areas. Interim life tables are produced annually for the UK and constituent countries and are available for 1980-82 onwards.

3.24 The ONS publishes period life expectancies at birth by local authority and other areas for England, Wales, Scotland and Northern Ireland from 1991-03 onwards and at age 65 from 2002-04 onwards (2004-06 for Scotland and Northern Ireland) (see [49]). In general, period life expectancy is greatest in England and lowest in Scotland. An article describing the data available is published in *Health Statistics Quarterly No 37* (see [38]). Age standardised mortality rates by local authority are also published.

3.25 The ONS have published period life expectancies at birth at ward level for England and Wales using data for the years 1999-2003 (see [43]). Life expectancy for small populations can be heavily influenced by local factors, including the presence of nursing homes and other medical and care establishments within wards. The period life expectancies can be used to estimate adjusted mortality rates. The ONS have also published standardised mortality rates by ward for 1999-2003 (see [44]).

CMI data

3.26 The CMI has only recently sought to collect postcode for both SAPS and life office data (see Appendix B). No analyses using postcode have yet been made available.

PENSION AMOUNT

3.27 The CMI Self Administered Pension Scheme (SAPS) investigation has reported differences in mortality among people with different pension bands in a series of Working Papers. For example, CMI Working Paper 31 presents results of mortality experience with an exposure of 5.7 million male life years and 4.5 million female life years between 2000 and 2006 (see [66]). The results of a comparison of the mortality of pensioners in various pension bands are shown in Table 3-3.

3.28 The clear differentiation of mortality rates by pension amount may be due to correlation with income level, socio-economic group or some other factor or factors. Income level is significant because a higher income may provide better access to private medical care, for instance. However, pension amount is not necessarily a good measure of income, as it depends on the period of service with a single employer as well as the level of earnings.

Table 3-3: Actual mortality in 2000-2006 compared to expected mortality according to the indicated tables (weighted by pension amount); experience of pensioners in various pension bands (source: CMI)

Male pension band (£)	Male: % of PCMA00 table	Female pension band (£)	Female: % of PCFA00 table
0 - 3K	136	0 - 1.5K	123
3 - 4.5K	129	1.5 - 3K	119
4.5 - 8.5K	118	3 - 4.75K	108
8.5 - 13K	100	4.75K+	93
13K+	79		

3.29 The CMI SAPS investigation has not yet been running for long enough to derive any meaningful data on mortality improvements by pension amount (or lives) for self administered pension schemes.

OCCUPATION

3.30 The occupation of individuals is not usually recorded in pension scheme data available to actuaries, although it might be available in life insurance data. Even if this information is available, the process of grouping each occupation could be onerous. However, occupational coding is a well-established area, eg, for census processing. The grouping of people into socio-economic groups according to occupations is possible with adequate resources.

INDUSTRY

3.31 The CMI SAPS investigation reports differences in mortality among pensioners of self-administered pension schemes in different industries (see [64]). The results are summarised in Table 3-4. Some of the differences are possibly due to the different mixes by socio-economic group of people working in different industries.

Table 3-4: Actual mortality in 2000-2004 compared to expected mortality according to the indicated tables (weighted by pension amount); experience of pensioners in various industries (source: CMI)

Industry	**Male: % of PCMA00 table**	**Female: % of PCFA00 table**
Financials	92	95
Miscellaneous	97	91
Utilities	99	92
IT	104	112
Non-cyclical consumer groups	105	109
Cyclical consumer groups	107	112
General industries	111	116
Local authorities	113	110
Cyclical services	118	119
Basic industries	118	120

3.32 The CMI is intending to undertake further analysis in this area, for example looking at the spread of experience within each sector as well as the overall results for a sector. In addition a pilot investigation is being undertaken into a narrower category of companies, namely retailers.

3.33 The CMI SAPS investigation has not yet been under way for long enough for there to be any reliable information about changes in mortality rates by industry over time.

HEALTH STATUS

3.34 There are numerous medical studies on the impact of specific diseases and risk factors such as high blood pressure, cholesterol level, body mass index and diabetes on mortality (see [21], the references in [6], and, for example, [1],

[12], [29], [32]). They could be used for setting mortality assumptions if information on the risk factors is available.

3.35 CMI analyses also provide some useful indications of the impact on mortality of overall health status.

3.36 For assurances, the main analyses are intended to cover lives accepted on normal underwriting terms and the pattern of initial selection shows how the high initial effects wear off with duration from policy issue. Some of the product categories involve limited underwriting, and hence may illustrate the impact of limited medical underwriting on mortality rates (although there may also be differences between the groups of lives).

3.37 CMI life office pensioner data differentiates between lives retiring at (or after) Normal Retirement Date and those retiring before. Many of these early retirements are likely to be as a result of ill-health. The mortality experience of such lives is indeed substantially higher than that of normal retirements, although the differential narrows with increasing age.

3.38 The CMI SAPS investigation differentiates between lives retiring in ill-health and those retiring in normal health, and reports higher mortality among those who retired on grounds of ill-health (see [66]). The results are summarised in Table 3-5.

Table 3-5 Actual mortality in 2000-2006 compared to expected mortality according to the indicated tables (weighted by pension amount); experience of pensioners by type of retirement (source: CMI)

Type of retirement	**Male % of PCMA00 table**	**Female % of PCFA00 table**
Ill-health retirement	206	191
Normal retirement	107	109

3.39 Data from the ONS Longitudinal Study suggest that mortality is higher for those who are temporarily or permanently sick (see [39]).

3.40 In addition the CMI analyses the mortality of impaired lives, in this case meaning those not accepted for life assurance on normal terms. The latest published results relate to the period 1987-1998 (see [53]).

3.41 There is no reliable information on whether ill health affects changes in mortality rates.

SMOKING

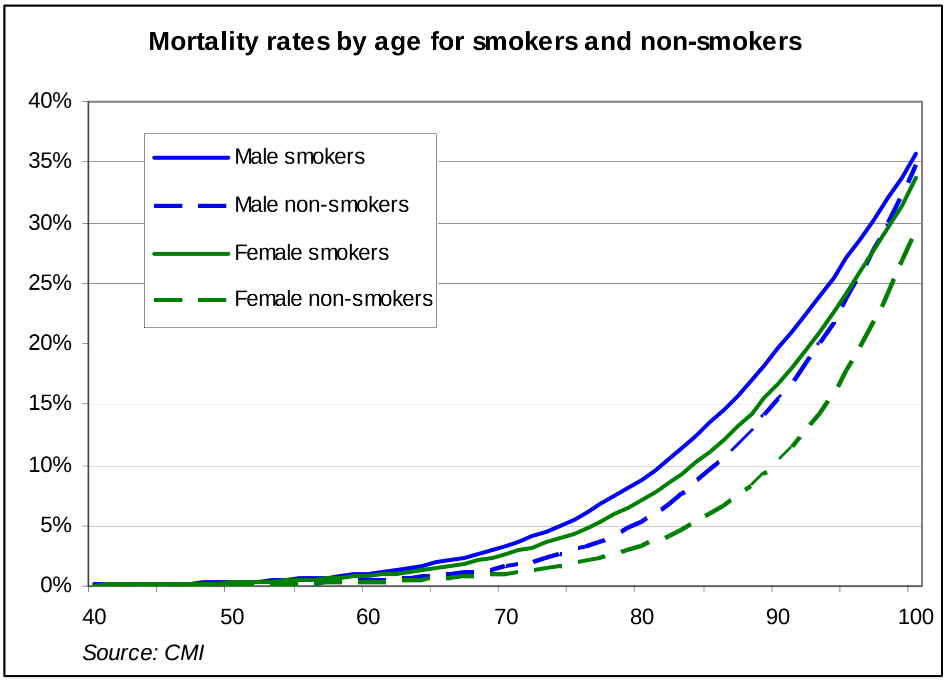
3.42 The fact that smokers have higher mortality than non-smokers has been well documented (see [9]). Doll and co-workers have published the mortality and survival rates among physicians who were continuing, past and non-smokers. The results suggest that those born between 1900 and 1930 who were smokers throughout their entire adult life had an expectation of life around 10 years less than that for non-smokers. However, if they gave up smoking by age 30 they had the same life expectancy as lifelong non-smokers. There were also relative gains for those who gave up at ages 40, 50 and 60 of around nine, six and three years of life respectively compared to those who continued to smoke.

3.43 The General Household Survey provides various time series of data on smoking (see [45]). *Health Statistics Quarterly No 34* provides an analysis of generational trends in smoking in Great Britain by socio-economic class by tracking average experiences of people born in the same time period (a method often referred to as pseudo cohort analysis) (see [38]). The analysis suggests that people born in 1926-1950 in manual households were more likely to become smokers than those born in non-manual households but that both group subsequently gave up smoking at similar rates. The 1956-1985 birth cohorts were less likely to smoke than those born earlier but compared to earlier cohorts, for the manual group, the vast majority remain smokers compared to earlier cohorts, with rates stabilising around 45% for males and 40% for females.

3.44 The CMI collects smoker-differentiated data on assurances from life offices. This was graduated to produce smoker-differentiated mortality tables for the first time in the "00" Series (see [60]). It is important to note that the definition of smoking is that used by the individual life offices who contributed data (which may be "no tobacco use in the last 12 months"), and usually reflects the status at the start of the policy. Smokers who cease smoking may then selectively withdraw, to obtain a cheaper, non-smoker premium, making this experience difficult to interpret.

3.45 Figure 3-4 shows the mortality rates by age from the CMI "00" series tables for assured lives.[1] It is notable that at most ages in the range shown the differentials between smokers and non-smokers are greater than those between the sexes.

Figure 3-4: Mortality rates for smokers and non-smokers from the "00" series tables for assured lives



[1] AMN00, AMS00, AFN00 and AFS00.

3.46 There is no reliable information on relative rates of mortality improvement for smoker and non-smokers. However, many people believe that a reduction in smoking has played a large part in the mortality improvements that have been seen over the past few decades. One argument that is made is that as people can only give up smoking once, mortality for current non-smokers is likely to improve more slowly than that for current smokers (who may give up in the future). However, care has to be taken with this argument. The definitions of the smoker and non-smoker categories, and the way in which those who give up smoking are treated, have significant effects on observed improvement rates.

MARITAL STATUS

3.47 The ONS publishes mortality data of people with different de jure marital status in the annual series *DH1 Mortality Statistics* (see [46]). This volume also contains mortality rates by marital status in age groups. Population estimates by marital status are also available. These can be used with the data on deaths by marital status to calculate single year age specific mortality rates by marital status. However, the data are only available up to age 90, and are unreliable at older ages.

3.48 The evidence is that married people experience lower rates of mortality than those who are unmarried. One study found that absolute differentials in mortality rates increase steadily with age, and that they increased in the 1990s, ie that mortality improvements appear to be greater for the married than for the unmarried (see [23]).

OVERLAPPING FACTORS

3.49 It is well-known that many of the risk factors affecting mortality overlap, in that they do not act independently on the risk. For example, there are proportionately more smokers among people in lower socio-economic groups than in higher groups, and it is plausible that occupation, postcode and income are often closely related.

3.50 In some cases, the link may be strong enough that one risk factor can be a very effective proxy for the others; for example if postcode is available, there may be no need to consider occupation and income separately. Otherwise, it may be necessary to estimate the joint influence of all the risk factors in use, which amounts to modelling the interactions between them.

3.51 This problem is common in many statistical settings, when the influence of several risk factors on some outcome needs to be estimated. Well-known and robust methods of estimating jointly such influences are available, and are included in most popular statistical modelling software packages. These modelling approaches may be very useful with mortality data, since they provide evidence-based guidance on which risk factors are significant and should be retained, which are unimportant (or well proxied) and may be dropped, and which need to be modified in the presence of others.

3.52 In the absence of sufficient data to perform a valid statistical analysis, it is important to be alert to the danger of double-counting.

4 MODELLING FUTURE MORTALITY

4.1 All forecasts are based on models – ie, simplified representations of reality. All models make assumptions about the behaviour of the phenomenon under investigation (in this case, mortality) and about the boundary conditions that must be satisfied (in this case, the initial situation). As they are simplifications, models inevitably have limits on their applicability and it is important that these are understood by their users.

4.2 There are three basic approaches: extrapolation, expectation and explanation. Extrapolative models extend historic patterns and trends into the future. Methods based on expectation use surveys (ie, the opinions of large numbers of people) or the opinions of experts about future developments. Explanatory models attempt to model causes and effects. The dividing lines between the different types of model are not clear cut. Extrapolative models may be influenced by expert judgement of overall trends, and explanatory models may extrapolate the effects of individual causes. However, the categorisation is a useful one, as it provides a framework within which to think about the large number of models that have been used to forecast future mortality rates.

4.3 With so many different models, producing a huge range of possible results, it is important to have some criteria for judging them. There are a number of desirable characteristics that models of future mortality may have, of which we consider two: "plausibility", and the ability to assist the user in supplying some indication of the level of uncertainty involved.

4.4 "Plausibility" is probably the more important characteristic, and the more difficult to define. It includes, for example, the desirability of a smooth transition between mortality rates for neighbouring ages and periods (including between observed, historic rates and forecast, future rates) – sharp discontinuities are inherently unlikely. It also includes the "reasonableness" of the long term forecast, though the notion of reasonableness varies widely. Most people would agree that, in the long term, it is unlikely that everyone will die at age 45. However, there is considerable disagreement over whether it is reasonable to assume that the current maximum life span, of around 120 years, will remain stable or whether it will increase (see [13], [25], [31]). For explanatory models the plausibility of the assumed causal relationships and parameters, and for expectation-based models the reasonableness of the methodology used to derive the expectations that are used, are also important. In practice, these are largely based on expert judgements.

4.5 As is observed in section 6, all forecasts have uncertainty associated with them, and it is important that their users have some idea of the extent of that uncertainty. Models that can supply some estimate of the level of uncertainty involved are particularly helpful to users, who can make use of the information when making decisions. Some of the difficulties that arise in modelling future changes in mortality rates, and hence sources of uncertainty, are discussed in section 5.

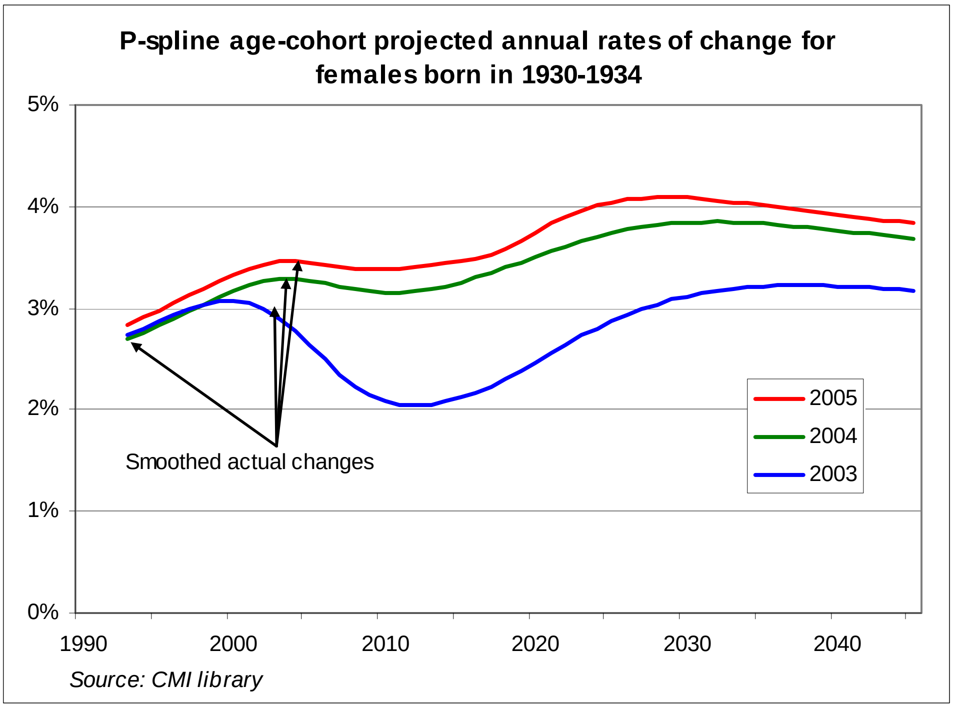
EXTRAPOLATIVE MODELS

4.6 Extrapolation is a common approach in demographic forecasting, and it is widely used to forecast future mortality. Extrapolative models are based on the assumption that the future will be (in some sense) a continuation of the past. This means that they automatically meet the plausibility test of a smooth transition between historic and forecast rates. However, the assumption that historical patterns will persist is clearly implausible. Extrapolative models, by their very nature, are likely to miss changes in the trend, or structural changes. Moreover, purely extrapolative models do not incorporate information about the effects of a possible biological limit to lifespan, future medical advances, and environmental and other risk factors (see [3], [24]).

4.7 Extrapolative models must incorporate judgments about the form of model to be fitted, the parameters used in fitting, and the historic period whose rates should be extrapolated, and whether to use a period or cohort perspective. These judgments are reflected in the range of results produced by extrapolative methods (see [7], [62] for some comparisons).

4.8 Some extrapolative models are very sensitive to the data used to fit them; omitting or including a single year's worth of data can significantly change the results. For example, Figure 4-1 shows age-cohort P-spline projections based on ONS data up to 2003, 2004 and 2005. The projections based on data to 2004 are very different to those based on data to 2003, showing much larger improvements. This characteristic, which is by no means unique to the P-spline model, is known as the *edge effect*: projections are heavily influenced by the trends in the most recent time periods.

Figure 4-1: P-spline age-cohort projected annual rates of changes in mortality based on data to 2003, 2004 and 2005 for birth years 1930-34



EXPECTATION-BASED MODELS

4.9 Methods of forecasting based on individual expectations of future life events are common in other demographic fields, such as fertility, but are not used to forecast mortality. However, methods involving consultation with experts on their expectations are fairly widespread. In particular, they are used by both the Social Security Administration in the USA and the ONS in the UK. Keilman et al give a wider perspective on demographic forecasting by National Offices (see [17]).

4.10 The ONS mortality projections involve interpolation between assumed recent rates of mortality improvement and assumed long term rates of improvement. The assumed long term rates, the period over which recent rates converge to the long term rates, and the pattern of convergence, are all determined by the ONS after consultation with an external expert panel, the offices of the three Registrars General and users of the projections (see [52]). The overall methodology has been the same for some years, but the assumptions are updated for each projection (which are usually published every two years).

4.11 Expectation-based models are usually plausible, as that is one of the criteria that experts commonly use when applying judgement. However, it can be difficult to estimate the uncertainty surrounding the forecasts they produce, as subjective assessments by experts of the levels of uncertainty in their own judgements are often not reliable, although Delphi methods can be used to generate meaningful estimates of likely error. It is notable in this context that, while the ONS produces three mortality projections (principal, high life expectancy, and low life expectancy), it does not assign any probabilities to them.

EXPLANATORY MODELS

4.12 The basic paradigm of explanatory models is that assumptions about the prevalence of diseases, the availability and efficacy of treatments, and changes in lifestyle and environmental factors are used to model mortality by cause of death. There are some variations on this; for example, Love and Ryan use major disease groups (rather than individual diseases), and look at overall mortality rates within disease groups, including deaths from other causes (see [19]).

4.13 Explanatory models span a huge range of complexity. Some are very simple, looking only at mortality by cause of death rather the explanations underlying those causes. However, even these simple models can be useful in

- identifying projections that are over optimistic or pessimistic;
- generating scenarios for use in stress and scenario testing; and
- complementing other methods for determining best estimate and variability.

4.14 For example, comparing possible projections to those derived by positing the eradication or postponement of all deaths from a specific cause can provide useful information on the plausibility or otherwise of the projections in question.

4.15 The WHO Global Burden of Disease project draws on a wide range of data sources to develop internally consistent estimates of incidence, health state prevalence, severity and duration, and mortality for over 130 major causes around the world (see [35]).

4.16 One area that is likely to be of considerable importance for modelling of future mortality is the increasing understanding of the scientific basis of ageing and age-related frailty, disability and disease. Although there is still much to be learnt, there is a growing consensus among biomedical scientists that the necessary detailed understanding of ageing may be attained in coming decades (see, for example, [18]). Already scientific understanding points to a significant degree of intrinsic malleability in the ageing process that might be exploited in future to reduce age-related morbidity and mortality. Furthermore, there is some evidence to suggest that the rapid changes in pressure of natural selection that have occurred over the last two centuries, particularly on the factors that influence trade-offs between fertility, resistance to infectious disease and mortality, might have created circumstances in which changes in the genetic make-up of populations could occur in just a few generations, with potentially significant effects on life expectancy (see [11]).

4.17 Booth points out that while explanatory models are often thought of as the ideal method of forecasting, their use in demographic forecasting has not on the whole produced more accurate forecasts than other methods (see [3]).

4.18 The plausibility of explanatory models depends on that of the underlying assumptions. However, they do have the advantage that it is often easier to explain their results than it is those of extrapolative models.

4.19 As the range of possible explanatory models is so broad, it is impossible to generalise about how well the uncertainty around their results can be estimated.

5 DIFFICULTIES WITH MODELS

5.1 There are a number of difficulties that arise when trying to build a model of future mortality. Some of these are common to all models, while others are more significant for one type of model than for others.

THE FUTURE IS UNCERTAIN

5.2 It is most unlikely that current trends in mortality will continue unchanged, though it is very difficult to say which will change and how. This difficulty applies to all three types of model, though it is especially significant for extrapolative models. It is also highly significant for explanatory models, which require both an understanding of current relationships between causes and effects and assumptions about how the causes and their relationships will evolve in the future.

5.3 Even a thorough understanding of past changes may not provide a good guide to the future, which is inherently uncertain. For example, in the past, the mortality of lower socio-economic groups has improved more slowly than that of the higher groups (although the extent to which this is true depends on the index that is used). There are three possibilities for the future: that this trend will continue; that, in the future, the mortality of lower groups will improve faster than that of higher groups; or that there will be no difference in the rates of change.

5.4 One argument in favour of the first view is that the relative rates of improvement are at least partly caused by better access to the latest medical advances, and that this differential is likely to continue. A contrary argument is that recent improvements have been largely due to lifestyle changes, such as better childhood nutrition and giving up smoking, which have been adopted more rapidly by those in higher socio-economic groups. There are fewer changes in lifestyle now available to the higher groups, the argument continues, but there are still many changes open to those in the lower groups, so their mortality can be expected to improve more rapidly in the future.

5.5 It is certainly plausible, and even likely, that future changes will be different for those in different socio-economic groups, but it is impossible to say what the difference will actually be.

LONG TERM

5.6 In order to be useful to actuaries, mortality models need to be able to cover at least the next 40 years, and in many cases the next 60-80 years. These periods are much longer than those used in other major modelling areas, such as economics and transport, and the uncertainties are enormous. Setting the large number of assumptions needed over such a long period is by no means an easy task. Moreover, a small change in assumptions can lead to significant changes in the long term results. Again, this is an issue with all three types of model.

5.7 Probabilistic models provide estimates in the form of probability distributions, rather than the single estimates produced by deterministic models. They therefore enable the estimation of the possible magnitude of errors, and how they differ between age groups, across the sexes, or by other variables of interest. They can therefore provide more information on which a decision about mortality assumptions can be based (see [16]).

DATA

5.8 There are two ways in which data problems affect the building of models. First, there is rarely sufficient data available to allow models to be validated satisfactorily. This affects all types of model. Second, sparse or poor quality data can make it difficult to derive good quantitative relationships between variables in explanatory models. Although more data is now being collected, historic data remains a problem.

5.9 The most obvious case of poor data availability is for cause of death, especially at older ages. Data for cause of death comes from death certificates, which are not generally completed by expert coders. A single cause of death is rarely meaningful at older ages, and there is little consistency as to which of the several possibilities are recorded.

5.10 Another problem area is socio-economic group both at death and through life. The figures on mortality and life expectancy by social class produced by the ONS, for example, are based on a sample of the population for whom social class is assigned by a set of priority rules at entry to the sample. As social class may vary through life, the experience of the sample may be misleading. Analyses based on occupation recorded on a death certificate may suffer from this occupation being ambiguous (eg, engineer) or simply inaccurate.

UNDERSTANDING OF PAST CHANGES

5.11 A major problem facing builders of all models of future mortality is that of understanding past changes in mortality rates.

5.12 For example, it is often argued that the UK has a pronounced cohort effect, in that the mortality of those born in (approximately) the early 1930s has improved faster than that of those born earlier or later. There are apparently also other, lesser, cohort effects that apply to people born at other dates. However, the existence of cohort effects has not been found in other populations in which such effects might be expected to exist, such as nineteenth century Finnish famine victims, and it would be possible for crossover effects to exist in which an advantaged group has relatively large numbers of frail survivors who experience higher than expected mortality in later life.

5.13 The prevailing theory about the cause of the cohort effect in the UK is that it is closely linked with reduced rates of smoking. However, there are a number of other theories, including diet (particularly as those involved were children or teenagers during the period of rationing in WWII and thereafter), the introduction of the NHS, and being born in periods of low birth rates (see [33])

5.14 Because there is no single generally accepted theory about the cause of the observed cohort in the UK, there are differing views on the extent to which cohort related effects will feature in future changes in mortality.

INTERACTIONS BETWEEN CAUSES

5.15 An additional difficulty that is especially relevant to explanatory models is poor understanding of the interactions between mortality risk factors and different causes of death. A person who has two diseases, for example, may die earlier than someone who has only one of them. There are also important interactions between socio-economic group and deaths from different causes, arising from lifestyle factors, behavioural differences and, for example, greater access to private health care.

5.16 For effective explanatory modelling, the quantitative and temporal effects of the interactions must be understood, and information is sparse in this area. Again, this is likely to change in the future as more relevant data is collected.

TEMPORAL RELATIONSHIPS

5.17 In order to build a model that links causes and effects, and that will provide forecasts of variables over future periods, it is necessary to understand the temporal relationships between the causes and effects, and possibly to have future forecasts of the relevant explanatory covariates (which may, of course, be inherently more difficult to forecast than mortality).

5.18 Unfortunately, the current state of knowledge about the mechanisms through which many of the factors that influence mortality (and, even more so, their interactions) work is not sufficient to enable comprehensive detailed models to be built. However, much useful work has been done on models that investigate specific causes of death or diseases, which can be used to investigate specific scenarios and provide good comparisons against and checks on other models.

EXPLANATORY MODELS

5.19 There are significant difficulties to be overcome in building fully comprehensive explanatory models. There is broad agreement on the types of factors that can be expected to influence future mortality rates (but much disagreement on the details). The factors that are usually identified are socio-economic class, lifestyle and behavioural changes, improvements in healthcare, and improvements in infrastructure (see also section 3). However, their utility depends on understanding:

a) The ways in which these causes have operated in the past;

b) Possibly what their levels will be in years to come (in some cases requiring long-term forecasts of these assumed determinants); and

c) How they are likely to operate in the future.

5.20 It is the group’s view that these three issues are not well enough understood to form the basis of a comprehensive explanatory model of mortality in the short term. However, this does not mean that development of these models should be discontinued, and some members of the group believe that it should be a priority. Such development will depend on the progress made in fields such as epidemiology, demography, etc.

6 UNCERTAINTY

6.1 It is, of course, impossible to tell exactly what the future will hold. Any projections of future mortality rates, however they are derived, are subject to risk and uncertainty. Actual mortality rates are most unlikely to match the projected rates exactly.

6.2 A distinction that is often made by economists and actuaries is that between quantifiable risk and inherently unquantifiable uncertainty.[2] There are many circumstances in which a number of different possible outcomes are possible. In some circumstances, the probabilities of the various outcomes can be derived from analysis or by observing past experience and drawing statistical inferences. For example, if we have a jar containing balls of two different colours, it is possible to take a sample from the jar and from that sample to estimate the proportion of balls of each colour. On the other hand, there are circumstances in which there is no basis, other than judgement, on which to assign probabilities. An example of this is an estimate of the probability of a violent revolution occurring in a specified country. Circumstances of the first type, where there is a mathematical basis for assigning probabilities, are said to exhibit *risk*; those of the second type, where there is no mathematical basis for so doing, are said to exhibit *uncertainty*.

6.3 Turner (see [30]) argues cogently that statements about future life expectancy, and hence about future mortality rates, are judgments about uncertainty, rather than risk – they are far closer to the category "I believe that there is a 50% probability that country X will have a violent revolution in the next 25 years" than to the category "there is a 95% probability that the percentage of red balls in the whole jar lies between 37 and 43%."

6.4 The uncertainty inherent in projections of future mortality rates arises from a number of sources.

6.5 The first is modelling error. Whatever method is used to derive the assumptions, they will be based on some sort of model of what the future will hold – this may be, for example, a model of the causes of future changes in mortality rates, or an extrapolative model based on past changes. To the extent that the model is not an accurate reflection of reality, the assumptions will differ from the actual outcomes. Moreover, any differences between the model and reality are often magnified over time; a model that provides a satisfactory approximation over the short term may be far from accurate over the long term.

6.6 The second source of uncertainty is parameter error: it is impossible to get exact estimates for model parameters because the data available is limited and inaccurate. Every model depends on parameters that are used to calibrate it – in other words, align its theoretical framework with the concrete situation in which it is being applied. Inevitable data limitations mean that the estimated parameter values will differ from the theoretical values.

---

[2] This distinction dates back to Frank H Knight's 1921 book, *Risk, Uncertainty, and Profit*. It is discussed in the BAS's consultation paper on its Conceptual Framework (see [2]).

6.7 A major difficulty when considering changes in mortality is the timescale; actuaries need to make assumptions about mortality rates for 40 or more years. Effective calibration of the models requires data spanning a long period. Collection methods and the composition of the population from which data is collected may change over time. Data collected over long periods is therefore often inconsistent, and may well provide unreliable estimates for the parameters.

6.8 A third source of uncertainty is random variation (sometimes known as process error). Even if the assumed mortality rates were an accurate estimate of the true underlying rates, random variations in the actual numbers of deaths, and hence in the observed rates, would be expected. The uncertainty due to process error is more significant if the model that is used to derive the assumptions is one in which the outcome in one period influences the outcomes in later periods. For large groups of people the difference between the observed and underlying rates would be expected to be small. However, for small groups of people the uncertainty from this source may be much larger than the uncertainty from modelling and parameter errors.

6.9 Other sources of uncertainty include data error and error due to expert judgement. In addition to affecting model parameters, so that the model fails to match actual future developments, inaccurate data can mean that the model fails to start from a position that matches reality. In the field of mortality, inaccurate data is especially prevalent in the areas of estimating the numbers of older people that are alive (and hence the mortality rates at older ages) and in recorded causes of death. Expert judgement is significant because any model will require some choices or decisions – no model can be implemented in a completely automatic manner. Each decision is a potential source of error.

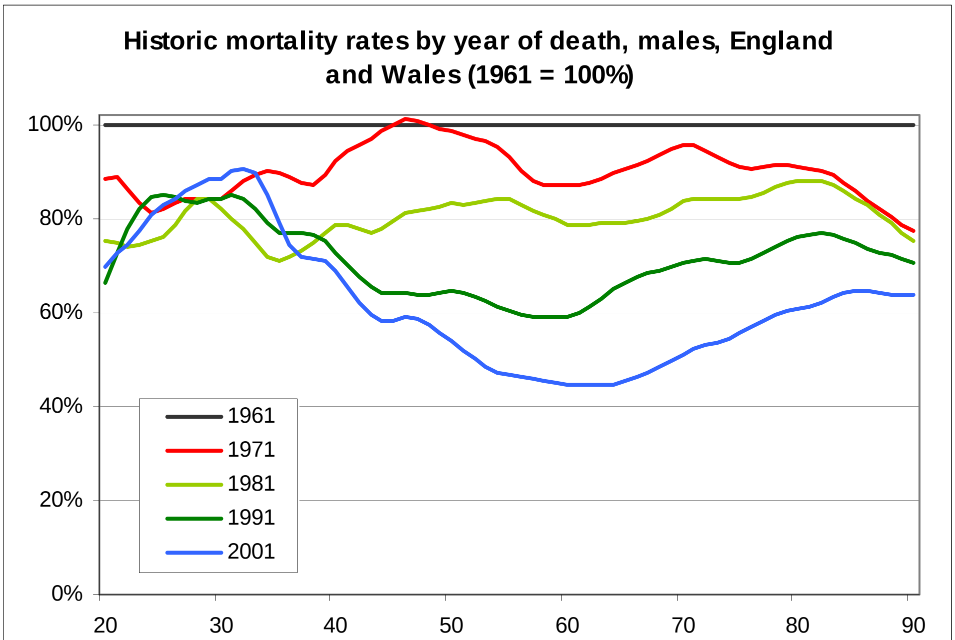
6.10 In addition, there is the problem of heterogeneity: there will always be unobserved variables so it will never be possible to provide a full explanation of all variation in mortality rates through the use of explanatory factors.

THE FUTURE IS UNCERTAIN

6.11 Mortality rates have undergone significant changes in the past, and all the evidence is that they will continue to change in the future. However, there is no consensus about the overall long-term trend, leading to high levels of model uncertainty.

6.12 Figure 6-1 shows that over the last 50 years mortality rates have changed much more for ages 40-80 than for older (or younger) ages. The rate for 60 year olds in 2001 was around 45% of the 1951 rate, while the rate for 90 year olds was around 65% of the 1951 rate. Increases in life expectancy have therefore been driven primarily through decreases in mortality rates at ages other than the very oldest. Some academics argue that since this mortality decline has already occurred, it cannot happen again. Since there is no evidence of large declines at the very oldest ages, the argument goes, the maximum lifespan (currently around 120 years) is unlikely to increase, and, overall mortality rates cannot continue to improve indefinitely (see [25]).

Figure 6-1: Historic mortality rates by age and year of death



Source: LifeMetrics

6.13 Others take a different view. There has been a linear increase in the highest life expectancy at birth recorded for all countries since 1841, due to a variety of causes. There is no reason to suppose that this will change: the causes in the future will be different from those in the past, but the overall effect is likely to continue. In addition, the argument continues, there is no reason to suppose that there is a biological maximum lifespan (see [31]).

6.14 In 2005, the Pensions Commission and the Government Actuary's Department (GAD) compared earlier official population mortality forecasts to actual outcomes and more recent forecasts. They found that the actual mortality rate for 65 year old males in 2003 was around 41% lower than had been predicted by GAD forecasts in 1984, only 20 years earlier (see [26]). Dowd et al summarise some recent projections of life expectancy for 65 year old males in the UK (see [10]). The highest projection, based on a constant 3% decline in mortality rates, gives a life expectancy of around 37 years in 2050. The lowest, taking an extreme version of Olshansky's view (see [25]) that there will be no further improvements, gives one of around 18 years.

6.15 The ONS published new mortality projections in 2007, based on data to 2006, and using revised assumptions (see [51]). The principal projection gives a cohort life expectancy of 25 years for a 65 year old UK male in 2050. The previous estimate, based on data to 2004, was 23.6 years. Over the course of two years, the estimate changed by nearly 18 months.

6.16 This lack of consensus on future long term trends simply emphasises that the future is unknown. The only thing that can be said for certain about any single projection of future mortality rates is that it will be wrong. There is necessarily considerable uncertainty about the course of future mortality rates, and this uncertainty will affect all calculations that use assumptions about them.

6.17 Dowd et al use a stochastic mortality model to produce estimates of the uncertainty in mortality forecasts (see [10]). Their estimates of uncertainty allow for possible uncertainty in the model parameters. According to their model, there is a 90% chance that the life expectancy of a 65 year old male in 2050 will be between 22 and 32 years. This range of around 10 years is large, but of course is based on the assumption that the particular model they use is valid. It seems likely that the general conclusions that the levels of uncertainty are high hold for any model, however, thus reinforcing the point that uncertainty is inherent in all projections of future mortality rates.

LIMITED DATA

6.18 Every model depends on parameters that are used to calibrate it – in other words, align its theoretical framework with the concrete situation in which it is being applied. Inevitable data limitations mean that the estimated parameter values will differ from the theoretical values. Some data limitations are discussed in section 5.

6.19 A major difficulty when considering changes in mortality is the timescale; actuaries need to make assumptions about the mortality rates for 40 or more years into the future. Effective calibration of the models requires data over a long period. Data collected over long periods is often inconsistent, as collection methods and the composition of the population from which it is collected change over time.

RANDOM VARIATION

6.20 Even if there was no uncertainty surrounding the estimation of future mortality rates for the population as a whole, there would still be uncertainty surrounding the number of deaths that could be expected in any given sub-group of the population. This uncertainty is much greater for smaller groups.

6.21 For example, suppose the underlying mortality rate is .003, ie we expect 3 out of every thousand people to die in a year. In a group of 10,000 people, we would therefore expect 30 deaths over the next year. However, it is unlikely that exactly 30 deaths would occur; in fact, there's about a 50% chance that the actual number will be between 26 and 34 (and therefore a 50% chance that it will be outside that range). A difference of more than 10% from the expected rate is therefore by no means unlikely. In a group of 100 people, we would theoretically expect .3 of a death over the next year. This is clearly impossible: the actual number of deaths must be a whole number. If there is a single death, the mortality rate is .01, which is a difference of over 200% from the expected rate.

6.22 This source of uncertainty is independent of the uncertainty surrounding the prediction of the expected rates of mortality, and for small groups may be much more significant.

ILLUSTRATING UNCERTAINTY

6.23 There a number of different ways in which uncertainty can be illustrated. All of them may be useful under some circumstances, and no one method is likely to be suitable in all circumstances. However, the presentation of a single projection with no indication of the uncertainty surrounding it will always be misleading.

6.24 Confidence intervals have a long history, but are difficult to calculate for most projections. However, they may be very useful in measuring the extent of stochastic uncertainty, and can be calculated automatically from probabilistic projections.

6.25 Fan charts are very useful as visual aids to communication, but are also unlikely to be feasible for most projection methods. The presentation of alternative scenarios, or alternative projections, may provide very concrete illustrations of model and parameter uncertainty.

7 REFERENCES AND BIBLIOGRAPHY

Both Booth (2006) and Coughlan et al (2007) contain extensive bibliographies.

[1] Bamia C, Trichopoulos D, Ferrari P, Overvad K, Bjerregaard L, Tjønneland A, Halkjaer J, Clavel-Chapelon F, Kesse E, Boutron-Ruault MC, Boffetta P, Nagel G, Linseisen J, Boeing H, Hoffmann K, Kasapa C, Orfanou A, Travezea C, Slimani N, Norat T, Palli D, Pala V, Panico S, Tumino R, Sacerdote C, Bueno-de-Mesquita HB, Waijers PM, Peeters PH, van der Schouw YT, Berenguer A, Martinez-Garcia C, Navarro C, Barricarte A, Dorronsoro M, Berglund G, Wirfält E, Johansson I, Johansson G, Bingham S, Khaw KT, Spencer EA, Key T, Riboli E, Trichopoulou A (2007). Dietary patterns and survival of older Europeans: the EPIC-Elderly Study (European Prospective Investigation into Cancer and Nutrition). Public Health Nutr. 10:590-8.

[2] Board for Actuarial Standards (2007). Towards a Conceptual Framework: Consultation Paper. Available from http://www.frc.org.uk/bas/publications/pub1444.html.

[3] Booth, H (2006). Demographic forecasting: 1980 to 2005 in review. International Journal of Forecasting 22 (2006) 547-581.

[4] Cairns, A J G, Blake, D, and Dowd, K, (2006) A two-factor model for stochastic mortality with parameter uncertainty: Theory and calibration. Journal of Risk and Insurance 73: 687-718. http://www.ma.hw.ac.uk/~andrewc/papers/ajgc49.pdf.

[5] Cairns, A J G, Blake, D, Dowd, K, Coughlan, G D, Epstein, D, Ong, A, Balevich, I (2007). A quantitative comparison of stochastic mortality models using data from England & Wales and the United States. Discussion paper PI-0701, The Pensions Institute. http://www.pensions-institute.org/workingpapers/wp0701.pdf

[6] Chatterjee, T, Macdonald, AS, Waters, HR (2007). A Model for Ischaemic Heart Disease and Stroke I: The Model. Submitted to The Annals of Actuarial Science. http://www.ma.hw.ac.uk/~andrewc/papers/hrw1.pdf

[7] Coughlan, G et al (2007). LifeMetrics Technical Document. http://www.jpmorgan.com/directdoc/lifemetrics_technical.pdf.

[8] de Grey, A, (2003). Critique of the demographic evidence for 'late-life non-senescence'. Biochemical Society Transactions 31, 452-454.

[9] Doll, R, Hill, A B (2004). The mortality of doctors in relation to their smoking habits: a preliminary report: (Reprinted from Br Med J 1954:ii;1451-5). BMJ 328, 7455, 1529-1533.

[10] Dowd, K, Blake, D, & Cairns, A J G (2007). Facing Up to the Uncertainty of Life: The Longevity Fan Charts. Discussion paper PI-0703, The Pensions Institute.

[11] Drenos F, Westendorp RG, Kirkwood TBL (2006). Trade-off mediated effects on the genetics of human survival caused by increasingly benign living conditions. Biogerontology 7:287-295

[12] Ezzatti M, Oza S, Danaei G, Murray CJ (2008). Trends and cardiovascular mortality effects of state-level blood pressure and uncontrolled hypertension in the United States. Circulation 117:905-14.

[13] Garssen, J (2006). Will life expectancy continue to increase or level off? Weighing the arguments of optimists and pessimists. Statistics Netherlands. http://www.cbs.nl/en-GB/menu/themas/bevolking/publicaties/artikelen/archief/2006/default.htm

[14] Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de.

[15] Keilman, N W (1990). Uncertainty in national population forecasting: Issues, backgrounds, analyses, recommendations. NIDI/CBGS Publications nr. 20, Amsterdam/Lisse: Swets & Zeitlinger.

[16] Keilman, N W (2007). UK national population projections in perspective: How successful compared to those in other European countries? Population Trends 129, 20-30.

[17] Keilman, N & Cruijsen, H (eds.) (1992). National population forecasting in industrialized countries. NIDI/CBGS Publications nr. 24, Amsterdam/Lisse: Swets & Zeitlinger.

[18] Kirkwood TBL (2008). A systematic look at an old problem. Nature 451: 644-7.

[19] Love, H & Ryan, D (2007). Disease and Death: Improving our understanding of the future. Presented to the Staple Inn Actuarial Society. http://www.sias.org.uk/siaspapers/listofpapers/view_paper?id=DiseaseandDeath

[20] LifeMetrics. http://www.lifemetrics.co.uk

[21] Doblhammer G, Hoffmann R, Muth E, Westphal C, Kruse A (2006). The Effects of Age, Sex, Education, Marital Status, Obesity and Smoking on Disability and Mortality: A Systematic Literature Review. University of Rostock. http://www.nidi.knaw.nl/en/micmac/publications/d17/micmac-d17.pdf

[22] Murphy M (1995). Methods for forecasting mortality and their performance. Reviews in Clinical Gerontology 5, 243-253.

[23] Murphy M, Grundy E, and Kalogirou S (2007). The increase in marital status differences in mortality up to the oldest age in seven European countries, 1990-99. Population Studies 61(3): 287-98.

[24] Olshansky, S J (1988). On forecasting mortality. The Milbank Quarterly, 66, 482-530.

[25] Olshansky, J, (2005). The future of human life expectancy. In: the uncertain future of longevity. London: Watson Wyatt.

[26] Pensions Commission (2005). A New Pension Settlement for the Twenty-First Century: The Second Report of the Pensions Commission. Appendix E: Uncertainties in Life Expectancy Projections.

[27] Richards, S, and Jones, G (2004). Financial aspects of longevity risk. Presented to the Staple Inn Actuarial Society. http://www.sias.org.uk/siaspapers/listofpapers/view_paper?id=LongevityRisk

[28] Shaw, C (1994). Accuracy and uncertainty of the national population projections for the United Kingdom. Population Trends 77, 24-32.

[29] Terry DF, Pencina MJ, Vasan RS, Murabito JM, Wolf PA, Hayes MK, Levy D, D'Agostino RB, Benjamin EJ (2005). Cardiovascular risk factors predictive for survival and morbidity-free survival in the oldest-old Framingham Heart Study participants. J Am Geriatr Soc.53:1944-50.

[30] Turner, A (2008). Uncertainty and risk in life insurance, banking and financial markets: Reflections on a turbulent year. Lecture delivered at the Cass Business School, City University. Text and slides available from http://www.cass.city.ac.uk/media/story_3_1148_102759.html

[31] Vaupel, J W, Kistowski, K G V, 2005. Broken limits to life expectancy. Ageing Horizons Autumn-Winter, 6-13.

[32] Wang TJ, Gona P, Larson MG, Tofler GH, Levy D, Newton-Cheh C, Jacques PF, Rifai N, Selhub J, Robins SJ, Benjamin EJ, D'Agostino RB, Vasan RS. Multiple biomarkers for the prediction of first major cardiovascular events and death. N Engl J Med. 2006; 355:2631-9.

[33] Willets, R C, 2004. The cohort effect: insights and explanations. British Actuarial Journal 10, 833-877(45).

[34] World Health Organisation. Data and statistics. http://www.who.int/research/en/.

[35] World Health Organisation. Global Burden of Disease Project. http://www.who.int/healthinfo/bodproject/en/index.html

[36] World Health Organisation Regional Office for Europe. Data. http://www.euro.who.int/InformationSources/Data/20010827_1.

INFORMATION AVAILABLE FROM THE ONS

[37] Trends in life expectancy by social class 1972-2005. http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=8460&Pos=1&ColRank=1&Rank=272.

[38] Health Statistics Quarterly. http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=6725.

[39] The ONS longitudinal study. http://www.statistics.gov.uk/services/Longitudinal.asp

[40] The National Statistics Socio-economic Classification. http://www.statistics.gov.uk/methods_quality/ns_sec/

[41] Health Inequalities Decennial Supplement no.15 (1997). http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=1382

[42] Health of Adult Britain 1841-1994 Decennial Supplement. http://www.statistics.gov.uk/STATBASE/Product.asp?vlnk=1548

[43] Life expectancy at birth for wards in England and Wales (experimental). http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14466.

[44] Standardised Mortality Ratios for wards in England and Wales. http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=14359&Pos=4&ColRank=1&Rank=160.

[45] General Household Survey. http://www.statistics.gov.uk/ssd/surveys/general_household_survey.asp

[46] DH1 Mortality Statistics. http://www.statistics.gov.uk/STATBASE/Product.asp?vlnk=620.

[47] More detailed topics for National population estimates - by marital status. http://www.statistics.gov.uk/CCI/Nscl.asp?ID=7563&Pos=1&ColRank=1&Rank=224.

[48] Interim life tables. http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=14459&Pos=&ColRank=1&Rank=422.

[49] Life expectancy at birth by health and local authorities in the United Kingdom. http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=8841.

[50] Age standardised mortality rates by local authority. http://www.statistics.gov.uk/CCI/Nscl.asp?ID=7615&Pos=1&ColRank=1&Rank=80.

[51] National Population Projections. http://www.statistics.gov.uk/statbase/Product.asp?vlnk=8519.

[52] National Population Projections: Review of Methodology for Projecting Mortality. National Statistics Quality Review Series Report No. 8 (2001).

CMI PUBLICATIONS

All CMI publications are available from http://www.actuaries.org.uk/Display_Page.cgi?url=/library/cmi.xml.

[53] The Mortality of Impaired Assured Lives, 1987-98. CMI Report 20, 2001.

[54] WP1. An interim basis for adjusting the "92" Series mortality projections for cohort effects.

[55] WP2. Responses to the draft report entitled A proposed interim basis for adjusting the "92" Series mortality projections for cohort effects and further commentary thereon.

[56] WP3. Projecting future mortality: A discussion paper.

[57] WP11. Responses to Working Paper 3 entitled Projecting future mortality: A discussion paper and further commentary thereon.

[58] WP15. Projecting Future Mortality: Towards a proposal for a stochastic methodology.

[59] WP20. Stochastic Projection Methodologies: Further progress and P-Spline model features, example results and implication.

[60] WP21: The Graduation of the CMI 1999-2002 Mortality Experience: Final "00" Series Mortality Tables – Assured Lives.

[61] WP 22: The Graduation of the CMI 1999-2002 Mortality Experience: Final "00" Series Mortality Tables – Annuitants and Pensioners.

[62] WP25. Stochastic projection methodologies: Lee-Carter model features, example results and implications.

[63] WP27. The "library" of Mortality Projections.

[64] WP29: An analysis of the results of the mortality of male and female pensioners of self-administered pension schemes for the period 2000 to 2004 based on data collected by 30 June 2006.

[65] WP30. The CMI Library of Mortality Projections.

[66] WP31. Report on the preliminary results of an analysis into the mortality experience of pensioners of self-administered pension schemes for the period 2000 to 2006 based on data collected by 30 June 2007.

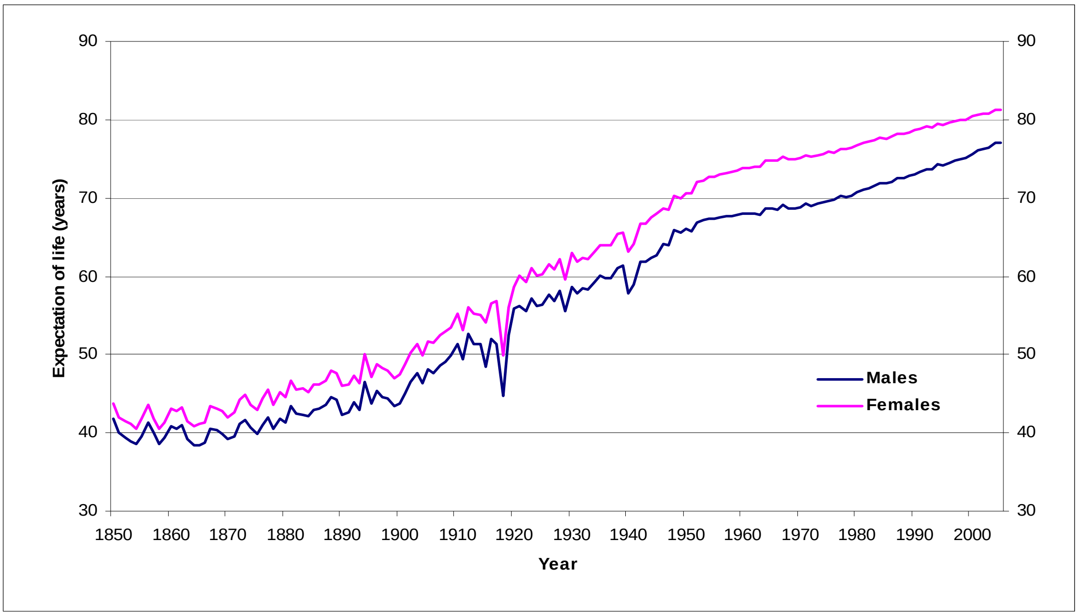
[67] WP32. Proposed graduations of the CMI SAPS 2000-2006 mortality experience based on data collected to 30 June 2007.

A POPULATION MORTALITY TRENDS IN THE UNITED KINGDOM

A.1 In common with other developed countries, during the course of the 20th century the United Kingdom saw a continuation of the pattern of falling death rates that began during 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.

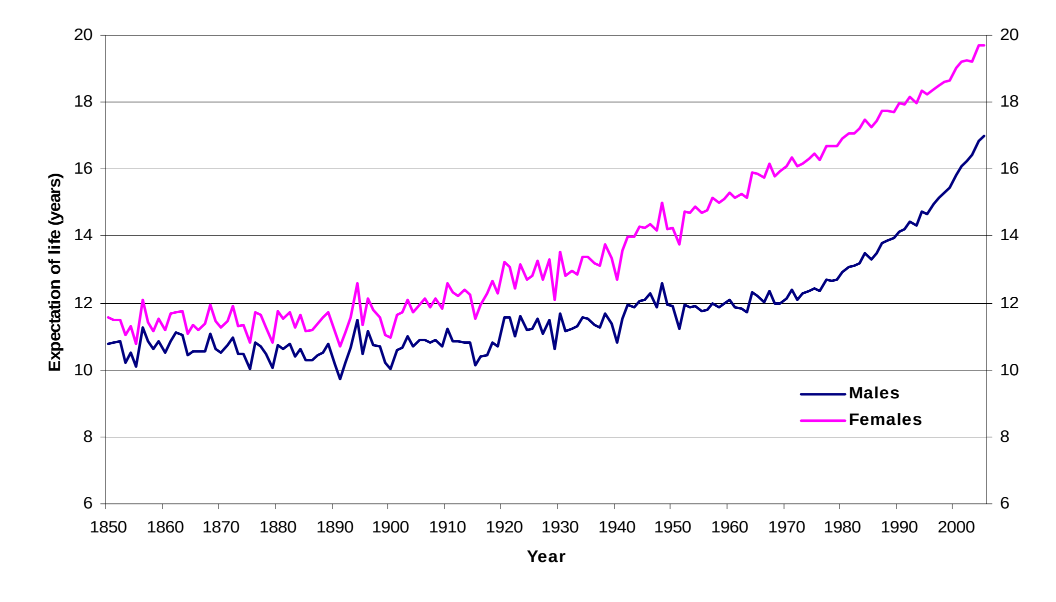
A.2 Period life expectancy at birth at the beginning of the 20th century was around 45 years for males and 50 years for females. Period life expectancy at birth then rose dramatically until the mid-1950s; since then there has been a continuing increase but at a less rapid rate (see Figure A-1).

Figure A-1: Period expectation of life at birth, England and Wales, 1850-2005 (Source: ONS)



A.3 The pattern for period life expectancy at age 65 is somewhat different. Figure A-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, particularly for males, as mortality at older ages began to improve more rapidly than female mortality.

Figure A-2: Period expectation of life at age 65, England and Wales, 1850-2005
(Source: ONS)



A.4 Table A-1 shows period life expectancy at birth and at age 65 for the United Kingdom and constituent countries, based on population data for the years 2004 to 2006.

Table A-1: Period life expectancy in years, 2004-06
(Source: Interim life tables 2004-6, ONS)

	At birth		**At age 65**	
	Males	**Females**	**Males**	**Females**
England	77.2	81.5	17.1	19.9
Wales	76.6	80.9	16.7	19.5
Scotland	74.6	79.6	15.8	18.6
Northern Ireland	76.1	81.0	16.6	19.5
United Kingdom	76.9	81.3	16.9	19.7

A.5 There has been a large increase in period life expectancy among older adults in recent years. Between 1980-82 and 2004-06 life expectancy at age 65 in the UK increased by 4.0 years for men and 2.8 years for females. Around one-quarter of this increase occurred over the last four years. In general the increases in life expectancy over the period have been broadly similar for each country. However, on average, for males in Scotland the increase was lower at 3.5 years. Conversely, females in Northern Ireland experienced a higher increase of 3.3 years. By comparison, expectation of life at birth in the UK has increased by 6.1 years for males and 4.5 years for females over the same period. Women continue to live longer than men, but the gap has been closing in recent years.

A.6 Improving mortality rates mean that the chance of a new born boy reaching age 65 has increased from 74 per cent (based on mortality rates experienced in 1980-82) to 84 per cent (based on mortality rates in 2004-06). For females the chance has increased from 84 per cent to 90 per cent.

A.7 The above life expectancy figures make no allowance for future changes in mortality. Allowing for the latest projected future improvements in mortality from the 2006-based population projections the cohort life expectancy at birth in the UK in 2006 is projected to be 88.1 years for a boy and 91.5 years for a girl. Cohort life expectancy for those aged 65 in 2006 is projected to be 20.6 years for males and 23.1 years for females. It is estimated that a boy born in the UK in 2006 will have a 91 per cent change of reaching age 65 and a girl a 94 per cent chance.

LIFE EXPECTANCY BY AREA

A.8 Life expectancy varies quite significantly between local authorities. At birth, the range is nearly 13 years for males, and 10 years for females (see Tables A-2 and A-3). At age 65, the variation is over eight years for males and over seven years for females (see Tables A-4 and A-5).

A.9 However, the overall variation is somewhat less than that suggested by the extremes. About half of local authorities have a life expectancy at birth for both sexes combined within one year of the median value.

Table A-2: Highest period life expectancy at birth, 2004-6, by local authority (Source: ONS)

Males **Local authority**	**Period life expectancy**	**Females** **Local authority**	**Period life expectancy**
Kensington and Chelsea	83.1	Kensington and Chelsea	87.2
East Dorset	81.4	East Dorset	84.7
Hart	80.7	Christchurch	84.4
Rutland	80.6	Rochford	84.3

Table A-3: Lowest period life expectancy at birth, 2004-6, by local authority (Source: ONS)

Males **Local authority**	**Period life expectancy**	**Females** **Local authority**	**Period life expectancy**
Eilean Siar	73.0	East Ayrshire	78.2
Inverclyde	72.2	Inverclyde	77.8
West Dunbartonshire	71.8	West Dunbartonshire	77.7
Glasgow City	70.5	Glasgow City	77.0

Table A-4: Highest period life expectancy at age 65, 2004-6, by local authority (Source: ONS)

Males **Local authority**	**Period life expectancy**	**Females** **Local authority**	**Period life expectancy**
Kensington and Chelsea	22.0	Kensington and Chelsea	24.8
East Dorset	20.3	East Dorset	22.5
Hart	20.0	Christchurch	22.4
Rutland	19.9	Rochford	22.2

Table A-5: Lowest period life expectancy at age 65, 2004-6, by local authority (Source: ONS)

Males **Local authority**	**Period life expectancy**	**Females** **Local authority**	**Period life expectancy**
West Dunbartonshire	14.9	North Lanarkshire	17.6
North Lanarkshire	14.9	West Lothian	17.6
Inverclyde	14.9	West Dunbartonshire	17.5
Glasgow City	13.8	Glasgow City	17.3

MORTALITY BY CAUSE OF DEATH

A.10 Figures A-5 and A-6 show age standardised mortality rates by selected major causes of death for England and Wales over the period 1911 to 2005.

A.11 As can be seen, the rapid improvements in mortality over the last 40 years or so have been largely driven by falls in mortality rates due to circulatory diseases, of around 60 per cent for both males and females. Mortality from cancer rose gradually over the period for males to a peak in the early 1980s followed by a decline during the 1990s. The pattern for female mortality from cancer is broadly similar over recent years. The trends in mortality from respiratory disease are more difficult to discern because of changes in the ICD coding relating to deaths involving certain respiratory diseases such as pneumonia during the 1980s and 1990s. 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.

Figure A-5: Mortality by major cause for males – England and Wales, 1911-2005 (Source: ONS)

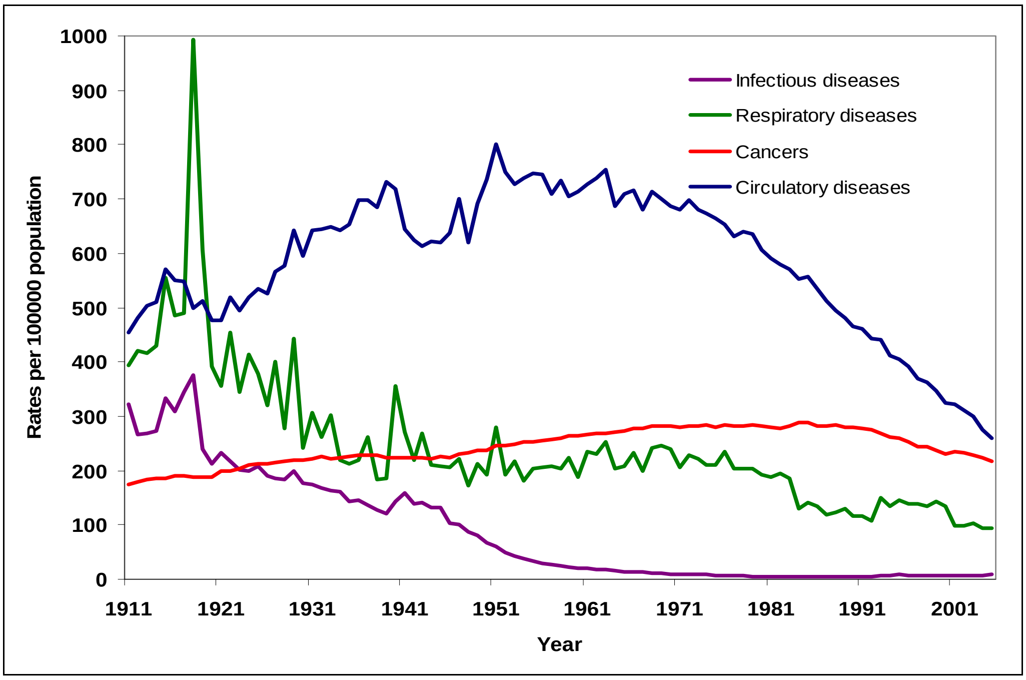
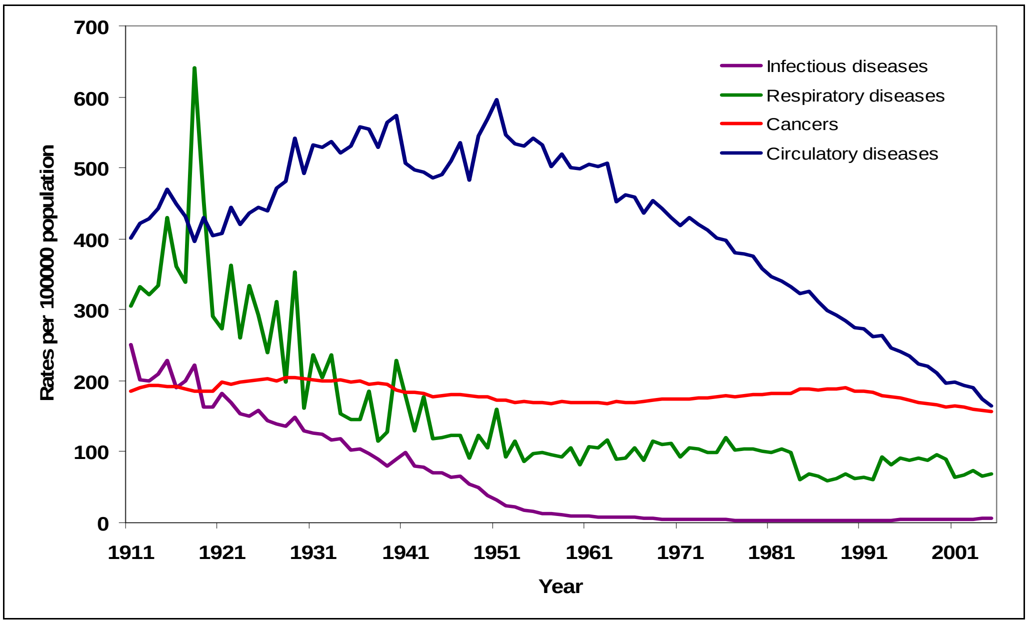


Figure A-6: Mortality by major cause for females – England and Wales, 1911-2005 (Source: ONS)



B CMI MORTALITY DATA

B.1 This appendix summarises the data collected, and held, by the CMI for its mortality investigations. This is considered separately for the self-administered pension schemes (SAPS) investigation and for the life office investigations. The latter are also sub-divided between the traditional data format, which applies to virtually all the data currently held by the CMI, and the 'Per Policy' format which was launched in 2005 and is being used for future data submissions.

SAPS DATA

B.2 Data is collected from scheme actuaries at the time of the triennial valuation, hence:

- Schemes submitted in respect of a valuation at 1/4/2007 would contain mortality experience from 1/4/2004 – 31/3/2007, i.e. spanning 4 calendar years;
- This investigation began collecting data in 2003. The first experience therefore relates to 2000 (arising from schemes submitted for 2003 valuations);
- The data for a particular calendar year is only "complete" several years later (i.e. 2004 will only be complete after all schemes with valuations in 2007 have been submitted).

B.3 The following points should be noted regarding the scope of the investigation:

- For practical reasons, only schemes with at least 500 current pensioners should be included in the investigation. This may mean that the experience is not typical of the entire pensioner population.
- Data is requested for pensioners who were active during the inter-valuation period. Deferred pensioners and members who have not retired should not be included.
- Data in respect of pensioners whose annuity is paid by an insurance company should be excluded.
- Both self-administered Defined Benefit and Defined Contribution schemes are included.
- Top-up schemes are excluded.

B.4 One record is requested per life, including the data fields shown in Table B-1.

Table B-1: Data fields for the SAPS investigation

Data Field	**Comments**
Gender	
Type of Pensioner	Split by: ▪ Retirement (excluding ill-health) ▪ Ill-health retirement ▪ Retirement (including ill-health) ▪ Dependant ▪ Unknown or combined The CMI's preference is (obviously) that normal and ill-health retirements are separated, but where this is not possible then data can be submitted on a combined basis
Date of Birth	
Date Became Pensioner	If during the current period
Date of Exit	Date of death, or effective date for other exits
Type of Exit	Death or other
Annual Pension at Beginning	One of these fields is compulsory, though both are preferred. If only one is provided, the other is estimated.
Annual Pension at End	
Date of Pension Reviews	
Postcode	Added to the list of data fields in February 2007

B.5 The FTSE Industry Classification is also requested in respect of each scheme. These changed at 31/12/2005, but the SAPS coding guide was only amended in February 2007.

'TRADITIONAL' LIFE OFFICE DATA

B.6 Data is collected annually, at least 6 months after the year-end to allow for late notification of deaths.

B.7 Data is submitted to separate investigations by product type, spanning assurances, individual annuities, individual pensions and insured pension schemes. Lives data is collected for all investigations, but amounts data is only collected for the immediate annuity and insured pension schemes investigations.

B.8 The assurances are sub-divided by underwriting method and by smoker status (data is also collected on various categories of impaired lives, but few offices are able to submit data to the required level of detail). Note that terminal illness is often covered under assurances and such claims are included, so that these rates are not "pure mortality" rates.

B.9 The data is "scheduled" meaning that the CMI does not receive details of individual lives (or amounts). Instead it receives the total number of policies at a particular age (nearest) and duration (but see below) that are in force or deaths. The categorisation of duration is pre-specified; for assurances and individual annuities the select period is 5 years from date of commencement, for individual pensions there is no segregation by duration and for insured pension schemes it is 10 years from the date of retirement.

B.10 Life offices are asked to amalgamate "duplicates", i.e. policies taken out simultaneously, but multiple policies with different offices cannot be detected.

B.11 The CMI has male assured lives data from 1947; other investigations started at later dates so there is a shorter history.

B.12 Note that exposure for the traditional life office investigations is calculated on a census basis (effectively averaging the start- and end-year in force data). For SAPS and Per Policy it is calculated using a more accurate (day-count) method.

'PER POLICY' LIFE OFFICE DATA

B.13 Offices are encouraged to submit data on this basis (although for now, data is still accepted on the traditional basis). A few offices have submitted 2005 data in this format; most others are expected to switch for 2006 or 2007 data.

B.14 The data consists of individual records per life per policy, including the data fields shown in Table B-2.

Table B-1: Data fields for Per Policy life office data

Data Field	Comments
Gender	
Product Type	This is no longer pre-defined. Instead the life office uses the product name and the CMI can then combine similar products, as required. The ABI New Business Code is also collected to assist in this categorisation.
Date of Birth	
Date of Commencement	
Type of Entry	Separates out policies taken out, e.g. as a result of exercising an option
Distribution Channel	
Date of Exit	Date of death, or effective date for other exits. For claims the dates of notification, admittance and settlement are also requested.
Type of Exit	Death, lapse, maturity, etc
Initial benefit amount	
Current benefit amount	
Postcode	

C MEMBERS OF THE WORKING GROUP

Member	Title
Adrian Gallop (A)	Office for National Statistics
Dave Grimshaw (A)	Secretary, Continuous Mortality Investigation
Tom Kirkwood	Professor, Newcastle University. Director, Institute for Ageing and Health
Joseph Lu (A)	Synesis Life
Angus Macdonald (A)	Professor, Heriot-Watt University. Director, Genetics and Insurance Research Centre
David Metz	Visiting Professor, UCL. Member, Financial Services Consumer Panel
Mike Murphy	Professor of Demography, LSE
Louise Pryor (A)	Project Director, BAS
Brian Ridsdale (A)	Chair, Continuous Mortality Investigation
Paul Seymour (A)	Chair, BAS
Richard Willets (A)	Paternoster
Robert Wright	Professor of Economics, University of Strathclyde

"A" denotes a Fellow of the Institute of Actuaries or the Faculty of Actuaries