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SHOULD PROJECTIONS OF MORTALITY IMPROVEMENTS BE SUBJECT TO A MINIMUM VALUE?

By S. D. Baxter

[Presented to the Institute of Actuaries, 26 February 2007]

The meeting held on 26 February 2007 consisted of a presentation, by the author, of the subject matter of this paper, followed by a discussion. The paper which appears here was completed later and relates to information available up to the date of presentation. Please note that, in the abstract of the discussion, all references to the presentation have been altered to refer to the paper.

ABSTRACT

Projections of future mortality typically used for funding pension scheme liabilities assume that future year-on-year decreases in mortality rates will slow rapidly, and that there is very limited potential for further decreases at the oldest ages. This paper considers the consistency of such projections with current trends in life expectancy. Particular focus is paid to whether future mortality should be subject to a minimum level of improvement to reflect general advances in medicine. Care is taken to exclude the additional increases in longevity arising from a concentration of positive health factors amongst the generation who are currently experiencing the 'cohort effect'.

If historic trends continue into the future, then period life expectancy from age 65 in England & Wales will increase at 26 days p.a. for women and 41 days p.a. for men, with additional increases arising from the 'cohort effect'. This is a faster rate of period increase in life expectancy than embedded in the interim cohort projections. One way to ensure that actuarial projections keep pace with the population trend is to subject projections to a minimum level of (geometric) improvement of *at least* 1¼% p.a. for men and ¾% p.a. for women, at all older ages and in all future years.

Consideration is given to the possible impact of differences between the socio-economic profile of England & Wales and the membership of the pension schemes to whom the projections will be applied ultimately. This paper also highlights that the application of a single minimum value, independent of time and age, simplifies a more complex underlying pattern, but that minimum improvements of 1¼% p.a. for males and ¾% p.a. for females represent an average of historic improvements in mortality seen in England & Wales.

The paper includes a survey of the history of the low levels of mortality seen currently. The survey includes some discussion on the potential for future improvements and considers topical issues, such as the potential impact of obesity on life expectancy projections (and, in turn, the minimum value applied to improvements).

The financial impact of subjecting projections of mortality improvement to a minimum value is quantified.

KEYWORDS

Mortality; Longevity; Annuities; Cohort Effect

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1. Introduction

1.1 *Introduction*

1.1.1 Within the pensions arena, the setting of a mortality assumption is the responsibility of trustees for funding purposes, and company directors (possibly in consultation with their actuary) for accounting purposes. There is an onus for these assumptions to be prudent[1] and best estimate,[2] respectively. In both instances, it is likely that the trustees or company directors will turn to actuaries to provide an indication of what might be reasonably justified as best estimate (or prudent).

1.1.2 In the past, human life expectancy has repeatedly exceeded the best estimates of experts around the world. By experts, I include actuaries, demographers and supra-national organisations, such as the World Bank and the United Nations — for a very stark analysis of this see Oeppen & Vaupel (2002).

1.1.3 It is uncertain whether this will continue to be the case in the future. However, our expectations of the future are 'anchored' in present observations. We have a propensity to be able to visualise negative impacts on life expectancy (such as obesity and epidemics) far easier than the improvements in life expectancy attainable from scientific breakthroughs. With this in mind, it makes sense to continue to question whether existing longevity projections can be considered best estimate, and to communicate to the recipients of our advice the uncertainty inherent in longevity projections.

1.1.4 This paper considers mortality improvements as having two components, namely: general 'background' improvements — those occurring from ongoing advances in medicine and health care and from improved lifestyles; and 'generational' effects, such as the cohort effect. The focus of this paper is on the former — namely whether projection methodologies should incorporate an allowance for some minimum level of general ('background') improvement in mortality *in addition* to the common practice of allowing for 'generational' effects.

1.1.5 The paper approaches the problem from a practitioner's point of view, namely that of a consulting pensions actuary. As such, it is deliberately, and unashamedly, simplistic in its approach.

1.1.6 Although the focus of this paper is in a pensions context, the author believes that much of the material will be relevant to those involved in

[1] For funding purposes, Paragraph 5(4) of the Occupational Pension Schemes (Scheme Funding) Regulations 2005 states that: "the mortality tables used ... must be based on prudent principles, ..."

[2] For example, Paragraph 23 of FRS 17 states: "The assumptions underlying the valuation should be ... and lead to the best estimate of the future cash flows that will arise under the scheme liabilities."

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advising on, or the setting of, assumptions about future mortality for the purposes of pricing, reserving and with-profits distribution within the life insurance industry.

1.2 *Contents*

The paper has been divided into the following main sections:

— *Section 2: Some Terminology* introduces some terminology used throughout the paper.
— *Section 3: The Problem and the Approach Adopted* discusses the approach which this paper takes in answering the question as to whether projections of mortality improvements should be subject to a minimum value (or 'underpin') in order to allow for general ongoing increases in longevity.
— *Section 4: Population Data* discusses general population data, before life expectancy from age 65 is looked at in more depth: for women in *Section 5: Female Population Data*; and for men in *Section 6: Male Population Data.*
— *Section 7: Male and Female Life Expectancy Differentials* provides a sanity check on the approach, by comparing the projections of the relative life expectancies of men and women.
— *Section 8: Different Populations* and *Section 9: Trends in Life Expectancies at Other Ages* challenges the conclusions from earlier sections by considering trends in life expectancy for different socio-economic groups and from a variety of other ages.
— *Section 10: Trends in Mortality Rates* looks at trends in the national mortality rates underlying the previous analysis.
— *Section 11: Past Improvements and The Future* seeks to put the current mortality rates into a historic context, and looks at topical issues which may affect the pace of future improvements.
— *Section 12: Practical Considerations* covers a number of practical aspects of applying underpins to mortality improvements, including the financial impact on pension scheme valuations.

1.3 *Appendices*

The paper includes six appendices, which provide additional information on topics raised in the main body of the paper:

— *Appendix A: A Summary of the '92' Series Projections and the Interim Cohort Projections* summarises the key features of the projection models heavily referred to in this paper.
— *Appendix B: Illustrations of Applying a Minimum to Projections of Mortality Improvements* provides an illustration of the level of mortality improvements which would be assumed if the reader adopted the approach discussed in the main body of the paper.
— *Appendix C: Statistical Measures for Fitted Trends* provides an algebraic

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specification of all of the trends fitted in the paper, along with the results of applying standard statistical measures of fit to these trends.
— *Appendix D: Ages other than 65* illustrates the trends described in Appendix C.
— *Appendix E: Additional Projections using the '00' Series of Tables* shows that the conclusions hold under different tables.
— *Appendix F: Female Valuation Annuities* confirms that the impact on the valuation of annuity benefits payable to women is comparable to the illustrations of the impact on the valuation for males provided in the main body of the paper.

2. Some Terminology

2.1 *Annual Rate of Improvement in Mortality*

2.1.1 The *annual rate of improvement in mortality* is the rate of *improvement* exhibited between one year and the next in the probability of dying in a given year of life.

2.1.2 In terms of pension scheme funding, *improvement* is an ambiguous term. At a personal level, we might anticipate that an improvement corresponds to a decline in the probability of death q_x in year of age x, and so an increased chance of survival to age $x+1$. However, trustees and sponsors of pension schemes can be forgiven for considering such an 'improvement' in mortality rates to mean quite the opposite, since it requires them to hold more funds to finance the pension scheme liabilities.

2.1.3 For the avoidance of doubt, the *annual rate of improvement in mortality* at time t is defined in this paper as the decrease in probability of death, as given by:

$$1 - \frac{q_{x,t}}{q_{x,t-1}} \tag{1}$$

where $q_{x,t}$ denotes the probability of death within one year for someone who is aged x exact at time t. This is the same convention as adopted in Working Paper 1 of the Continuous Mortality Investigation Bureau (hereafter referred to as CMI WP1).

2.2 *Older-Age Life Expectancy*

I define *older-age life expectancy* as the life expectancy of a 65 year old. For pension schemes advisors this is important, as it represents the length of time for which pension payments are payable. For actives and deferred pensioners, to whom payments may not start for many decades, and so for whom longevity risk is greatest, this is a particularly useful measure at which to look.

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2.3 *Life Expectancy*

Unless stated otherwise, all life expectancies (including *older-age life expectancy*) are period life expectancies, i.e. based upon the $q_{x,t}$ values for different ages x, at a single point in time t. Further, all life expectancies used are complete expectations of life, calculated using the approximate formula $\sum_{t=0}^{\omega-x} {}_tp_x(1-\frac{1}{2}q_{x+t})$, with ω taken to be 120.

3. The Problem and the Approach Adopted

3.1 *Mortality Improvement Considerations*

3.1.1 In setting an appropriate level for future improvements in mortality rates, the author believes that there are, potentially, three considerations:

— What allowance do we wish to make for general improvements achievable via ongoing medical advances and improvements in health care and in lifestyle?
— Which generations will experience a 'cohort effect'?
— For how long should we anticipate that the cohort generation will continue to exhibit faster improvements in mortality rates?

3.1.2 As at 31 March 2007, for schemes which submitted recovery plans to the Pensions Regulator, the medium cohort projections were the most widely used for funding valuation purposes (The Pensions Regulator, 2007).

3.1.3 It is important to realise that the interim cohort projections 'overlaid' a generational effect onto existing projections — the '92' series (see Appendix A). As a consequence, users of the interim cohort projections are implicitly relying on the '92' series projections to provide the allowance for the longer-term period element of general improvements in the first of the three considerations in ¶3.1.1.

3.1.4 It is the first of the three considerations in ¶3.1.1, on which this paper focuses. In particular, it considers whether the '92' series improvements underlying the interim cohort projections should be adjusted to ensure that the rates of improvement do not fall below a certain 'base level', and, if so, what the value of this 'base level' (minimum) might be. Discussion of the last two questions is beyond the scope of this paper — although, given the difference in the generations experiencing the 'cohort effect' in the GAD and CMI data (see Appendix A), the author encourages further research of the second consideration, in particular.

3.2 *The Approach Adopted in this Paper*

3.2.1 In this paper I consider how *older-age life expectancy* has improved in England & Wales over the last 160 years. A simple piece-wise linear form is fitted, which is designed to capture the key features of the data.

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Care is taken to avoid the possibility of confounding general improvements with the cohort effect. This provides a simple way to project general improvements in *older-age life expectancy* into the future. By comparing the extrapolation of the population trend with projected life expectancies under the standard '92' series mortality tables with the '92' series improvement factors, published in Continuous Mortality Investigation Report Number 17 (CMIR 17), it is possible to identify what level, if any, of minimum improvements in mortality rates (*underpins*) would be needed for the population trend to be mirrored by the projections. These minima can then be used with the cohort projections to provide an allowance for general ('background') improvements.

3.2.2 To avoid spurious accuracy, values for the minima are considered at ¼% intervals. Given the simplicity of the approach adopted, I believe that any greater granularity would be inappropriate.

3.2.3 I have chosen to focus on *older-age life expectancy*, since:

— It is a concept readily understandable by trustees, company directors and the wider pensions community. Life expectancy is a quantity from which non-actuaries can form an opinion as to whether an 'assumption' is best estimate. In particular, the Pensions Regulator draws trustees' attention to trends in life expectancy in the Regulatory Code of Practice 3, stating: "Particular attention should be paid to assumptions about future mortality. Here the experience is of a sustained trend in one direction, that of longer life expectancy (i.e. decreasing mortality rates) ..."
— The members of pension schemes for whom there is greatest uncertainty about life expectancy are the youngest members, i.e. the active workforce and deferred pensioners who will retire in the future.
— It is a good proxy to the quantity, ultimately, of concern, namely the value of an annuity payable from retirement age. Further, the 2005 NAPF 'Annual Survey of Occupational Pension Schemes', summarised in NTC Publications (2007), shows that approximately 78% of private sector defined benefit schemes have a normal retirement age of 65, making it a sensible age on which to focus.
— There is a potential risk that, as a profession, we focus our energies on using sophisticated techniques to model the evolution of mortality rates, but forget to check the credibility of the resultant life expectancies. Starting with older-age life expectancy is a helpful way to see 'the wood for the trees'.

The conclusions are reviewed at other ages in Section 9. The consistency of the conclusions with trends in the underlying mortality rates are considered in Section 10.

3.2.4 In order to get a long, non-subjective history of life expectancy, it is necessary to use period life expectancy. Period life expectancy captures the most recent history of improvements in longevity. This is not

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possible with cohort life expectancy (which is life expectancy by year of birth), as the generations from the early 1900s onwards are still alive in considerable numbers, preventing accurate calculation of attained life expectancies.

3.2.5 Period life expectancy also has the merit that I will be looking at the annual rate of improvement in mortality. The usual definition for this was given in Section 2, as the decrease in the q_x value in successive calendar years, i.e. a period affect. Further, period life expectancy is also an item commonly quoted in the media and by the Government — so is a quantity on to which those outside of the profession can 'anchor'.

3.2.6 In setting a minimum to mortality improvements, I have focussed on determining a single value to use at all ages and over the period of future projection. This has the dual merits of being:

— *relatively simple to produce the resulting mortality tables*; therefore providing a pragmatic compromise between the existing assumptions, which may deemed by trustees as imprudent, and adopting the full sophistication of trend fitting and projection methods, such as the Lee-Carter and *P*-spline (see CMI WP15) methods, which require considerable parameter fitting; and

— *easy to communicate to other professionals and clients alike.* For example, the concept can be explained as:

> "We have looked at the national trend in older-age life expectancy and projected this into the future. We have then used published improvement factors, adjusted so as to ensure that the increase in life expectancy is at least as great as that implied by the national trend."

3.2.7 In carrying out the analysis, I have projected forward the '92' series tables (amounts based) using the associated improvement factors. The author recognises that:

— *'00' series vs. '92' series.* The Pensions Regulator's Code of Practice encourages trustees to use the latest information with regard to mortality — as such it is likely that the newly (at time of preparing this paper) published and approved '00' series will be used increasingly, and this has been observed by the author between the original presentation of this paper and its publication.

— *Amounts vs. lives based.* It is usual to use amounts-based tables when valuing pension scheme benefits, since it is the amount of pension which survives to each successive year which is of concern. Whilst life expectancies are more meaningful on a lives-based table, for both ease of communication and to avoid the difficulties involved in converting appropriately from an amounts to a lives-based table, the life expectancies commonly quoted by pensions actuaries are typically based on amounts tables. For these reasons, the author has based his analysis on an amounts-based table.

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Crucially, though, the decision as to whether to use the '92' series or the '00' series, or to use an amounts-based or lives-based table, only influences the initial shape of the table which will be projected. It should, therefore, be no surprise that the same conclusions are reached if either the '00' series of tables or a lives-based table were to be used — this is illustrated in Appendix E.

3.2.8 Throughout this paper the focus is on the '92' series projection factors. In CMI WP15 a number of new projection methodologies were proposed, including the Lee-Carter and *P*-spline methods. The author accepts that, once the new statistical methodologies are readily understood, and consensus is agreed within the profession as to how best to calibrate such models (for example to ages where the data are very sparse), they may replace the projections considered in this paper. The author believes, however, that much of this paper is also relevant when considering these and other projection methodologies (e.g. communicating the results of projections via life expectancies and an appreciation of the historic context of longevity trends).

4. Population Data (England & Wales)

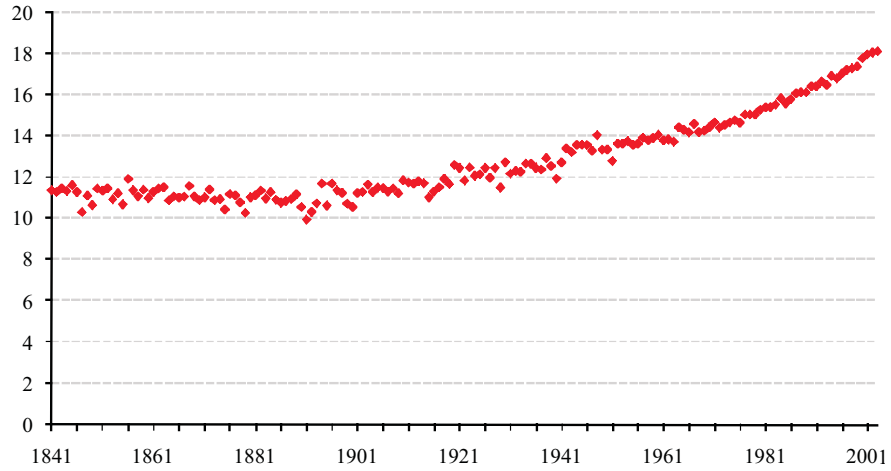
4.1 I have focussed on the longest (publicly available) history of England & Wales life expectancy, namely that stored on the 'Human Mortality Database' (HMD, 2006). This dataset is fuller (and so more credible) than anything readily available either from the CMI datasets (considered later) or from the Office of National Statistics[3] (ONS). The data start from 1841 (i.e. broadly in the middle of the Industrial Revolution), enabling us to see the impact of modern scientific and medical advances. The reader is reminded that the 'cohort effect', referred to in Section 3, relates to a different generation in the national population data compared to the CMI projections — namely a group of individuals born between 1925 and 1945, and centred on the 1931 birth year; rather than the generation born between 1920 and 1942, centred on 1926.

4.2 In producing period life tables, the HMD smoothes the raw central death rates at ages over 80, owing to the amount of variation in the raw mortality rates. This paper has been based upon the smoothed mortality rates, one-year probabilities of death and the life expectancies produced by the HMD, since:

— the focus of this paper is on identifying the trends in the underlying data, so it is inevitable that some smoothing will be necessary; and

[3] In practice, the dataset used includes data from the ONS and appends this to historic datasets.

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Source: HMD (2006)

Figure 1. History of England & Wales life expectancy from age 65 (unisex)

— in fitting older-age mortality, the HMD smoothing algorithm uses a form of logistic mortality model known as the Kannisto model, which has been shown to perform well compared to other models, e.g. the Gompertz Makeham Law, the Weibull model (see Thatcher *et al.* (1998) for more details).

4.3 Figure 1 shows how unisex life expectancy of 65 year olds has changed since 1841. From this, we can see immediately that, prior to the turn of the 20th century, *older-age life expectancy* remained fairly constant, at around 11 years. However, once we enter the 20th century and the age of modern medicine, life expectancy starts to improve in a broadly[4] linear fashion. In addition, there seems to be a step upwards, starting in the late 1990s, when we would expect the cohort effect to start (at the population level) having an impact.

4.4 Based on this observation, it would seem appropriate to consider fitting a simple model of the form:

$$LE(t) = \alpha + \max(0, \beta(t - T)). \tag{2}$$

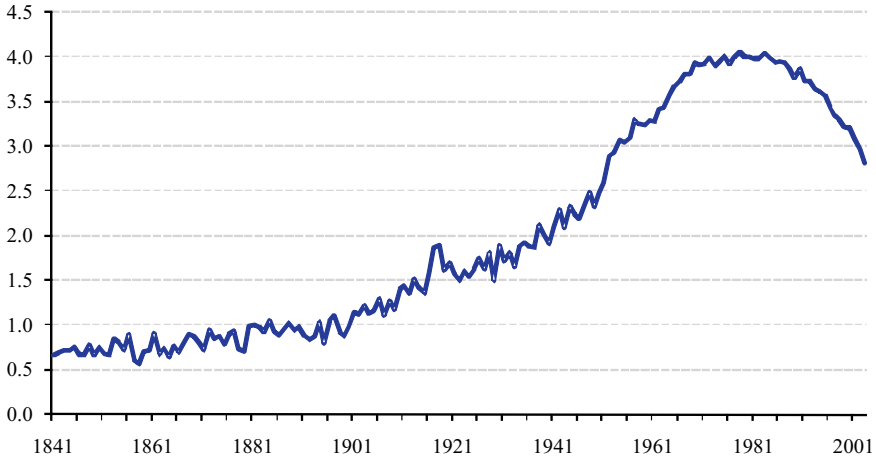
[4] Or, more precisely, improving at a rate which seems to be very slowly accelerating over time — however, as shown later in this paper, the underlying trends for males and females are different, and the simplistic linear model is a pragmatic approach which gives credible fits to the underlying male and female data.

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In the above:
— $LE(t)$ represents the *older-age life expectancy* at time t;
— α represents the level of *older-age life expectancy* prior to the impacts of modern medicine/living;
— β represents the annual increase in *older-age life expectancy* once the benefits of modern medicine/living come into effect; and
— T represents the time at which modern medicine starts to have a discernible impact on the life expectancy of 65 year olds.

The author stresses that this is a deliberately simplistic and pragmatic approach — more advanced techniques can be used to fit curves to the data (e.g. the *P*-spline method, see, for example, CMI WP15, Currie *et al.*, 2004), or Eilers *et al.*, 1996), but are not necessarily any more informative for extrapolation purposes. Those readers who may have reservations regarding linear extrapolations are assured that the conclusions are revisited in terms of the underlying mortality rates in Section 10.

4.5 The life expectancies in Figure 1 apply at the population (i.e. unisex) level. As Figure 2 shows, there has been a very discernible 'hump' in the difference in life expectancy from age 65 between men and women. In the mid 19th century women outlived men (from age 65) by around nine months, rising to a peak of four years in the late 1970s/early 1980s. This difference



Source: Own calculations using data from HMD (2006)
Difference plotted is female life expectancy *minus* male life expectancy.

Figure 2. History of differences in life expectancy at age 65 between men and women (England & Wales)

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in life expectancy should come as no surprise, indeed, it is one of the reasons why we have different standard tables for males and females. In Sections 5 and 6 I fit a model to the data for each of males and females in turn.

5. Female Population Data

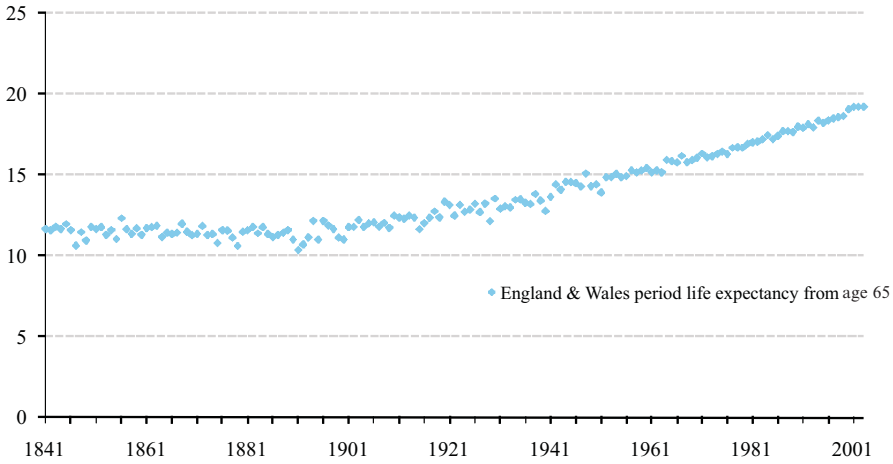
5.1 *Initial Analysis*

5.1.1 The older-age life expectancy data for women (Figure 3) suggests that a model similar to that described by equation (2) is likely to be appropriate. Indeed, the actual data appear incredibly linear from around about 1910 through to the 1990s.

5.1.2 Figure 4a illustrates the fitted model,[5] which takes the form:

$$LE_{women}(t) = 11.50 + \max(0, 0.0756^{*}(t - 1907)) \tag{3}$$

i.e. period life expectancy from age 65 of around 11 years six months up

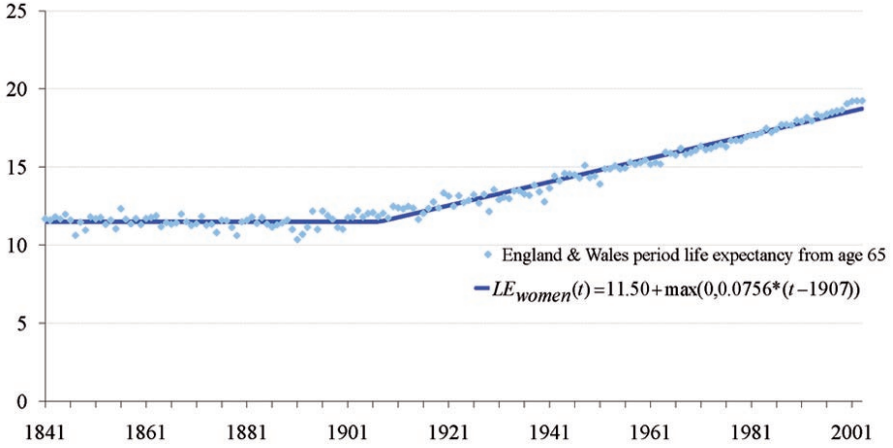


Source: HMD (2006)

Figure 3. History of female life expectancy from age 65

[5] The fitting has been based upon least squares minimisation for curve fitting.

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Source: Own calculations based on HMD (2006)

Figure 4a. Trend in female life expectancy from age 65 (fitted to the period 1841 to 2003)

until 1907, and then increasing by around about 28 days for each year thereafter. The model appears to be a good fit, and this is confirmed statistically, with a coefficient of determination[6] of 97.6%.

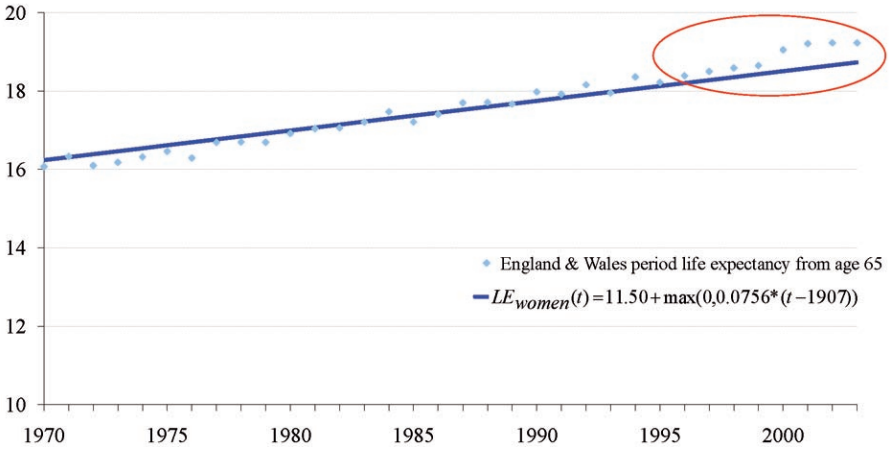
5.2 *Confounding with the 'Cohort Effect'*

5.2.1 We are aiming to identify any underlying trends in life expectancy before making a separate allowance for the cohort effect. This means that it is important to consider the extent to which the cohort effect is included in the analysis. When looking at period life expectancies, we would expect any effect to be slight, since the cohort generation only started to reach age 65 in 1990. Indeed, the impact on older-age life expectancy will be minimal until the cohort generation members start to reach their mid 70s, when mortality rates start to be high enough to impact on life expectancy (see Section 10).

5.2.2 Figure 4b focuses on the trend in life expectancy over the most recent years. In 1996 those at the centre of the population level cohort effect (i.e. those born in 1931) reach age 65, and those born at the start of the cohort enter their 70s, and so, potentially, start to impact on older-age life expectancy. One could *loosely* conclude that there appears to be a series of upwards deviations from our trend line starting in 1996, consistent with the

[6] The coefficient of determination is a measure of goodness of fit. A perfect fit has a coefficient of 100%.

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Source: Own calculations based on HMD (2006)

Figure 4b. Trend in female life expectancy from age 65 (fitted to the period 1841 to 2003; focus on 1970 to 2003)

cohort effect. Although these appear above the trend line, the long period over which this trend line has been set, i.e. almost 90 years prior to these 'cohort' data points, means that they will have caused only small distortions in the trend fitting.

5.3 *Removing the 'Cohort Effect'*

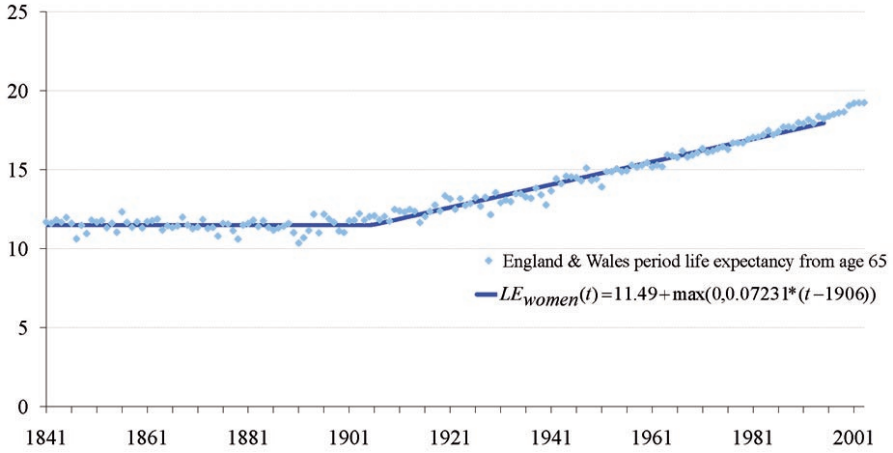
5.3.1 When fitting the male trend in Section 6, we find that the analysis is distorted by the data points from the late 1990s. This is because the most recent linear trend starts much later — consequently the trend is ultimately fitted to data up to and including 1995. To ensure that the male and female trends are directly comparable, I have refitted the female trend line excluding the data after 1995. This gives:

$$LE_{woman}(t) = 11.49 + \max(0, 0.07231^{*}(t - 1906)) \quad (4)$$

i.e. a life expectancy from age 65 of 11 years and six months prior to 1906. The life expectancy then starts increasing from a slightly earlier date, and at the slightly slower rate of 26 days per year. The slightly slower rate suggests that the cohort effect may have been slightly dragging up the female life expectancy trend.

5.3.2 Figure 5 illustrates the revised trend. One thing which we can note is that the fitted trend is regularly below the data points from the mid 1980s

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Source: Own calculations based on HMD (2006)

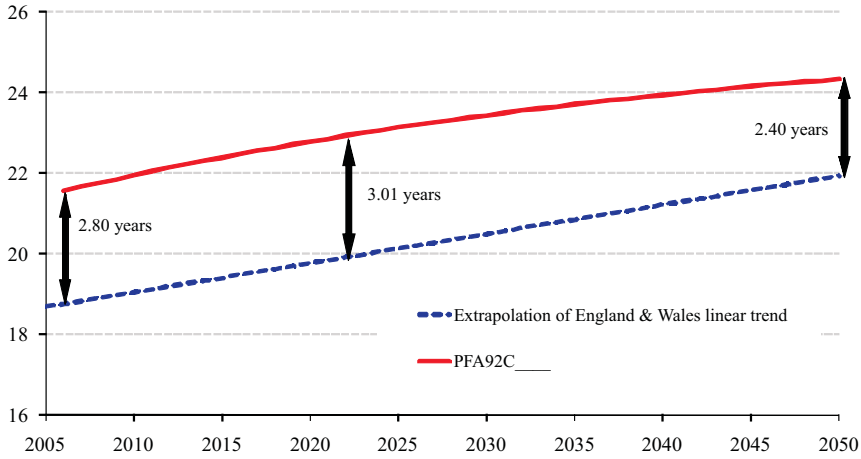
Figure 5. Trend in female life expectancy from age 65 (fitted to the period 1841 to 1995)

onwards. In statistical terms, this means that the trend is at risk of failing a 'grouping of signs' test — and Appendix C confirms this to be the case. This is unsurprising, given the simplicity of the trend fitting. However, we should be aware that this means that any extrapolation of the linear trend shown in Figure 5 may be an understatement of the rate at which female life expectancy is currently improving. In particular, the minimum level of improvement derived later may be too low.

5.4 *Extrapolation and Comparison to the '92' Series Projections*

5.4.1 By having removed any impact of the cohort effect, the trend in Figure 5 reflects purely general 'background' improvements in mortality, i.e. what the cohort improvement projections implicitly rely on the '92' series projections to model. This means that we can compare the '92' series projections (without cohort improvements) to an extrapolation of the trend line in Figure 5. For the purposes of these comparisons, I have considered the comparative trends from 2006. This is because the rates of improvement used in a valuation will generally either start from a base table which is assumed to capture mortality at the date of the valuation (2006 or 2007, at the time when this paper was prepared) or has been fitted to the central year of any mortality investigation (most likely one to three years prior to the current valuation date).

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Source: Own calculations
PFA92C____ denotes the period life expectancy under the PFA92base table rolled forward with '92' series improvements to each calendar year plotted.

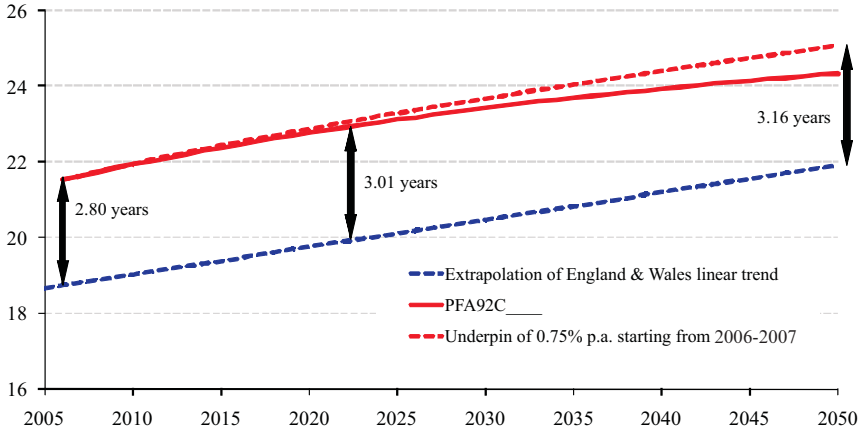
Figure 6. Projected changes in female life expectancy from age 65 over time

5.4.2 Figure 6 shows that the '92' pensioner amounts-based series (with '92' series improvements) gives a longer period life expectancy from age 65 in 2006 than the population as a whole. This is hardly surprising, given:

— *The nature of the individuals on which the tables are based.* Life office pensioners will tend to rate higher in terms of longevity drivers, such as income and lifestyle, than the population as a whole. One interpretation of the scaling factor often used with standard mortality tables is that it compensates for differences between different populations. For example, if the population of a pension scheme is more typical of the population as a whole rather than of life office policyholders, then we might anticipate seeing a scaling factor above 100%.
— *The usage of an amounts-based table*, which will give more weight to more affluent pensioners, who typically live longer and experience lower mortality.

5.4.3 Initially, the '92' series projects a slight widening of the differential from 2.8 years in 2006 to 3.0 years come the 2020s, before it declines back to 2.4 years in 2050. One can debate whether or not the gap should be widening, but, once it does, a reasonable estimate might be for subsequent increases in life expectancy to occur at around 26 days per annum or greater, and so follow the national trend. Figure 7 shows that one way to achieve

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Source: Own calculations

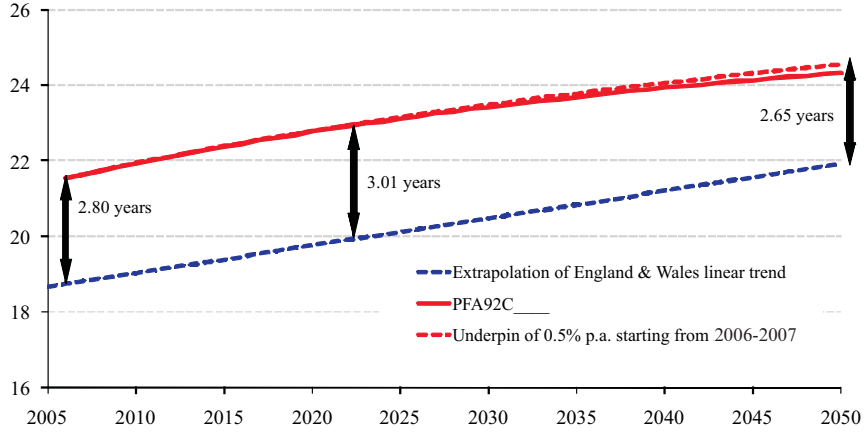
Figure 7. Projected changes in female life expectancy from age 65 over time (comparison with an underpin of 0.75% p.a.)

this would be to apply a minimum (or 'underpin') to the *future* improvements in mortality rates of 0.75% p.a.

5.4.4 Using a minimum level of improvements of 0.75% p.a. causes a slight increase in the size of the gap over time, and so a slightly more rapid increase in life expectancy than the England & Wales trend. However, this increase is consistent with that anticipated over the next 15 years under the '92' series projections. Further, reducing the minimum by ¼% to 0.5% p.a., we obtain a line barely divergent from the '92' series projections, as is shown in Figure 8.

5.4.5 It is important to note that this minimum has been calculated as a single value which applies in all future years and at all ages (i.e. including the oldest ages). Appendix B provides illustrations of the annual improvements under both the original '92' series projections and the interim cohort projections, which result from applying a uniform minimum improvement of this kind.

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Source: Own calculations

Figure 8. Projected changes in female life expectancy from age 65 over time (comparison with an underpin of 0.5% p.a.)

6. Male Population Data

6.1 *Initial Analysis*

6.1.1 Looking at the changes in life expectancy for males — Figure 9 — it is immediately clear that the simplistic model suggested by equation (2) is less likely to hold for males. The trend appears to be more complex, and possibly polynomial or exponential in nature, as illustrated by the polynomial trend line in Figure 10.

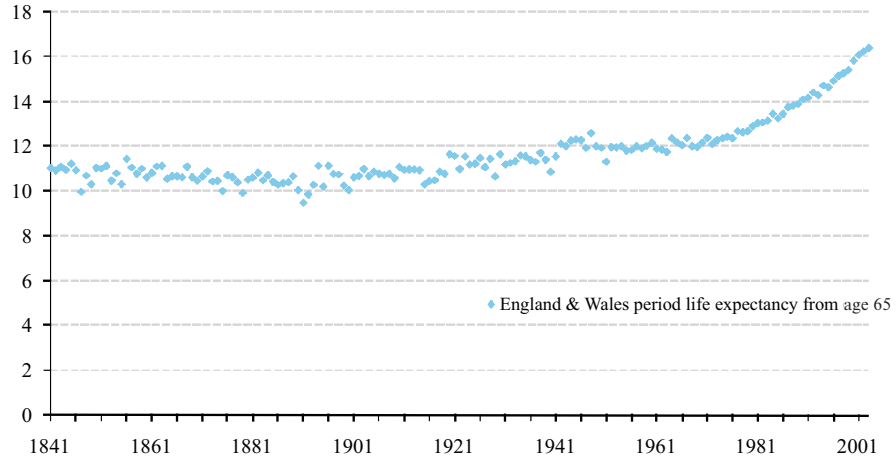
6.1.2 Although it would be possible to use more advanced polynomial fitting with these data, we might be inclined to summarise the broad features of the data set as:

— There was stagnation in old age life expectancy before about the 1910s.

— After this modern medicine seems to have had a very gradual linear improvement in life expectancy until the immediate post Second World War years, when life expectancy appears to plateau. The author suggests that possible reasons for this could include smoking trends (with those generations who experienced the greatest increase in smoking prevalence entering the over 65 population) and the after-effects of active service impacting *older-age life expectancy* for war veterans.[7]

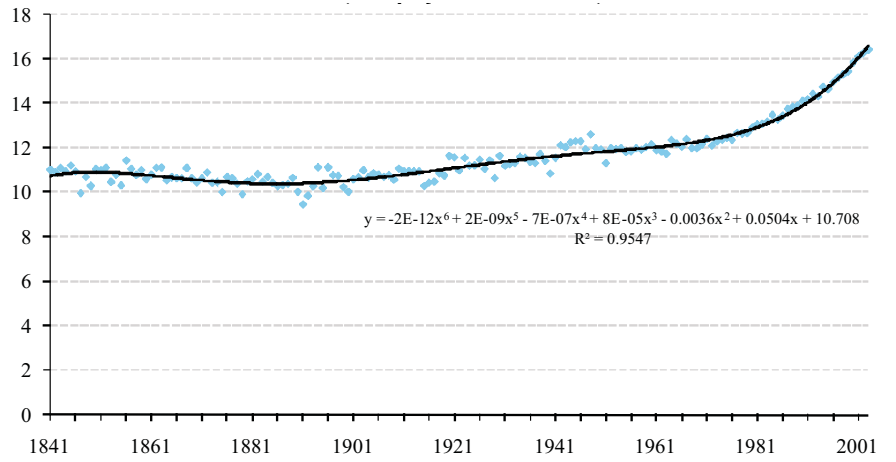
[7] These reasons, in particular, could explain the different patterns for men and women.

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Source: HMD (2006)

Figure 9. History of male life expectancy from age 65



Source: Own calculations using data from HMD (2006)

Figure 10. History of male life expectancy from age 65 (England & Wales) (with polynomial trend line)

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— Then, from the late 1960s, there was a rapid linear increase in life expectancy until the mid 1990s, when the increases become even more rapid (i.e. the 'cohort effect').

6.1.3 This summary suggests a simple model which captures the broad features of the data, and, in so doing, offers insight into plausible levels at which to set any minimum level of an annual improvement in mortality. It has the additional benefit of avoiding fitting a polynomial which can be heavily determined by small deviations in the later data points, resulting in a function which grows quickly outside the dataset (which the polynomial in Figure 14 would clearly do). Further, if we did want to fit a more complicated polynomial form to the data, then we might just as well look directly at the *P*-spline or Lee-Carter methods (which also provide statements of uncertainty which simple extrapolation cannot).

6.1.4 Mathematically, I am therefore suggesting a piecewise linear form of:

$$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases} \tag{5}$$

where $\gamma = \beta(T_1 - T_0)$. Fitting this to the data from 1841 to 2003 gives a solution which can be written in the equivalent form of:

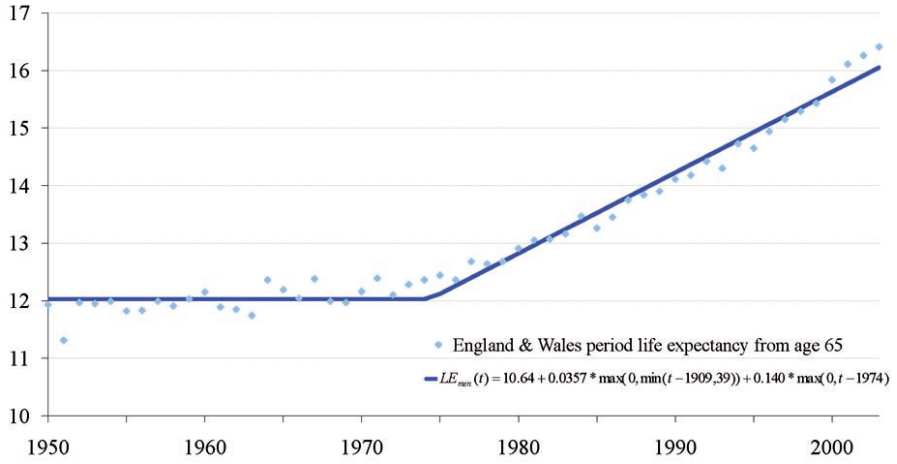
$$LE_{men}(t) = 10.64 + 0.0357^* \max(0, \min(t - 1909, 39)) + 0.140^* \max(0, t - 1974). \tag{6}$$

This corresponds to a life expectancy from age 65 of around ten years eight months prior to 1909, with life expectancy increasing by around about 13 days for each year thereafter until 1948, when life expectancy from age 65 plateaus at just over 12 years. Life expectancy stays at this level until 1974, after which it increases at around 51 days a year, i.e. almost twice the rate deduced for women. Figure 11 plots this functional form since 1950.

6.2 *Confounding with the 'Cohort Effect'*

It can be seen immediately that, in the later years, the fitting seems to have been skewed by the points in the late 1990s. In particular, in order for the line to follow the acceleration in the late 1990s, the function has taken a form whereby it starts later in the 1970s, and with a higher gradient than we might otherwise have expected. Since approximately 20% of the total number of data points post 1970 occur in the mid and late 1990s, this suggests a potential 'double-counting' of the cohort effect. The double-counting arises since the premise of this paper is that we make a separate

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Source: Own calculations using data from HMD (2006)

Figure 11. Trend in male life expectancy from age 65 (fitted to 1841 to 2003, shown for 1950 to 2003)

decision as to whether or not to overlay cohort improvements on our base projections.

6.3 *Removing the 'Cohort Effect'*

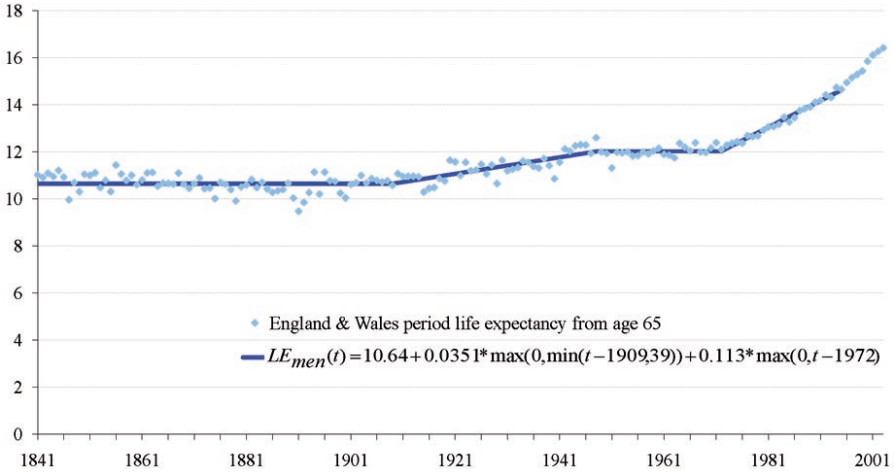
6.3.1 Fortunately the concern over potential double-counting of the cohort effect is simple to address, by fitting to the data up to (and including) 1995 only. Although, by including data up to 1995, individuals born at the outset of the national cohort effect, i.e. between 1925 and 1930, are included, only the mortality rates at ages below 70 will have been impacted for these individuals. The low level of mortality rates between ages 65 and 70 means that this is unlikely to have materially impacted the underlying trend in life expectancy from age 65. This is confirmed, in that the same conclusions are reached if we remove the data post 1990.

6.3.2 The approach of removing the data after 1995 assumes that all of the extra increases in the late 1990s are attributable to the generational 'cohort' effect. To the extent that some of this is a change in a period trend (or that historic trends have been in part generational), the simplistic approach used here may understate (overstate) current trends.

6.3.3 Fitting to the data up to, and including, 1995, gives:

$$LE_{men}(t) = 10.64 + 0.0351^{*} \max(0, \min(t - 1909, 39)) + 0.113^{*} \max(0, t - 1972) \quad (7)$$

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Source: Own calculations using data from HMD (2006)

Figure 12. Trend in male life expectancy from age 65 over time (fitted to the period 1841 to 1995)

i.e.:

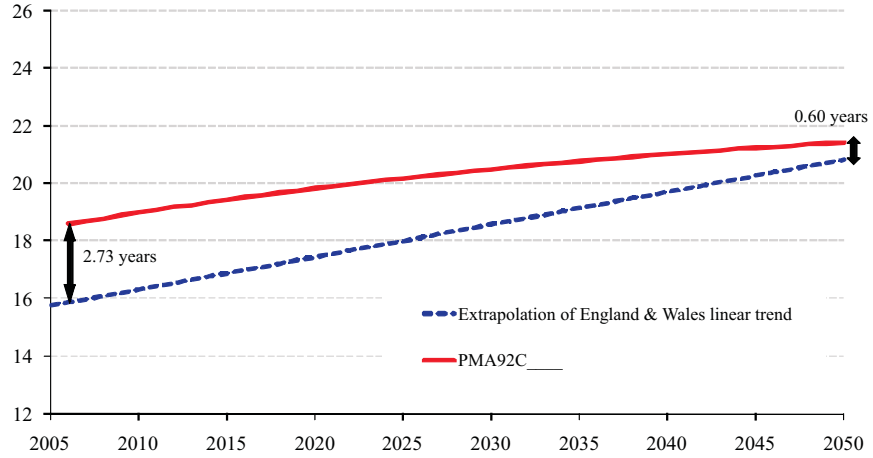
— the more rapid recent increases start slightly earlier (1972) and occur at a slower rate of 41 rather than 51 days a year;
— as the most recent linear trend starts earlier, it does so from a slightly lower level (i.e. in the form of equation (5), γ takes a reduced value of 12.01 rather than 12.03); and
— the period of stagnation in the 1950s and 1960s starts at the same time (1958), albeit at a slightly reduced level. Since the life expectancy up to 1909 is unchanged, this has resulted in the fit giving a slightly slower rate of year on year increase during the first half of the 20th century.

The fitted trend is illustrated in Figure 12.

6.4 *Extrapolation and Comparison to the '92' Series Projections*

6.4.1 The fitted trend can be extrapolated into the future, and compared with the '92' series projections of period life expectancies, in a similar fashion as is done for women. Figure 13 shows a rapid convergence of the '92' series projections with the extrapolated England & Wales trend, i.e. if the current trend of increases in *older-age life expectancy* continues in the future, then relying on the '92' series projections to allow for the impact of general improvements in longevity (e.g. via the cohort projections) is likely to be inadequate.

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Source: Own calculations
PMA92C____ denotes the period life expectancy under the PMA92base table rolled forward with '92' series improvements to each calendar year plotted.

Figure 13. Projected changes in male life expectancy from age 65 over time

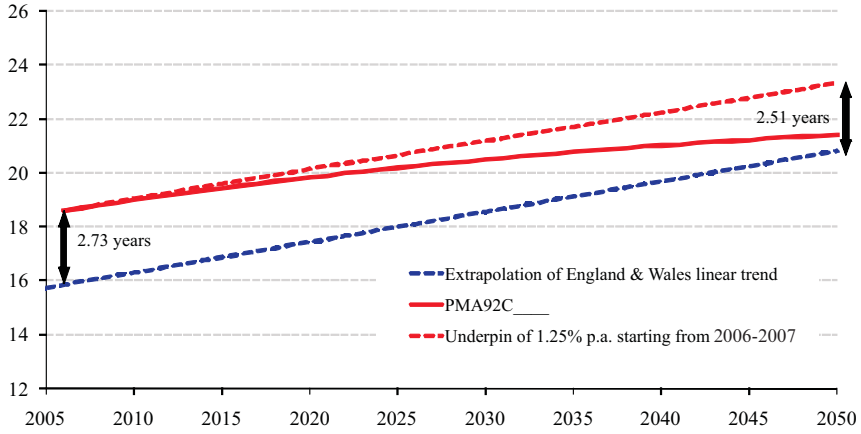
6.4.2 Figure 14 illustrates that one way to ensure that the '92' series projections achieve a similar level of yearly increases in life expectancy is to apply a minimum level of annual improvement (at all ages) in mortality rates of 1.25% p.a. It is unsurprising that a higher minimum is required for men than for women, since the '92' series uses the same set of improvement factors for men and women (CMIR 17), yet the current trend is for faster life expectancy increases amongst men than amongst women.

6.4.3 Using minimum improvements of 1.25% p.a., the gap between the '92' series projections and the underlying population trend converges very slightly, i.e. the underpinned projections increase by slightly less than 41 days per annum. This should be borne in mind if a minimum of 1.25% p.a. is used for funding valuations (where the onus is on prudent assumptions).

6.4.4 Figures 15 and 16 show how improvements of 1.5% p.a. give projections of life expectancy which increase significantly faster than those at the population level; whilst improvements of 1% p.a. result in life expectancy increasing considerably slower than that projected for England & Wales, with the gap reducing to one year and nine months by 2050.

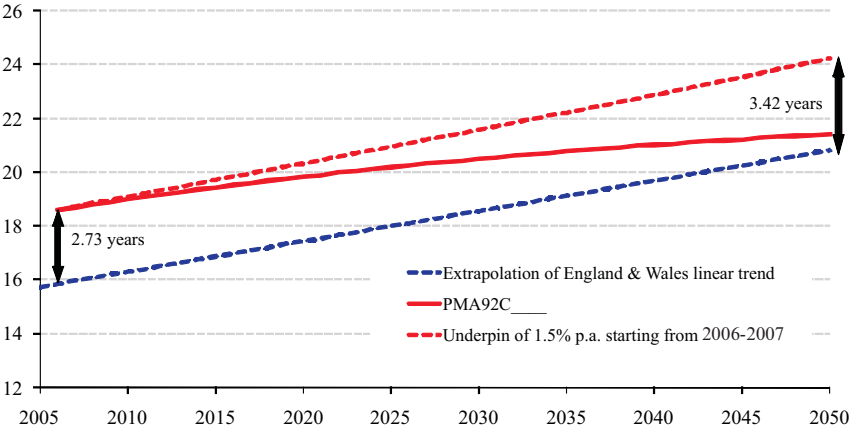
6.4.5 By way of comparison, the GAD and the ONS currently assume a reversion of mortality improvements (albeit in m_x rather than in q_x) in national projections, to a long-term trend of 1% p.a. over 25 years and

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Source: Own calculations

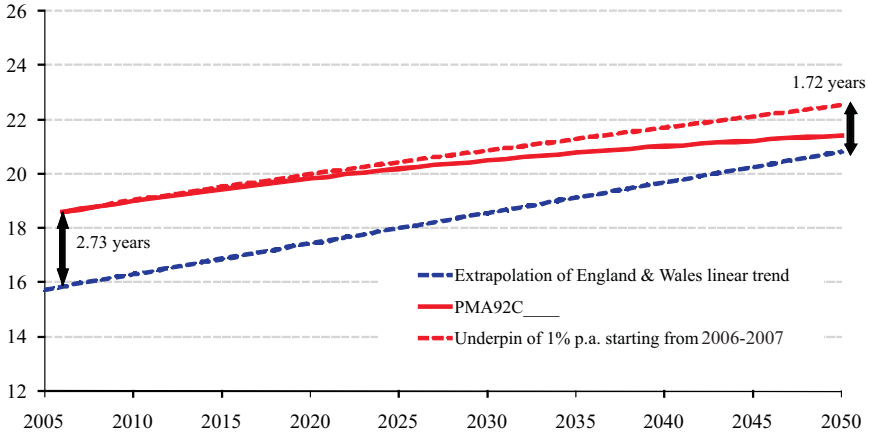
Figure 14. Projected changes in male life expectancy from age 65 over time (comparison with an underpin of 1.25% p.a.)



Source: Own calculations

Figure 15. Projected changes in male life expectancy from age 65 over time (comparison with an underpin of 1.5% p.a.)

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Source: Own calculations

Figure 16. Projected changes in male life expectancy from age 65 over time (comparison with an underpin of 1% p.a.)

improvements constant at 1% p.a. thereafter (GAD, 2004). That the GAD use a slightly lower value for the minimum is unsurprising, since:

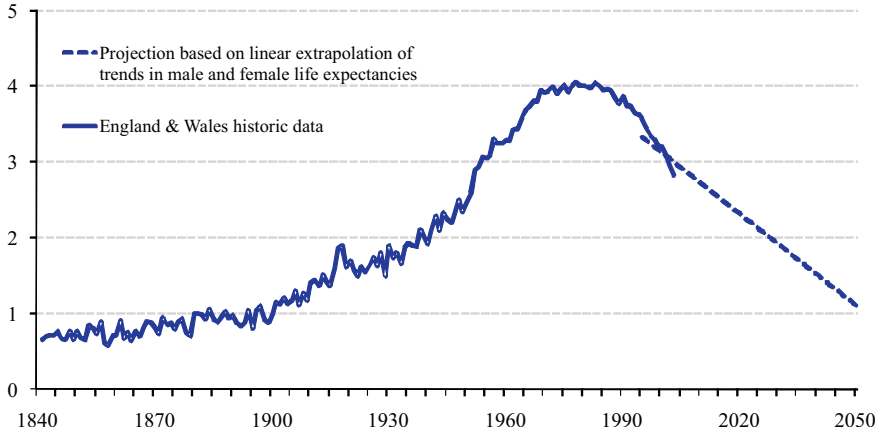
— the same level is assumed for men and women; and
— the same underpin is assumed at all ages, and, for many ages below 65, mortality improvements have, for men, been running at a lower rate (see Willets *et al.*, 2004).

7. Male and Female Life Expectancy Differentials

7.1 In modern history women have tended to outlive men, although the same cannot be said for classical history. Many reasons are suggested for this, including Darwinian selection, because of the need for women to live longer to nurture children. For further details on the history of, and the reasons for, gender differentials in mortality the reader is referred to Kalben (2002).

7.2 With this background in mind, it is important to consider what the projections produced earlier assume about the difference between male and female life expectancies. Figure 17 shows the difference (female *minus* male) in national life expectancies, both historically and based on the extrapolation of the male and female life expectancy trends. Although the rate of increase in life expectancies for men is considerably faster than for women, the extrapolations essentially reverse, by 2050, the large difference

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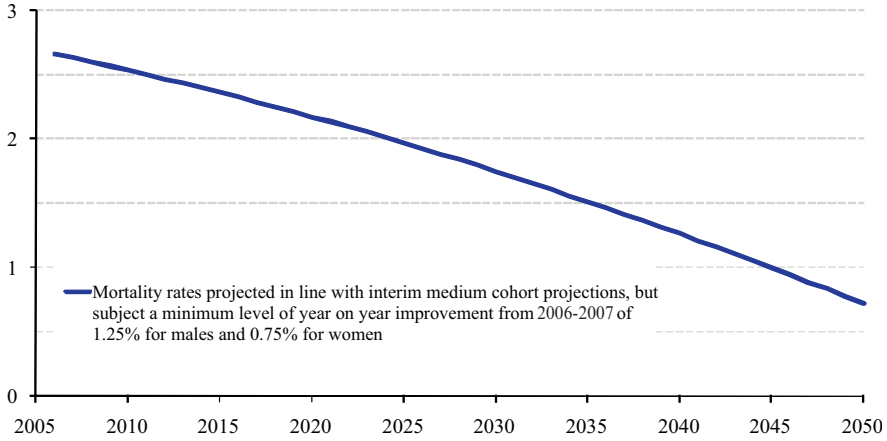
Source: Own calculations using data from HMD (2006)

Figure 17. Historic and projected difference in period life expectancy at age 65 between men and women (England & Wales)

in life expectancy which arose between 1900 and 1980. Importantly, within the typical timeframe of current members of a United Kingdom pension scheme reaching age 65, period life expectancies of men will not exceed those of women.

7.3 When valuing pension benefits, though, we typically use mortality rates specific to future years, i.e. we use mortality rates dependent on an individual's birth year. Hence, we should ensure that, once we project mortality with differing improvements for men and women, we are not assuming that men outlive women. Since any minimum improvements in older age will continue to be compounded beyond an individual attaining age 65, it is important to consider the difference in cohort life expectancies between men and women. Figure 18 confirms that the male cohort life expectancy from age 65 remains below that for women over the time horizon of possible retirements from the current membership of most defined benefit pension schemes.

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Source: Own calculations

Figure 18. Difference in projected *cohort* life expectancy at age 65 between men and women

8. Different Populations

8.1 *The Importance of Different Populations*

Sections 5 and 6 identified a minimum level to annual improvements in mortality, which, when used with the '92' series projections, ensured that the projections of period life expectancy increased at least as quickly as the trend within the 'national' (i.e. England & Wales) data. However, maintaining a constant difference between the life expectancy projections may not be appropriate for some users of the tables. For example, where the characteristics of the scheme membership are more similar to those of life office pensioners than of the population as a whole, it may be more appropriate to ensure that the life expectancy follows any trends exhibited in the life office pensioner data. Similarly, pension schemes where the membership has a different socio-economic profile to either life office policyholders or the 'national' population may also wish to modify the analysis of Sections 5 and 6.

8.2 *Pension Scheme Populations*

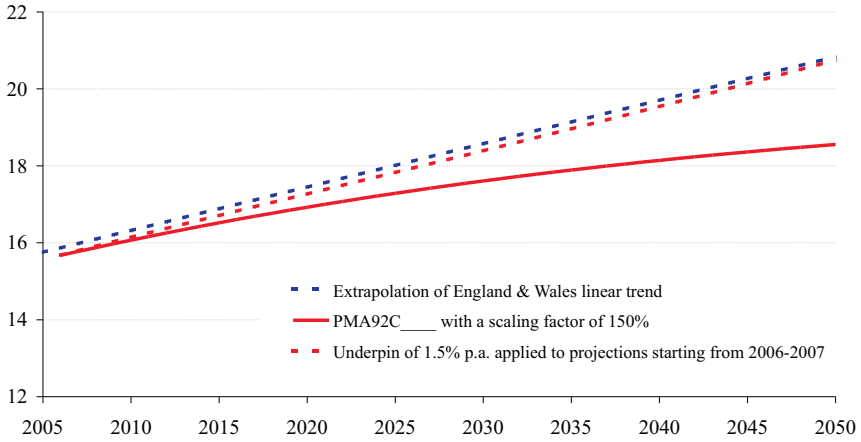
8.2.1 Inevitably, the characteristics of an individual pension scheme differ from both the life office pensioners on whom the '92' series tables were based and the population as a whole — for example, the members will typically be concentrated in specific geographical regions, industries, social classes and income bands. For very large schemes, it is possible to capture this variation in socio-economic profile via the use of a scheme specific

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mortality table(s), graduated to the actual scheme experience. For the majority of schemes, though, a scaling factor, typically, will be applied to capture, broadly, differences in mortality rates between the population being valued and the population underlying a published table. The scaling factor may be set via general reasoning or via a mortality experience investigation. For example, see CMI WP17 (and also CMI WP4 and CMI WP9) for the ratio of actual to expected deaths seen in the CMI investigation of the experience of self-administered pension schemes — typically these ratios are in excess of 100%, although they reduce with increasing pension amount, to less than 100% for those pensioners with the highest incomes. When referring to such papers, though, the reader should note that the 'A/E' ratios are an average across a range of ages — in practice an age dependant scaling factor often better reflects the underlying experience. For the purposes of this section, I will use an age independent scaling factor — which the author's experience suggests is common practice.

8.2.2 A natural question to ask is whether the life expectancy projections continue to look valid once a scaling factor has been applied. To answer this we can repeat the analysis of Sections 6 and 7, but with a 'high' scaling factor, e.g. 150%, which, for males, gives a life expectancy assumption which is very similar to the population as a whole.

8.2.3 Figure 19 shows that, when using a scaling factor of 150%, a



Source: Own calculations

Figure 19. Projected changes in male life expectancy from age 65 over time (comparison with '92' series amounts-based tables with a scaling factor of 150%)

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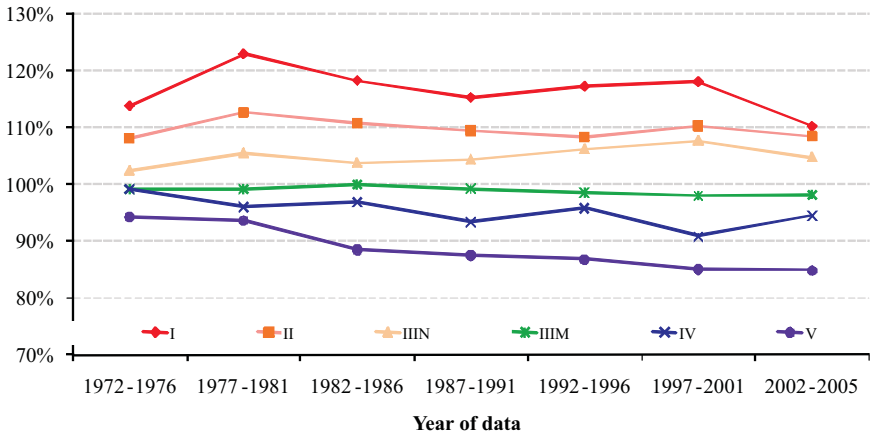
minimum level of improvements of 1.5% p.a. is needed in order for the male projections to follow the population trend as closely as possible. The different minimum value arises because a large scaling factor brings forward the incidence of deaths, and so a greater minimum is needed for the same absolute increase in life expectancy.

8.3 *Period Life Expectancy in Different Social Classes*

8.3.1 Ultimately, the scaling factor is applied to the pensioner mortality tables published by the CMI, to adjust the mortality assumption being used, to allow for members of the pension scheme having a different socio-economic profile to that of life office pensioners. The example of 150% above might, for example, relate to a former heavy industrial company where the socio-economic profile is skewed towards the lower social classes. Consequently, it is reasonable to consider whether the increases in life expectancy have been running at the same rate for different socio-economic classes as for the population as a whole.

8.3.2 Figure 20 shows that life expectancy has been increasing faster than average for the highest social classes and slower than average for the lowest social classes. This is unsurprising, since the higher socio-economic classes are typically more receptive to new information on health/medical care, and so are 'early adopters' of new practices.

8.3.3 Figure 20 also suggests that the ratio of *older-age life expectancy*



Source: Own calculations using data from the Office for National Statistics Longitudinal Study

Figure 20. Changes in life expectancy from age 65 by social class relative to population average (males)

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Table 1. Male life expectancy as an approximate percentage of population average by social class

Social class	I	II	IIIN	IIIM	IV	V
Proportion of average	115%	110%	105%	100%	95%	90%

to the national average has, for men, been fairly stable for all bar the lowest social classes (V — unskilled manual workers), where the ratio has been falling consistently. Whilst the ONS Longitudinal Study includes only seven time periods, which are too few to draw definitive conclusions, it does indicate possible ratios for the relative levels of life expectancy between different social classes (Table 1).

8.3.4 It should be noted that female life expectancy by social class has not been in such stable ratios to the average — see Richards & Jones (2004).

8.4 *Should we Determine the Minimum Improvements by Keeping the Difference between Life Expectancies or the Ratio of Life Expectancies Constant?*

8.4.1 The available data make it difficult to discern trends between the lives on which the published tables are based and the population as a whole. Ensuring that the life expectancies arising from actuarial mortality projections keep pace with the extrapolation of current trends in population life expectancy (i.e. using absolute differences rather than ratios) appears to be a pragmatic solution, which is easier to communicate to the recipients of our advice.

8.4.2 However, in light of the observations of ¶8.3.3, an alternative approach might be to model mortality improvements so that the ratio of life expectancy between the specific population under consideration and the national population is projected to remain constant.

8.4.3 In the context of using life expectancy projections to educate the level of any minimum improvements, this means that we need to decide whether life expectancy projections should increase by at least 26 days per annum for women and 41 days per annum for men, or whether the scheme members will continue to live for a specific percentage longer than the England & Wales population (e.g. 10% for a pension scheme dominated by socio-economic class II). If we adopt the second approach, then a higher minimum level of improvement would need to be applied — as can be seen from Table 2.

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Table 2. Minimum improvements suggested by different approaches of projecting life expectancy

	Males	Females
Minimum improvement for life expectancy to increase at same rate as the extrapolated England & Wales trend	1.25%	0.5% - 0.75%
Minimum improvement to maintain ratio with extrapolated England & Wales trend	1.50%	0.75% - 1.0%

Source: Own calculations

9. Trends in Life Expectancies at other Ages

9.1 The levels of underpin suggested in Sections 5 and 6 were derived by considering *older-age life expectancy*, i.e. the period life expectancy at age 65. This was designed to focus attention on the value of greatest concern to pension schemes (the length of time for which pension payments are made); for those members for whom there is greatest longevity risk (the current active workforce and deferred membership). It is possible that different values of the minima would have been suggested had I considered members retiring at other retirement ages or pensions in payment. Table 3 summarises the results of repeating the analysis from earlier sections, but based on a selection of different ages.

9.2 Full details of the trend lines fitted can be found in Appendix C, and the relevant figures are produced in Appendix D. For each age, data relating to years which may have been impacted by, and so result in potential double-counting of, the cohort effect have been excluded. No values for males from age 55 are included in Table 3. This is because the current linear trend in improvements starts in the late 1960s, and from the 1980s onwards the 1925 to 1945 'cohort' generation starts to distort the life expectancies — thus the trend excluding cohort years occurs over too short a period to project reliably.

Table 3. Level of minimum improvement suggested by trends in life expectancy at different ages

	Males		Females	
Age	Constant difference	Constant ratio	Constant difference	Constant ratio
55			0.75% - 1%	1%
60	1.5%	1.5% - 1.75%	0.75%	1%
65	**1.25%**	**1.5%**	**0.5% - 0.75%**	**0.75% - 1%**
70	1.25%	1.5%	0.5% - 0.75%	0.75%
80	1% - 1.25%	1.25%	0.5% - 0.75%	0.75%
90	0.5%	0.5%	0.25% - 0.5%	0.5%

Source: Own calculations

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9.3 A very noticeable feature of the details provided in Appendices C and D is that the simple functional form, described earlier, is good at capturing (in terms of the coefficient of determination) the trend at each of the ages shown in **bold** type in Table 3 (and also at ages 75 and 85, which, although not included, have also been analysed by the author).

9.4 Table 3 shows that underpins based on projecting life expectancy from age 65 are also appropriate for other retirement ages (i.e. similar values are achieved for ages 55 and 60). However, when considering the life expectancy of current pensioners, a lower underpin may be appropriate at older ages. In the context of setting assumptions for valuing benefits of a pension scheme, this means that the simple approach adopted here is appropriate for all bar the oldest pensioners, and so the most mature of pension schemes.

9.5 The results above suggest though that, by using a single value, an underlying age structure is being simplified. This is no surprise, given the complexity of the trends in underlying mortality rates. Section 10 explores this further.

10. Trends in Mortality Rates

10.1 *Life Expectancies and Mortality Rates*

10.1.1 Ultimately, life expectancies are a function of underlying mortality rates. The approach in the previous sections has been a deliberate simplification, whereby I focussed on the quantity of greatest concern to pension schemes — life expectancy. Whilst this ensures that the projections used by Scheme Actuaries look credible in the context of extrapolating past trends, a more rigorous approach is to identify the trends in the improvements in mortality rates at different ages. Ultimately, this is the approach which the Profession has been exploring with the Lee-Carter and the *P*-spline methodologies (see CMI WP15 and the CMI WP27).

10.1.2 In this section I consider whether:

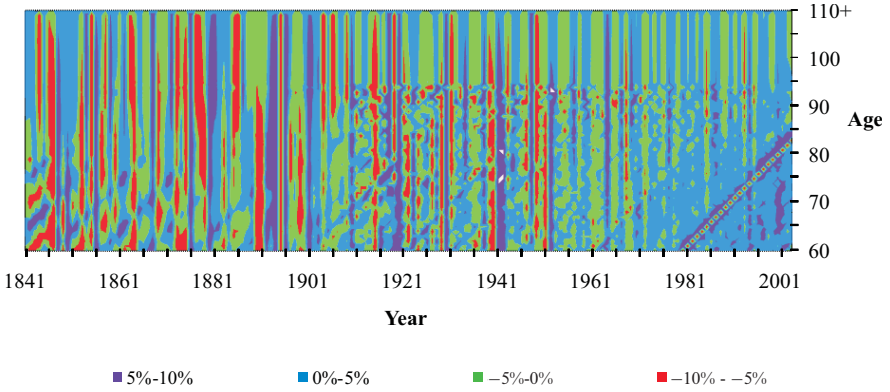
— the conclusions of the previous sections should be revised in light of trends in the underlying mortality rates; and
— historic trends highlight any material simplifications in the use of a single underpin.

10.2 *Improvements in England & Wales Mortality — Males*

10.2.1 The previous sections have suggested that the need to apply a minimum level to annual improvements in mortality rates may be greater for males than for females. Figure 21 shows the improvements in (smoothed) older-age male mortality probabilities between 1841 and 2003.

10.2.2 Figure 21 shows that before 1970 there was considerable variation in improvements, with years of improving mortality being followed by years

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Source: Own calculations using data from HMD (2006)
Degradations/improvements in excess of 10% have been excluded.

Figure 21. Annual rate of improvement in male mortality (1841 to 2003)

of degradation. It would appear that cyclical factors, such as particularly cold winters, play an important role — for example, there is a vertical band of worsening mortality rates at all ages in 1963.

10.2.3 It is perhaps no surprise that, from 1970 onwards, we see an increasing dominance of improvements in the range 0% p.a. to 5% p.a. At this point the U.K. entered an era of increased medical care and barriers to seasonal variations, such as improved housing conditions, which should have meant that seasonal variations have less dramatic an impact on older-age mortality. Substantial variation can still occur though — consider the very cold winter of 1985, which is shown as a period of worsening mortality at nearly all ages over 65.

10.2.4 Figure 21 also shows two interesting 'cohort effects':

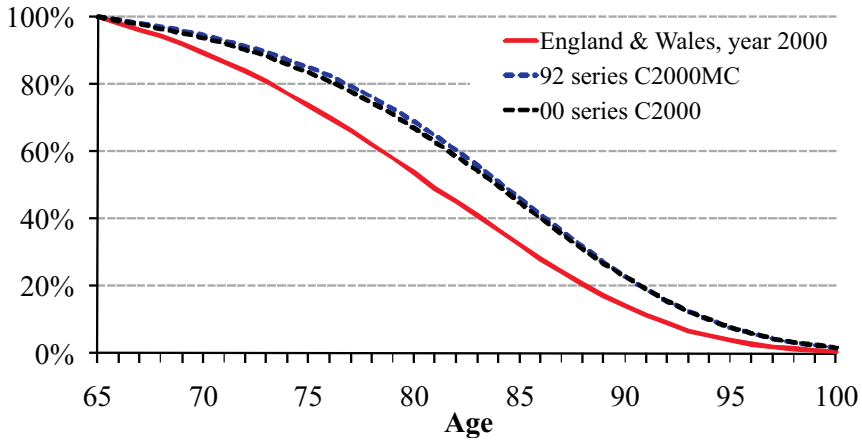
— the diagonals from 1960 onwards, which correspond to generations born after 1900, exhibit a clear trend of improved later life mortality; and
— the 1919 birth cohort appears to have experienced improved later life mortality compared to surrounding generations, as noted by a clear diagonal of improvements of the order of 5% to 10%, which appears to have been reversed by the 1920 birth cohort. One contribution to this is the post World War I baby boom, since the 1919 and 1920 births are skewed towards the later and earlier parts of those years respectively, which, all else being equal, would cause an improvement in mortality in 1919 followed by a worsening in 1920, due purely to age differences. We may also be seeing some selection effect amongst those who survived the 1918-1919 influenza epidemic in gestation and in the first year of life.

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10.2.5 Figure 21 provides little indication, though, as to the average rate at which improvements in mortality occur. It is possible to look at Figure 21 in greater detail (for example differentiate by 1% bands) — however, the considerable variation in mortality from year to year, and from age to age, makes it very difficult to discern underlying trends without applying smoothing techniques. One simple approach to identifying the trends is to focus on specific age bands and to use averages over time (i.e. smooth over age and time).

10.2.6 By considering the post-retirement survival curve from age 65, Figure 22 shows that the period life expectancy is mainly influenced by the mortality rates between ages 75 and 90. In practice, the valuation of pension scheme liabilities is increasingly based on year of use tables, which use cohort life expectancies. Figure 23 shows a typical cohort survival curve used in a current pension scheme valuation for a male retiring at age 65 in 2006, and contrasts this with the survival curve for a male retiring at age 65 in 2050, with and without the minimum improvements of 1.25% p.a. suggested earlier. We can see that, as time goes on, it will be the improvements in the 80 to 95 age groups which will be most important.

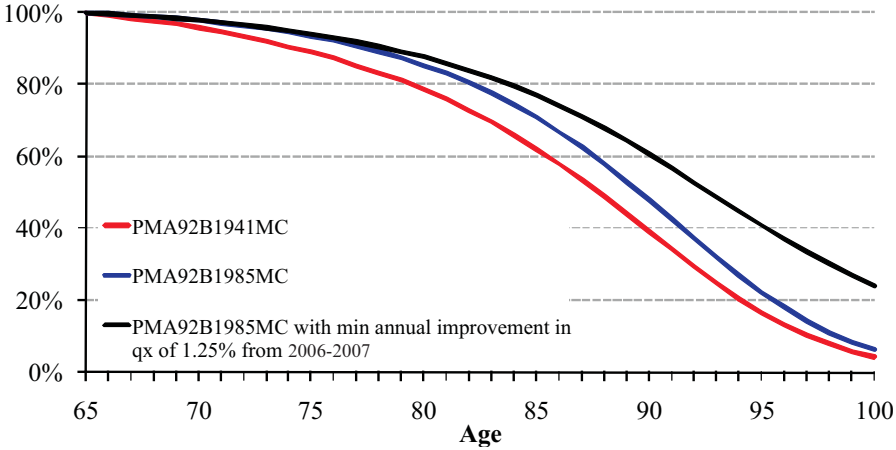
10.2.7 This suggests that we should focus on how the improvements in male mortality rates have changed for three key five-year age bands, 75 to 79, 80 to 84 and 85 to 89. In order to smooth out the impacts, for example, of harsh winters, it is necessary to take an average over a number of years. Inspection shows that an averaging period of at least eight years is needed



Source: Own calculations using HMD (2006)

Figure 22. Period survival curve from age 65 (males)

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Source: Own calculations

Figure 23. Cohort survival curve from age 65 (males)

before the underlying trends become apparent — for the purposes of this paper I have looked at ten-year periods, as these highlight the key features clearly. Since the improvement is a multiplicative effect, a geometric mean is used to average improvements between calendar years (see Richards *et al.* (2005) for discussion of alternative methods, such as kernel and *P*-spline methods). The results for the period 1900 to 2003 are shown in Figure 24.

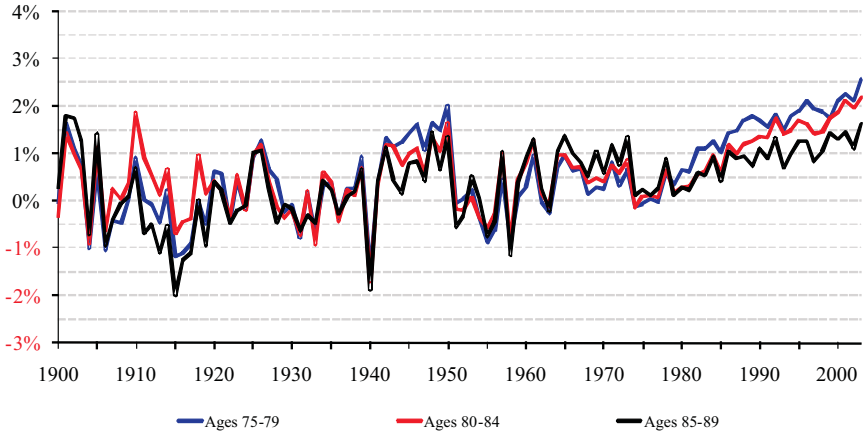
10.2.8 Figure 24 shows how, over the first 70 years of the 20th century, the average of the annual rate of improvement in mortality has varied considerably. The geometric mean over this period was 0.3% p.a. for the 75 to 79 and 85 to 89 age bands, and slightly higher, at 0.4% p.a., for the 80 to 84 age band. From the start of the 1970s though, a discernible trend emerges, and it is perhaps unsurprising that this correlates with both the period of sustained improvements in life expectancy, seen in Section 6, and the period of sustained improvements in mortality rates noted in ¶10.2.3.

10.2.9 Figure 25 focuses on the period since 1970, and extends the graph to include the adjacent five-year age bands (i.e. 70 to 74 and 90 to 94). It is important to note that the cohort generation only enters the 70 to 74 year old band from 2000, so the graph has not been distorted by cohort effects.

10.2.10 A number of important observations can be made from Figure 25, including:

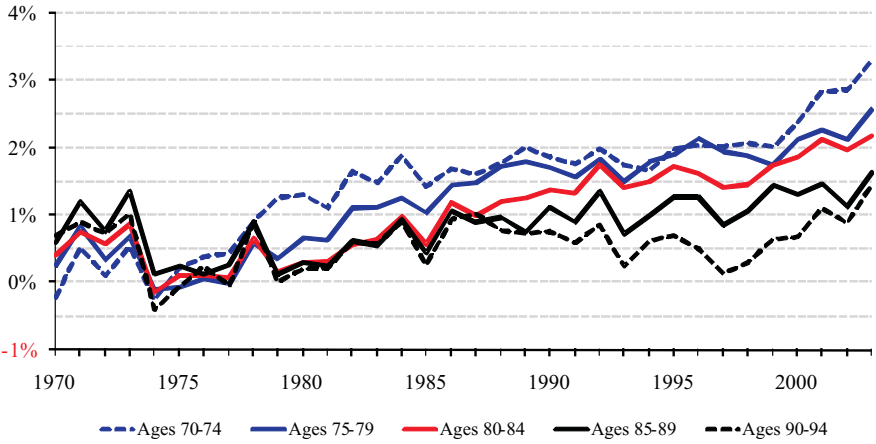
— There is a clear trend of increasing levels of improvement, suggesting that, if recent historic trends were to continue into the future, a rate of improvement derived from historic experience may underestimate future improvements. This is amplified by the use of a 'lagged' geometric

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Source: Own calculations using HMD (2006)

Figure 24. Improvements in male mortality
(England & Wales 1900 to 2003; ten-year geometric average)



Source: Own calculations using HMD (2006)

Figure 25. Improvements in male mortality
(England & Wales 1970 to 2003; ten-year geometric average)

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mean (i.e. means up to and including the year plotted), which will understate the *current* rate of improvement in current periods of acceleration.

— The rate of improvement appears to have an age structure, with higher improvements seen at the younger ages, and lower improvements at older ages. This is consistent with the results of Section 9 (in particular Table 3). Consequently, the use of a single minimum level of improvement is a simplification of underlying trends. It is unsurprising that this age structure exists, as many theories of ageing refer to the accumulation of damage in older age, and so the removal of one cause of death may only serve to allow another cause more 'freedom to kill'.

— Care is needed in extending the improvement to older ages. Figure 23 highlighted how, as mortality rates at ages below 90 fall, so the older ages have a greater influence on life expectancy. These ages are presently experiencing lower rates of improvement than the underpin suggested previously of 1.25% p.a. In the absence of *ageing of mortality improvements* (whereby the higher rates of improvement migrate to the older ages), there is a risk of overstating life expectancies by using a single minimum — however, the ageing of mortality improvements has been noted in both England & Wales data (Willets *et al.*, 2004) and in other countries (Wilmoth, 1997) .

— The level of improvement derived from life expectancies of 1.25% p.a. is broadly an average of the historic rates of improvement over the key age bands.

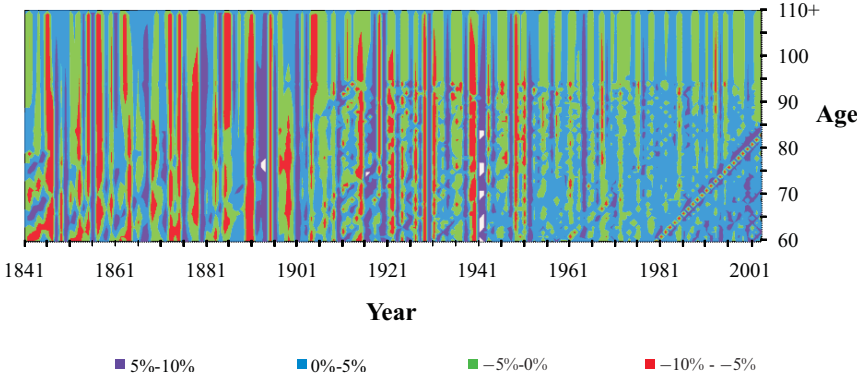
— If trustees or sponsors are seeking an assumption whereby improvements continue at recent levels, then a minimum rate of mortality improvement closer to 2% p.a. may be appropriate.

10.2.11 One response to the first three points of ¶10.2.10 is to use a more sophisticated approach, whereby we derive an age and term dependent model to future improvements. However, adopting such an approach is essentially a further step towards detailed analysis and projection of historic trends, akin to the Lee-Carter (Lee & Carter, 1992) and the *P*-spline methodologies. Although such an approach should not be ruled out, further discussion will be left to other authors.

10.3 *Improvements in England & Wales Mortality — Females*

10.3.1 Figure 26 shows the pattern of improvements in female mortality over the period since 1841. It exhibits similar features to the corresponding figure for males. However, during the 20th century we see a greater prevalence of improvements in mortality rates at older ages. This corresponds to the start of the sustained trend in increasing *older-age life expectancy*. Figure 26 also shows how, from 1950 onwards, the impact of environmental factors, such as cold winters, appears to become less

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Source: Own calculations using data from HMD (2006)
Degradations/improvements in excess of 10% have been excluded.

Figure 26. Annual rate of improvement in female mortality (1841 to 2003)

significant as the figure becomes more monotone. This corresponds to the period when life expectancies become very concentrated on the fitted trend line.

10.3.2 Unlike the equivalent figure for males, there is no obvious start to the cohort effect. However, we do see the beneficial impact of having been born in 1919, albeit to a lesser extent. Figure 26 shows that there has been considerable variation since the 1950s, with mortality changes occasionally oscillating between improvements and degradations. These oscillations are mirrored in the figure of the level of geometric averages of improvements (Figure 27).

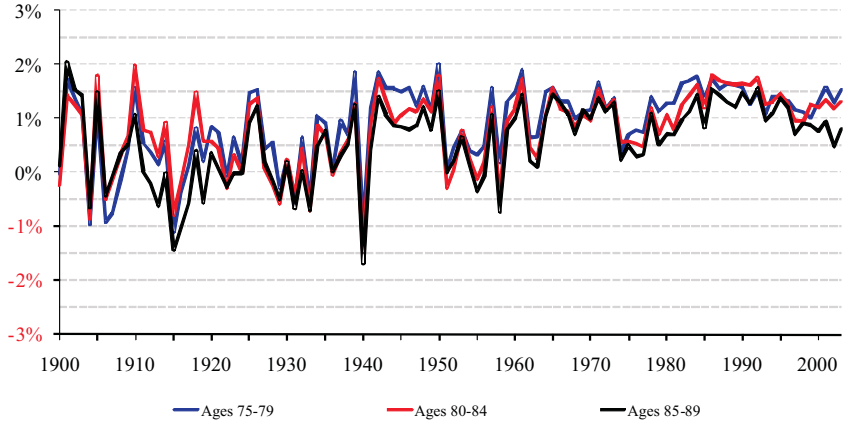
10.3.3 Figure 27 highlights the volatility in improvements up until the second half of the 20th century. As we start to enter the 1970s, so the rates of improvement stabilise, with mortality amongst 75 to 90 year olds improving by between 0.5% p.a. and 1.5% p.a. The average level of improvement over the 20th century amongst both 75 to 90 year olds, and 70 to 95 year olds has been 0.8%, i.e. comparable to the level of improvements deduced from trends in life expectancies in Section 6.

10.3.4 Figure 28 shows that the age structure of improvements is less pronounced for females than for males. Some evidence of the *ageing of improvements* is seen, with the 75 to 79 and 80 to 84 age bands showing the modal improvements.

10.4 *Longevity in the 21st Century (Willets* et al.*, 2004)*

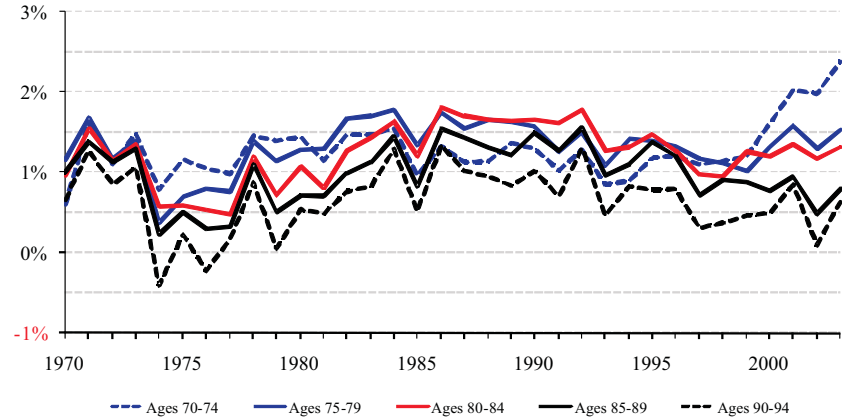
10.4.1 A more comprehensive analysis of trends in mortality rates, including analysis by cause and international comparisons, can be found in

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Source: Own calculations using HMD (2006)

Figure 27. Improvements in female mortality
(England & Wales 1900 to 2003; ten-year geometric average)



Source: Own calculations using HMD (2006)

Figure 28. Improvements in female mortality
(England & Wales 1970 to 2003; ten-year geometric average)

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Willets *et al.*, 2004). This paper deals with trends in improvements in (central) mortality rates (rather than probabilities), and uses raw ONS data (see ONS, 2003b). It looks at the trends in totality, i.e. including the cohort effect, and so, whilst it observes the cohort effect, it does not explicitly attempt to assess the level of any underlying long-term trend excluding the cohort effect.

10.4.2 Some of the key conclusions of Willets *et al.* (2004) are:

— There is a clear age dependence to mortality improvements, with the greatest improvements over the 20th century having occurred in the later years of life.

— Mortality improvements are 'shifting' through into the older ages — this explains why improvements in *older-age life expectancy* have been more marked in the second half of 20th century. The paper highlights current evidence that:
  — at the oldest ages mortality rates could limit at 50%, not at 100%, as assumed by the '92' series projections (see Thatcher *et al.* (1998) for more details); and
  — "a maximum theoretical human life expectancy is not immediately in sight."

— The average level of improvements between 1960 and 2001, over all ages and all sexes, was 1.3% p.a. The paper also shows the age structure to improvements at older ages, as shown in Table 4. This verifies that an average level of around 1.25% p.a. for males may be reasonable, although it suggests a higher level of improvements for females than the 0.75% p.a. deduced here. It also verifies the decrease in male improvements with age, seen in Section 10.2, and the 'peak' in female improvements amongst the 75 to 84 year olds, seen in Section 10.3. It should be noted that the period covered by Table 4 means that most age groups will include some of the accelerated improvements during the cohort effect. Later in Willets *et al.* (2004), the authors consider the 40 year period ending in the late 1990s — this gives slightly lower figures, which are very similar to those seen in Sections 10.2 and 10.3.

Table 4. Average annual rate of mortality improvements (1960 to 2001)

Age Group	Male	Female
65-69	1.7%	1.2%
70-74	1.4%	1.2%
75-79	1.2%	1.3%
80-84	1.0%	1.3%
85+	0.8%	0.8%

Source: Willets *et al.* (2004), exert from Table 2.3, original data source ONS (2003b)

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— The improvements between 1989 and 2001 amongst those aged 60 and over are shown to have arisen principally from improvements in circulatory disease mortality.

11. Past Improvements and the Future

11.1 *Background*

11.1.1 The analysis so far has identified the level of improvements which should underpin future projections based on historic trends. This has been predicated on the assumption that past trends in improvements in mortality will continue at a similar rate in the future. However, the author concurs with the sentiment expressed in the abstract to Willets *et al.* (2004) that:

> "future projections should be grounded in as good an understanding of the past as possible."

11.1.2 The aim of this section is to provide some general (and topical) background as to how we have achieved current rates of mortality; and considers briefly the prospects for the future. The material presented here is (necessarily) far from exhaustive, and is designed to stimulate discussion, as opposed to being a definitive survey. The reader will undoubtedly think of other factors — and I would encourage him or her to consider the implications of those factors on the level of any minimum to future mortality improvements. For more detailed analysis in the trends associated with specific causes of death, the reader is directed to ONS (2003a), ONS (2006) and Willets *et al.* (2004).

11.2. *Epidemiological and Health Transitions*

11.2.1 There are two intertwined explanations of how modern levels of longevity have been achieved — the epidemiological and the health transitions. The *health transition* describes the increases in longevity in terms of changes in health care practices and other social determinants, whilst the *epidemiological transition* explains declining mortality in terms of specific diseases (see Figure 29). This section summarises the key elements of each, based largely on Riley (2001). In addition, a number of the paragraphs draw upon Olshansky (2001) and ONS (2003a).

11.2.2 *Health transition*

11.2.2.1 The *health transition* describes how social behaviours and health policy have influenced the decline in mortality. Early health practices centred on an understanding that disease was synonymous with filth. Initially this understanding was limited, with filth being determined in terms of foul smells and decomposing organic matter. Whilst there was an appreciation of the

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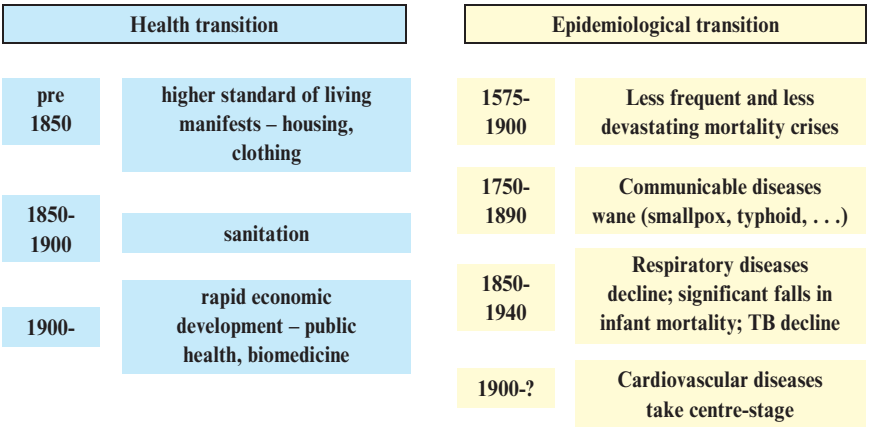


Figure 29. Representation of the epidemiological and health transitions

need to dispose of refuse and faeces in pits away from dwellings, an aversion to smells did little to motivate personal hygiene — in the 18th century it was widely perceived that the air had harmful properties, and so exposure to it, e.g. in bathing, should be avoided.

11.2.2.2 The introduction of cotton led to more readily washable clothing, and so to the reduction in the transmission of disease via the control of parasites, such as fleas and lice. By the 19th century, ceramics and pewter, which could be washed with water and soap, were also widespread, having replaced wooden eating utensils.

11.2.2.3 The Industrial Revolution brought with it an initial increase in mortality within the U.K., known as the *urban penalty*. Migration from rural to urban areas caused a rapid expansion of the towns and cities, leading to overcrowding and a refuse burden. No longer could refuse be readily disposed off in pits away from dwellings; whilst overcrowding created dark, dank environments, well suited to the propagation of diseases, especially tuberculosis. Initially, the sanitation of towns and cities continued to be based on the practice of avoiding foul smells.

11.2.2.4 Water filtration was gradually introduced — for example, the sand filtration of London's supply of water from the Thames was introduced in 1829. The need to separate the delivery of water to houses from the removal of sewage was only understood once epidemiologists, such as John Snow, identified that certain diseases (e.g. cholera) were borne by water. Sewage systems (including flush toilets) expanded as a consequence, albeit initially to the most affluent members of society. As economic growth from the Industrial Revolution freed up public and private capital and resources, so this led to investment in housing and sanitation, including elaborate

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sewage systems, most notably as a consequence of the 1875 Public Health Act. Municipal regulations from the mid-18th century onwards also started to favour light and ventilation, resulting in a reduced communicability of diseases.

11.2.2.5 The philosophy of avoiding filth (known as *filth theory*, for those interested in further reading) gradually led on to an understanding that disease is transmitted via germs (*germ theory*). From the mid 1850s onwards, attention started to move away from the fact that filth contained the disease to the germs themselves and their carriers, pioneered by Louis Pasteur and Robert Koch. As a consequence, heat and chemicals were increasingly used to kill germs — including the pasteurisation of milk, and the antiseptic cleaning of rooms holding the sick and the infirm. There also became a widespread understanding of when and why to wash.

11.2.2.6 The introduction of legislation limiting child labour (such as the 1851 Factory Act) and the increased accessibility of elementary education (1870 to 1891) increased child survivorship. A greater proportion surviving to early adulthood increased per capita productivity — this, in turn, helped to provide the income growth to finance further increases in life expectancy[8] through investment in public health and biomedicine.

11.2.2.7 The health transition in the 20th century was dominated by biomedicine and public health spending. *Antibiosis* — the process by which life could be used to destroy life — became the focus of medical research. However, it was not until the onset of the Second World War and the need to ensure sufficient medicine for troops that mass production of antibiotics became possible. Antibiotics (and a greater understanding of blood transfusion) paved the way for surgeons to be able to conduct invasive procedures safely, and over the second half of the 20th century surgical knowledge rapidly increased, facilitating complex life-saving operations on vital organs, such as the heart and the brain.

11.2.2.8 The National Health Service (NHS): "designed to secure improvement in the physical and mental health of the people of England and Wales and the prevention, diagnosis and treatment of illness" (as a result of the 1946 NHS Act) was introduced in England & Wales in 1948. The NHS replaced a fragmented health care system, whereby wealth often determined the availability of medical services. It introduced three levels of care:

— *primary care*, whereby general practitioners provided medical services for the local community;
— *community services* providing welfare services, including health visitors, midwives, immunisation services, ambulance services, etc.; and
— *hospital services*.

[8] Life expectancy growth is weakly correlated with income growth.

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Although this *tripartite system* has evolved since 1948, and has undergone considerable restructuring (see 'History of the NHS'[9]), the state provision of free basic health care has been a major driver in the recent decline in mortality rates, and a possible explanation for the 'cohort effect' (Willets, 2004).

11.2.3 *Epidemiological transition*

11.2.3.1 Whilst the health transition describes the public health advances which have facilitated a decline in mortality, an alternative description is in terms of how the causes of death have changed over time, known as the *epidemiological transition*.

11.2.3.2 Prior to the Industrial Revolution, limited headway had been made in reducing mortality, consequently limited improvements were seen in life expectancy. Life expectancy would often show marked dips, as a result of mortality crises owing to food shortages (arising from crop failures at a time when it was difficult to move food between areas) and localised disease and conflict. From the late 16th century onwards, the prevalence of these mortality crises decreased, partly as a result of potato and beans diversifying the diet away from grain; and partly due to reduced civil conflict. Mortality crises continue to be seen to the modern day, though, in the forms of wars, epidemics (such as AIDS in the developing world, or the influenza pandemic of 1918-1919) and, in the developing world, famine.

11.2.3.3 As mortality crises waned, many of the population still failed to achieve anywhere near their potential longevity owing to infectious diseases. Whilst public health projects, such as sanitation, were reducing the communicability of diseases like smallpox, cholera and typhoid, so scientists actively sought and found vaccinations. The discovery of a vaccination against smallpox (Edward Jenner, 1796) drove much of the decrease in mortality in the early 19th century throughout Western Europe. Vaccination research has continued to the modern day. Large falls in infectious disease mortality were seen during the second half of 20th century, owing to the introduction of childhood immunisations for diphtheria, polio, tetanus, whooping cough, measles, mumps and rubella.

11.2.3.4 As Western Europe industrialised, and smallpox death rates fell, so tuberculosis became the leading cause of death. It started to wane in Britain in the 1840s, with a clear decline in the 1870s. Tuberculosis (TB) is transmitted by microscopic organisms, bacilli, which are killed by sunlight, and so much of the initial decline is attributable to the aforementioned municipal regulations. Tuberculosis mortality declined particularly steeply following the introduction of effective treatments, including antibiotics and the Bacillus Calmette-Guérin (BCG) vaccine. Although the BCG vaccine was

[9] http://www.wales.nhs.uk/sites3/Documents/201/AnIntroductiontoNHSWales.pdf

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available in 1921, mortality rates fell most notably once it was introduced into the school population in the 1950s.

11.2.3.5 By the mid-20th century, populations of developed countries routinely started to live to later life, and the focus shifted away from infant mortality towards diseases associated with adulthood and ageing. With age, the human body, essentially designed as a vessel for the successful continuation of the species — or more specifically of our genes — starts to show the impact of 'wear and tear'. This manifests itself in the form of a clogged-up and tired cardiovascular system, resulting in heart attacks and strokes; accumulated DNA damage resulting in cancer; and a weakened immune system, which increases the susceptibility to infectious diseases. In particular, the emergence of cardiovascular disease as the leading cause of death stimulated considerable research in the second half of the 20th century. This research included the Framingham Heart Study,[10] innovative in moving away from identifying causes of disease and the testing of antibiotic agents against placebos to the identification of risk factors (including smoking, high blood cholesterol, obesity, etc.). Indeed, Unal *et al.* (2004) identified that around 58% of the decrease in coronary heart disease mortality between 1981 and 2000 was from changes in risk factors.

11.2.3.6 Although cardiovascular disease continues to be the leading cause of death amongst the elderly, Table 5 shows the remarkable progress which has been made in reducing mortality rates from heart disease at those ages to which *older age life expectancy* is most sensitive, i.e. 75 and over. In particular, for both men and women it has been the principal reason for falls in mortality rates over the last 30 years. This may lead us to be cautious

Table 5. Deaths per 10,000 in over 75 year olds — 2000 compared with 1970

	Males			Females		
	1970	2000	Change (1970 to 2000)	1970	2000	Change (1970 to 2000)
Cardiovascular disease (Circulatory system)	721	405	↓44%	615	347	↓44%
Respiratory diseases	274	211	↓23%	150	169	↑13%
Cancers	201	222	↑10%	109	132	↑21%
All other causes	126	137	↑9%	112	170	↑52%
TOTAL	1,322	976	↓26%	986	818	↓17%

Source: Own calculations based on ONS (2003b)[11]
Totals may differ from the sum of individual diseases owing to rounding.

[10] A longitudinal study, started in 1948, covering over 5,000 residents of a Massachusetts town, which collected data on 80 variables during the course of routine medical examinations.
[11] The classification of diseases is based on that provided in ONS (2003a), but with diseases of the circulatory system defined to be ICD codes 390 to 459 under ICD-8.

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about extrapolating the trend lines which were fitted earlier, since it has been fitted to a period dominated by improvements in cardiovascular mortality.

11.2.3.7 Despite the dramatic progress made in reducing heart disease mortality, it continues to be a bigger killer in the U.K. than in other developed counties, such as France and Japan, by a factor of three to four times (Willets *et al.*, 2004). This suggests that there is substantial potential for a continued decline in U.K. cardiovascular mortality rates.

11.3 *Future Medical and Health Care Advances*

11.3.1 The end of the 20th century heralded an era where we saw, for the first time, a substantial proportion of the population living to old age. With this ageing of the population, so medicine is focussing attention on old-age morbidity — and, although many of these ailments may not be curable, we are increasingly finding ways to keep people alive for longer. In particular, achieving reductions in death rates amongst the over age 75 population would serve to increase noticeably *older-age life expectancy*. A comprehensive treatment of current medical research is beyond the scope of this paper; however, a number of areas are briefly discussed below, along with a general discussion on the scope for life expectancy to improve, based on international comparisons.

11.3.2 It is important to realise that a reduction in mortality from one disease has a dampened impact on overall death rates at older ages — this is because disease-specific mortality rates are increasingly negatively correlated with age (Willets *et al.*, 2004). The reduction (or eradication) of one disease often increases the mortality rates associated with another, secondary disease. This can be seen in Table 5, in the increase of mortality from 'all other causes'.

11.3.3 Within England & Wales, many of the improvements are likely to be driven by the Department of Health's *National Service Framework* (NSF). Launched in 1998, this is a rolling programme of long-term strategies for improving specific areas of care. It covers, currently, a variety of areas, including coronary heart disease, cancer, chronic obstructive pulmonary disease (COPD — a form of lung disease which accounted for 21% of the respiratory disease deaths in 2000) and older people. The framework contains specific targets, and provides milestones as to how these targets will be achievable. It also highlights the social inequalities in disease incidence (e.g. coronary heart disease is 50% more prevalent in social class V than in the population as a whole), and will target resources at reducing the socio-economic divide in health.

11.3.4 Cardiovascular disease accounts for over 40% of deaths amongst over 75 year olds. However, it seems likely that, if the total eradication of heart disease and stroke which some scientists have predicted (e.g. BBC, 2004) were to come to pass, it would not result in overall mortality rates

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which are 40% lower, owing to the negative correlation between the diseases referred to above. However, any continuation of the current trend of declining fatalities from cardiovascular disease is likely to have a significant impact on *older-age life expectancy*. The NSF considers reductions in cardiovascular disease a priority, with one of the first two frameworks being dedicated to coronary heart disease (CHD). The specific aim of the NSF is to achieve a 40% reduction in heart disease mortality amongst under 75 year olds by 2010. Methods of achieving this include the increased use of aspirins, beta-blockers and statins, quicker thrombolysis treatment and the promotion of healthier lifestyles, such as reductions in smoking prevalence (via support services and the use of nicotine replacement therapy), and increased healthy eating and physical activity. It is expected that full implementation of the framework will not be achieved before 2008, and that it will take several years before the full benefit will be seen. Although not specifically targeting over 75 year olds (and so mortality amongst those for whom *older-age life expectancy* is most sensitive), the framework is likely to have beneficial impacts on older generations. (NHS, 2000a; and NHS, 2006; provide more details on the National Services Framework's approach to CHD.)

11.3.5 As death rates from cardiovascular disease dwindle, so the focus of medical research is likely to be on the other major killers of the elderly, and, in particular, on the prospects for reductions in deaths from cancers and respiratory diseases. Together these diseases account for 44% (34%) of deaths amongst over 75 year old males (females).

11.3.6 More is known about the incidence of, and survival from, cancer than most other diseases, due to the existence the National Cancer Intelligence Centre (NCIC), which collates notifications of cancer registrations. In particular, cancer is relatively heterogeneous in terms of its causes, although diet has been shown to be a risk factor for most cancers. The main cancers contributing to the death rates shown in Table 5 are lung cancer, colorectal cancer,[12] and breast cancer amongst women and prostate cancer amongst men.

11.3.7 Lung cancer is essentially a 20th century disease — ONS (2003a) describes how, prior to 1940, it did not have its own International Classification of Diseases (ICD) code, yet, by the end of the 20th century, it was the most common cause of death from cancer in the world. It is particularly aggressive, and has one of the lowest survival rates of all cancers. Consequently, mortality reductions are most likely to be achieved by the eradication of its key risk factors. Doll & Hill (1950) are widely recognised as having established the link between smoking and lung cancer, and Cancer Research UK estimates that tobacco is the cause of 90% of lung cancers.[13]

[12] Also known as colon cancer or bowel cancer.
[13] http://www.cancerhelp.org.uk/help/default.asp?page=3823

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Changes in smoking patterns will, therefore, be a significant determinant of future lung cancer mortality rates, and will also have secondary impacts, as active smoking is also a cause of cancers of the throat, mouth, pancreas, bladder, stomach, liver and kidney (WHO, 2006).

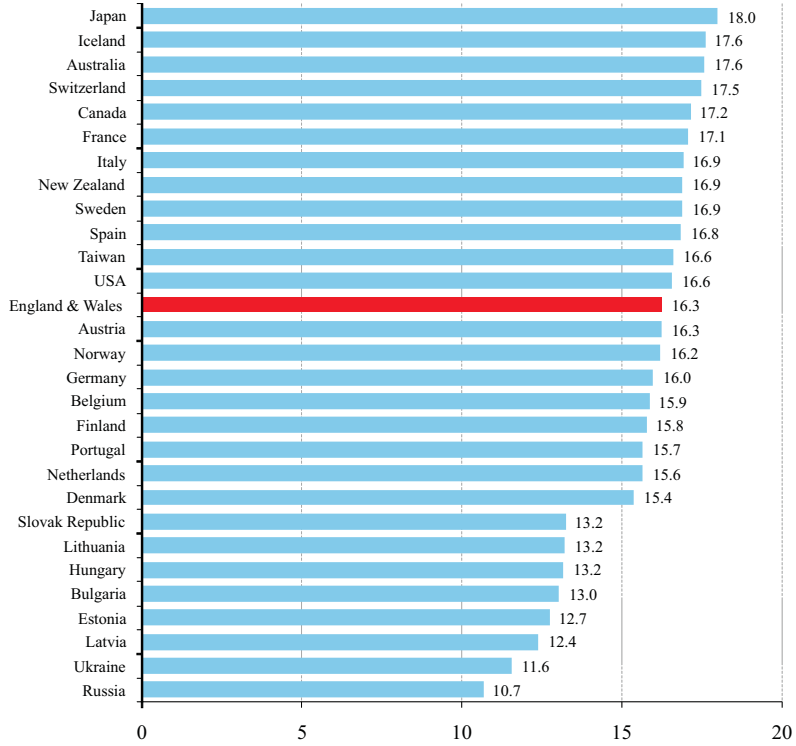
11.3.8 With other cancers, early detection and diagnosis is often critical to reducing mortality rates. For example, identifying breast cancer through screening programmes and colorectal cancer through regular colonoscopies enable treatment to be given earlier, and result in good survival rates (compared to lung cancer). Continued investment in diagnosis and treatment programmes is likely to be a significant driver in reductions in mortality rates from these cancers. For example, the breast cancer screening programme in England & Wales only started in 1995, and the NHS Cancer Plan (part of the NSF) has recently extended this to cover women in the age range 65 to 70 (in addition to those between 50 and 65), whilst colorectal screening is now being rolled out for all adults between ages 60 to 69. Although the NHS Cancer Plan is also trialling PSA, a form of prostate cancer screening, screening has been shown to be less effective in reducing prostate cancer mortality (see ONS, 2003a; and Lu-Yao *et al.*, 2002). In practice, it is likely to be a number of years before the improvements introduced by the NSF are fully recognised in reduced mortality rates, and so provide an ongoing source of reduced mortality rates. (NHS(2000b) provides more details on the NHS Cancer Plan.)

11.3.9 The vast majority of deaths owing to respiratory disease in later life are due to pneumonia, and, in particular, bronchopneumonia. In 2003 a programme of vaccination against pneumococcal disease (the most common cause of pneumonia) was introduced in England and Wales, with the vaccine usually offered with that for influenza. Initially this targeted those aged over 80, but since 2005 has targeted those aged 65 and over (ONS, 2006).

11.3.10 'Old age' (or more specifically senility without psychosis) is also a recognised cause of death within the ICD coding, where no other specific cause of death can be given. Amongst the deaths for 'all other causes' shown in Table 5, old age accounted for 24% of female deaths and 12% of male deaths in 2000. In particular, 'old-age' was the cause of 4% (8%) of *all* deaths amongst over 85 year old males (females). As mortality rates from other diseases fall, it is likely that the significance of 'old age' as a cause of death will increase, especially as an increased proportion of the population routinely live to their late 80s and 90s. This may act as a limiting factor on the sustainability of historic levels of improvement.

11.3.11 Whilst general improvements in life expectancy may be sustainable at historic levels from continued medical advances and health care improvements, there is also considerable potential for increases in life expectancy from existing knowledge. For example, the England & Wales life expectancy is far from the highest amongst developed nations. Figure 30 contrasts the older age life expectancy in England & Wales against 29 other

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Source: HMD (2006)

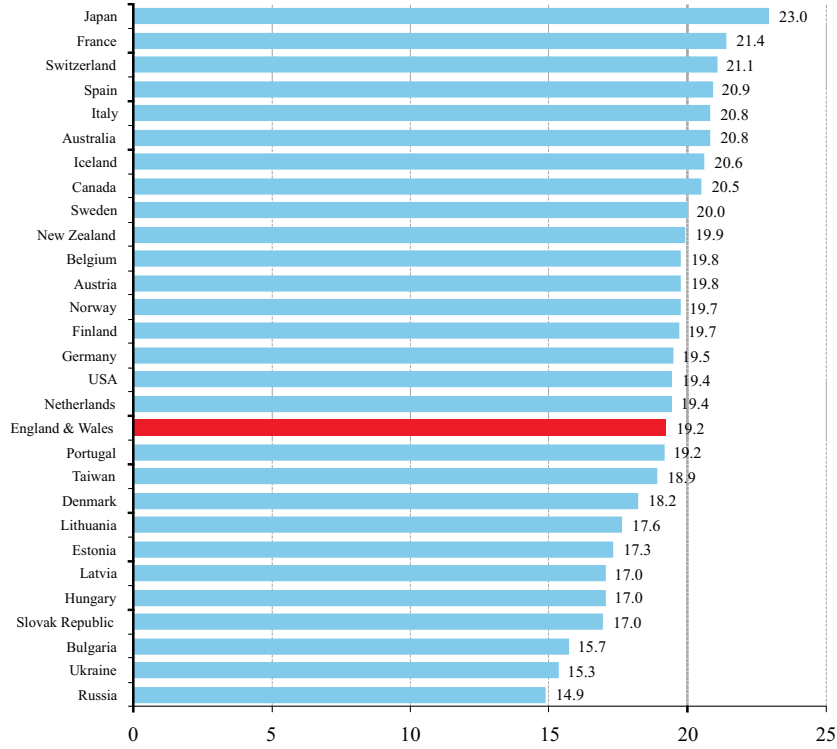
Figure 30a. Male period life expectancy from age 65 (data for 2002)

countries for which the Human Mortality Database holds data. The comparisons relate to 2002, which, as at February 2007, was the latest year for which information was available for all 29 countries.

11.3.12 It is evident from Figure 30 that England & Wales has the potential to benefit from the dietary and health care practices of other countries, such as Japan, Switzerland, Iceland and France. Even if life expectancy were to remain static in these countries, then, based on the extrapolation of historic trends derived earlier, England & Wales would not top the leader board until 2025 for men and 2064 for women. In reality, the cohort effect being observed in the U.K. means that, if the rest of the world saw no improvements and current trends continued in England & Wales, we might reasonably expect to become 'gold-medallists' sooner than this.

11.3.13 We should also be alert to the risk of over-optimism, for instance with an increasing number of aged, and increased morbidity rather

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Source: HMD (2006)

Figure 30b. Female period life expectancy from age 65 (data for 2002)

than mortality, the focus of public and private research may shift away from prolonging life to improving the quality of life in later years. One can conceive other reasons why future improvements may be lower than those implied by the historic level, for example mortality crises arising from obesity (see below) and avian flu, or the possibility that climate change combined with an unprecedented world population growth will lead to acute food shortages and increased conflict for scarce resources. However, many such potential pandemics have been averted in the past, for instance AIDS in the developed world.

11.4. *The Smoking Transition*

11.4.1 Smoking has been shown to be a major contributor to respiratory diseases, heart disease and lung cancer — diseases which, in 2000, accounted for 69% (66%) of deaths amongst the over 75 year old males (females).

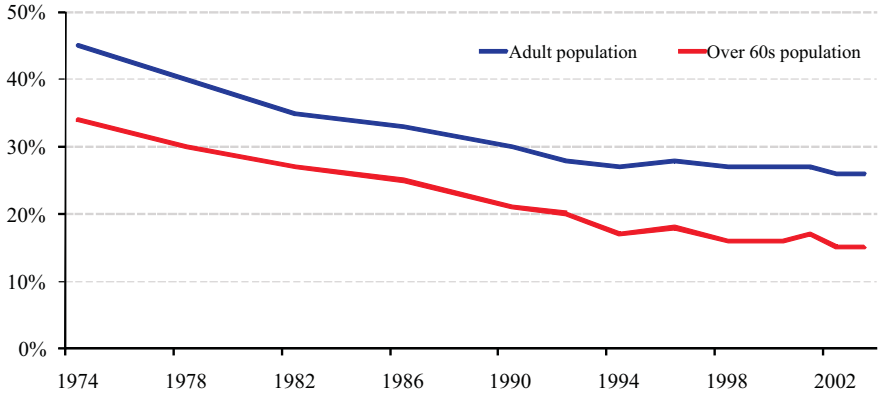
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Although many of these deaths will not be a direct result of smoking, changes in smoking habits have been an important factor in the recent decline in mortality rates. For instance, Willets (2004) and Willets *et al.* (2004) identify that trends in smoking have made a significant contribution to the cohort effect. However, in Willets *et al.* (2004), the authors also comment that:

> "... changes in smoking behaviour may not have *significantly* distorted *average* all-age mortality improvement rates over the whole period in question"

Thus, whilst historic changes in smoking habits may be driving the cohort effect, these changes are less significant in terms of general period improvements, and so of any underpin.

11.4.2 Figure 31 shows the clear downward trends during the 1970s and 1980s in the proportion of the Great Britain population which smoked. Although this trend levelled off in the 1990s, over a quarter of adults and 15% of over 60 year olds continue to smoke. The long latency period for lung cancers, as a result of smoking for at least 20 years (ONS, 2003a), suggests that declines in lung cancer incident rates seen in the last decades of the 20th century can reasonably be expected to continue into the 21st century. Further, the Government has set targets to continue to reduce the number of smokers — for example, the Department of Health has a published target of reducing the number of adults who smoke to 21% by 2010, whilst the NHS Cancer Plan and, more recently, the Public Services Agreement (Department of Health, 2004), aim to reduce the socio-economic inequality



Source: Office for National Statistics

Figure 31. Percentage of population who smoke

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in smoking status (and so lung cancer mortality) by reducing smoking rates amongst routine and manual workers from 32% in 1998 to 26% by 2010.

11.4.3 It is possible that the ban on smoking in public places in England (July 2007), Wales (April 2007), Scotland (March 2006) and Northern Ireland (April 2007) will be a driver of further falls in the proportion of the population who smoke. It will also be of benefit to the non-smoker population, since passive smoking is a risk factor for diseases such as lung cancer (see Cancer Research UK — Lung Cancer and Smoking statistics for further details on the research into the effects of passive smoking). In light of the comment from Willets *et al.* (2004) quoted in ¶11.4.1, a further decline in both active and passive smoking may be the source of a new cohort effect rather than requiring an allowance for a higher level of general improvements.

11.5. *The Nutritional Transition and the Obesity 'Epidemic'*

11.5.1 *Background*

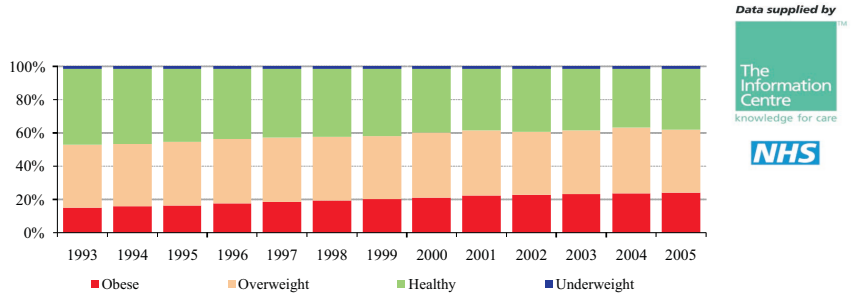
11.5.1.1 During the late 19th century and the 20th century, research showed the existence and importance of vitamins and minerals in food. As a consequence, diets could be designed so as to meet minimum vitamin and mineral requirements. Whilst this helped to ensure childhood growth and had a beneficial impact on some diseases (e.g. Vitamin D in the diet reducing the incidence of rickets), it had little impact on mortality rates.

11.5.1.2 More recently, economic development has resulted in an increasingly sedentary workforce, which requires a lower calorific intake than previous generations; however, dietary patterns have not reflected this. Instead, diets have continued to be rich in fats, sweeteners and refined carbohydrates. Unsurprisingly, this excess energy intake has been accompanied by an increase in the proportion of people who would be classified as overweight (BMI[14] of between 25 and 30 kg/m^2) or obese (BMI of 30 kg/m^2 or greater). Between 1993 and 2005 the proportion of adults in England who were classed as obese increased from 15% to 24% (Figure 32a). The increase was similar for men and women, although a greater proportion of women were obese in 2005 (25% of women compared to 23% of men), and a greater proportion of men were overweight (43% of men compared to 33% of women).

11.5.1.3 Figure 32b shows that obesity is most prominent amongst over 35 year olds. In particular, it is worth noting that 27% of over age 65s (i.e. existing pensioners) were categorised in the Health Survey for England 2003 as obese. For more detail on obesity-related trends, the reader is directed to Chapter 5 of ONS (2006).

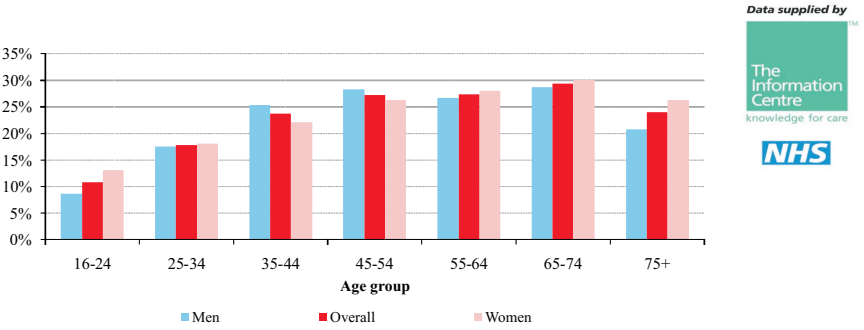
[14] BMI = Body Mass Index, and it is defined as the ratio of an individual's weight in kilograms to the square of his or her height in metres.

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Source: Own calculations based on data from the Health Survey for England (Downloaded from The Information Centre www.ic.nhs.uk; Copyright © 2007. Re-used with the permission of The Information Centre. All rights reserved.)

Figure 32a. Changes in obesity prevalence in England (1993 to 2005)



Source: Own calculations based on data from the Health Survey for England (Downloaded from The Information Centre www.ic.nhs.uk; Copyright © 2007, Re-used with the permission of The Information Centre. All rights reserved)

Figure 32b. Obesity by age in England (2003)

11.5.2 *Aetiology of obesity*

11.5.2.1 Two explanations dominate views on the cause (or *aetiology*) of obesity. Both acknowledge that being overweight or obese arises from an imbalance between energy intake and energy consumption; however, they differ on the source of this imbalance.

11.5.2.2 One view suggests that the imbalance arises as a result of a lack of discipline on the part of affected individuals — in which case a 'cure for obesity' is likely to be an issue for social policy. If obesity becomes a major health issue, then the author would suggest that public policy is likely to

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focus its energies on educating and on providing incentives for healthier behaviours. Indications of this can already be seen in the introduction of health warnings on certain foods, analogous to the warnings which appear on cigarette packets, and the NSF Cancer Plan promoting the 'five-a-day' philosophy of eating five portions of fruit and vegetables a day. However, as Friedman (2000) notes, dieting remedies alone tend to fail.

11.5.2.3 The alternative view is that body weight is controlled physiologically — in which case a conscious decision to eat less is unlikely to regulate energy intake successfully. Instead, obesity treatments are likely to include pharmacologically imposed controls on appetite and digestive inhibition, along with surgical intervention in the forms of gastric restriction or bypass. Evidence for this physiological view is increasing — and, with it, insight into how it might be possible to moderate the processes which lead to obesity.

11.5.2.4 For example, Friedman & Halaas (1998) identified the importance of the hormone leptin in the regulation of body weight. Decreased leptin levels stimulate the brain into increasing food intake, whilst increased levels decrease food intake — unsurprisingly, studies have shown that obese individuals tend to be leptin-resistant (see Friedman (2000) for further references). Although leptin treatment has not provided an immediate solution to obesity, the growing understanding of the mechanics of leptin resistance is offering a number of novel approaches to tackling obesity (Kopelman & Grace, 2004). Thus, whilst obesity trends might lead us to the use of a lower level of minimum improvement, we should be alert to the fact that there is a considerable volume of research focussing on both the mechanics of obesity and the ways of reducing the severity of any obesity 'epidemic'. This includes government initiatives to increase public understanding of what constitutes a healthy diet as part of the National Services Framework.

11.5.3 *Impact of obesity on life expectancy*

11.5.3.1 The adverse impacts of obesity are often cited as a reason for assuming some slowing of mortality improvements relative to historic trends. Obesity, although a relatively new issue in the U.K., has been of concern for longer in the United States of America, and follow-ups to the Framingham Heart Study have provided an insight into the impact of obesity. For example, Hubert *et al.* (1983) identify obesity as an independent risk factor for cardiovascular disease. It has also an acknowledged risk factor for cancers, such as colorectal cancer and breast cancer (where it amplifies hormone-related risk factors in post-menopausal women) — see Cummings & Bingham (1998) for further discussion, including the wider relationship between diet and cancers.

11.5.3.2 There are contrasting views on the impact which obesity has on life expectancy. For example, Peeters *et al.* (2003) use the longitudinal Framingham Heart Study to estimate that being overweight could reduce life

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expectancy from age 40 by up to three years, and being obese could further reduce life expectancy by up to four years, i.e. a total of seven years (although this is highly dependent on smoking status — with the impact for non-smokers considerably lower). However, Olshansky *et al.* (2005) use BMI specific mortality rates to estimate the increase in U.S. life expectancy from birth which would occur if all those who are currently obese were to obtain an 'optimal' BMI (defined as 24). The conclusion of Olshansky *et al.* is that life expectancy from birth would be between 0.21 and 1.08 years higher if obesity did not exist in the U.S.A., with the range reflecting different assumptions as to the typical BMI of an obese individual (and different values by black/white males/females). Olshansky *et al.* describe this estimate as conservative, owing to the rising prevalence of obesity amongst children and young adults which will translate into a higher risk of death amongst future middle aged and older populations. Whilst this is clearly of concern to those responsible for the future planning of state benefit systems (indeed, much of Olshansky *et al.*'s paper is dedicated to the impact on the SSA), it is likely to be of less concern to those who advise U.K. pension schemes, many of which are not open to benefit accrual for these younger adults. With such differing views, though, we should, perhaps, be alert to the risk of being overly pessimistic about the impact of obesity and unduly revising any minimum level of improvements downwards.

11.5.3.3 It is possible to use the estimated impacts of life expectancy, above, to assess very crudely what impact obesity might have in England & Wales, via the following formula:

$$\begin{aligned}\text{Reduction in } \textit{older age life expectancy} = {} & \text{Impact of obesity on U.S. national life expectancy} \\ & \div \text{ Proportion of U.S. population who are obese} \\ & \times \text{ Potential for new obese over 65s in the U.K.}\end{aligned}$$

The formula assumes that the impact of obesity on life expectancy is similar in the U.K. and in the U.S.A. — different lifestyles, health provisions and racial mix mean that this may not hold.

11.5.3.4 Using this approximation implies a potential reduction in *older-age life expectancy* of 1.5 years.[15] The analysis of Sections 5 and 6 can be repeated, with the gap between the underpinned projections and the extrapolated trend being allowed to close by 1.5 years over the period to 2050 (i.e. assuming that it will take until 2050 for all over 65 year olds to be obese). This suggests that the impact of obesity could be to reduce the level of

[15] i.e. 0.6 (the approximate mid-range reduction in life expectancy suggested by Olshansky *et al.*) *divided by* 30% (the proportion of adults in the U.S.A. who are obese — Olshansky *et al.* (2005)) *times* 75% (the potential rise in the proportion of the over 65 population who are obese from Figure 38, i.e. from 25% to 100%). Note that no allowance is made for the age profile of obesity in the U.S.A.

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minimum annual improvements in mortality by 0.5% for males. However, this, in isolation, is likely to be an overestimate, since it assumes that:

— most of the reduction in life expectancy from birth arises after age 65; and
— the current rising prevalence of obesity will lie unchecked, and that this will ultimately result in *all* over 65 year olds being obese.

11.6. *Socio-Economic Transition*

11.6.1 A *socio-economic transition* occurred during the 20th century, as the population became increasingly employed in skilled professions. Hicks & Allen (1999) quantify this migration. Between 1911 and 1991[16] the proportion of the occupied population of Great Britain who were classed as Social Class IV (partly skilled manual workers) fell from 39% to 22%, with a commensurate increase, 13% up to 32%, in Social Class II (managerial and technical). At the same time, the proportion of unskilled workers (Social Class V) fell from 10% to 6%, and the proportion of professional workers (Social Class I) increased from 1% to 5%. Hicks & Allen also illustrate that the majority of this migration through the social classes happened in the second half of the 20th century.

11.6.2 In the context of understanding trends in life expectancy and mortality, this is important — since higher socio-economic classes generally have longer life expectancy. This is a common trend around the world (see Riley, 2001), and is largely a result of:

— the middle classes typically being more welcoming of expert advice on health and welfare, and so early adopters of new practices; and
— the poorer sections of society often being the last to receive public and private investment.

Consequently, the analysis presented in earlier sections is likely to be confounding the impacts of general improvements in medicine and health care (the epidemiological and health transitions) with the changes in the socio-economic profile of the U.K.

11.6.3 The social class classification system has undergone a number of changes, including a current proposal to adopt the *National Statistics Socio-economic Classification* for use from 2001. This makes it difficult to draw direct comparisons at dates more recent than 1991. However, in 2001[17] approximately 20% of the population worked in semi-skilled or unskilled jobs (categorisations used by the Market Research and Marketing Industries, and broadly comparable to social classes IV and V).

11.6.4 The need for certain basic services means that there is limited

[16] Although some revisions were made to the official social class classifications during this time (see Rose (1995) for a history), these will not have impacted on the general trends.
[17] 2001 Census Table S066 — Sex and approximated social grade by age; obtained from Census Customer Services, ONS.

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scope for extensive continuation of the socio-economic transition, i.e. material further reductions in the proportion in semi-skilled and unskilled jobs. Further, pension schemes typically relate to a specific industry, where it is less likely that the membership will have exhibited a material socio-economic transition. Therefore, any element of historic trends which relates to the *socio-economic transition* is less likely to be seen within a specific pension scheme, and might justify the use of a lower level of minimum improvement.

11.7. *The Future is Ultimately Unpredictable*

11.7.1 Ultimately, any estimate of future longevity based on historic trends is no more than a reasoned guess.

11.7.2 The actual improvements may be considerably faster than suggested by historic trends. For instance, the life expectancy of Japanese women continued to defy expectations by experiencing large reductions in mortality rates amongst over 75 year olds during the 1990s, despite having relatively low mortality rates already (Richards *et al.*, 2007).

11.7.3 Improvements may also be considerably slower than history implies. For example, contrary to the U.S. Social Security Administration's (SSA) projections, rises in *older-age life expectancy* stalled for women in the 1980s and 1990s (Olshansky *et al.*, 2005).

11.7.4 In order to understand the plausibility of our models, it is essential, therefore, that we, as a Profession, have strong links with medical and health care experts to help to inform our understanding of the possibility for future improvement. In doing so, though, we need to be alert to the inherent uncertainty as to what scientific breakthroughs are possible in the next 50 or more years — many of the medical advances achieved over the last century would have been unimaginable to medical professionals and actuaries alike a hundred years ago.

12. Practical Considerations

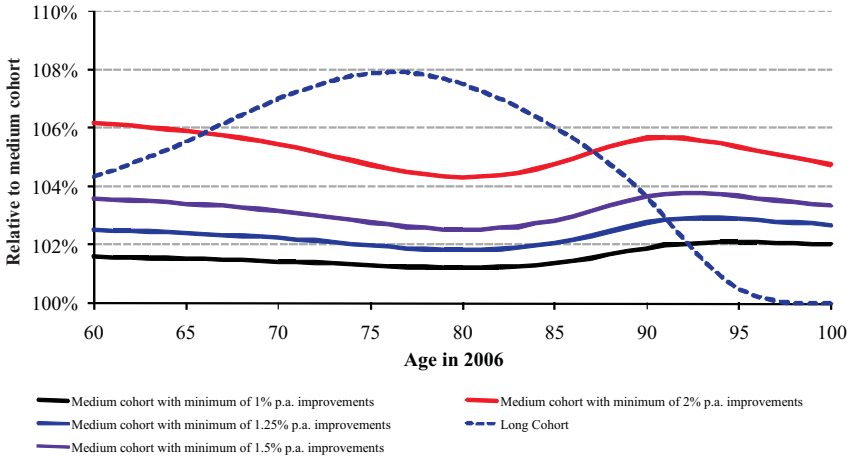
12.1 *The Impact on Pension Scheme Valuations*

12.1.1 Figures 33 and 34 illustrate how much more valuable a *valuation annuity* is — compared to a base line of the '92' pensioner amounts-based tables with medium cohort improvements — under a number of different levels of the minimum annual rate of improvement in mortality.[18] A *valuation annuity* is defined to be a single life annuity with an attaching reversionary annuity. Figures 33 and 34 are based upon the valuation of benefits for a male — the comparable figures for women are included in Appendix F.

12.1.2 The valuation annuities are based on a net discount rate of 2%,

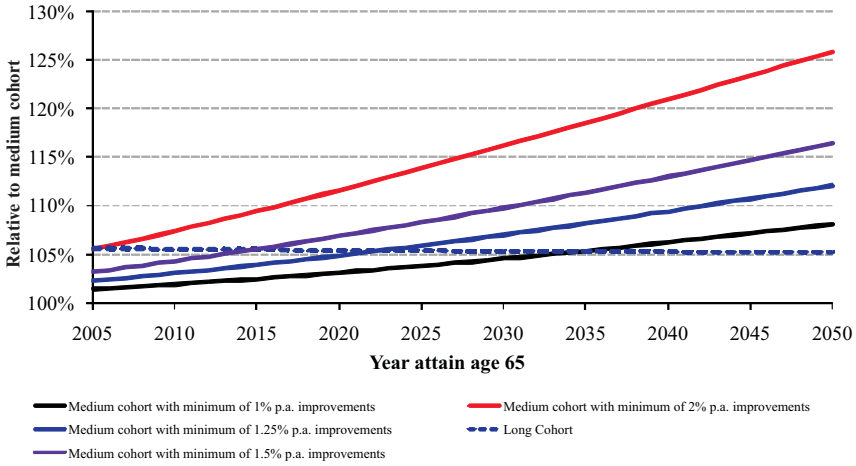
[18] For simplicity, the same minimum level of improvement has been applied to both males and females in generating Figures 39 and 40.

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Source: Own calculations

Figure 33. A comparison of (male) valuation annuities — current pensioners



Source: Own calculations

Figure 34. A comparison of (male) valuation annuities — future retirees

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the spouse's benefit is assumed to be 50% of the member's pension, 90% of members are assumed to be married, and men are three years older than their wives. A terminal age of 120 has been assumed throughout.

12.1.3 The decision as to the level of any minimum and the allowance for the cohort effect are separate considerations. However, for those members currently in receipt of benefits, applying a minimum of up to 2% p.a. to medium cohort improvements generally results in lower values than adopting a long cohort without a minimum (Figure 34). Applying a minimum to long cohort improvements would, however, produce higher annuity values still.

12.1.4 For future retirees, the impact of the minimum can be material on the value placed on their benefit promise. The decision of whether to apply a minimum, and, if so, at which level, is likely to be as material as the decision as to how long the cohort generation will experience accelerated improvements.

12.1.5 For example, looking at the 1.25% p.a. minimum identified when considering male improvements in Section 6, and applying this to medium cohort projections for both males and females, would, relative to just using medium cohort projections:

— increase the present value of benefit obligations by around 1% to 2% for pensioners and around 5% for actives and deferred pensioners;
— increase the cost of benefits accruing by around 5%;
— increase the transfer value of benefits (on an expected cost basis) by between 2% (for deferred members close to retirement) and 12% (for the youngest deferred pensioners);
— project defined contribution funds to give considerably lower pensions at retirement; and
— increase the duration of overall liabilities, potentially requiring adjustments to an LDI strategy which a scheme has in place.

Whilst these comments are based on Figures 33 and 34, which relate to males, we see an almost identical impact on valuation annuities for women (see Appendix F).

12.2 *The Lee-Carter and* P-*Spline Techniques*

12.2.1 CMI WP15 presented research into alternative projection methods, the Lee-Carter and the *P*-spline. In principle, these methods enable us to capture, more thoroughly, the trends in mortality rates at different ages and within generations. These new methodologies have the additional benefit of helping us, as a profession, to quantify the uncertainty around mortality projections and to communicate this with our clients.

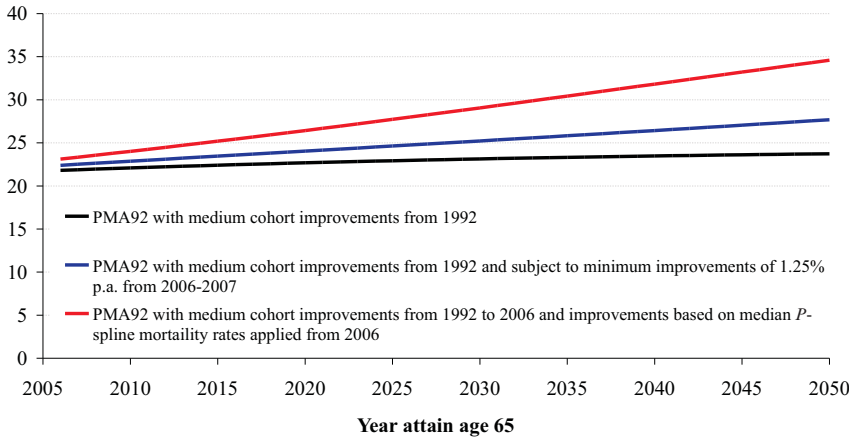
12.2.2 Currently, software has been made available by the CMI to actuaries to start to use the *P*-spline method. Just prior to the completion of this paper, the CMI also published working software for carrying out

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mortality projections using the 'Lee-Carter' method. The parameterisation of these models is ultimately the responsibility of individual actuaries. For larger consultancies with a research budget, it may be viable to investigate the sensitivity of the model to these parameters, whilst independent actuaries are likely to be reliant on research published via the Institute and the Faculty, the CMI or the Staple Inn Actuarial Society — and, in particular, the CMI's library of projections (published in CMI WP27, subsequent to the presentation of the material in this paper).

12.2.3 In light of the likelihood that these new techniques will become more widely used over the next few years, we should be cognisant of the life expectancy values which these techniques might produce. In particular, if we are to introduce minima to mortality improvements now, which, in itself, is likely to result in material increases in liability values, then we need to be aware of whether or not it is likely that the new techniques will result in further increases, or, indeed, if using minimum improvements may be overstating life expectancies (and so, in turn, benefit valuations).

12.2.4 Figure 35 shows how the medium cohort projections allow for only very modest improvements in future (cohort) life expectancy from age 65. The figure contrasts this with the life expectancies when a minimum is imposed on the mortality improvements, and with an illustrative *P*-spline



Source: Own calculations using CMI software and male dataset
P-spline improvements are based upon age-cohort projections, using the entire male assured lives dataset for the period 1947-2003 and parameters: porda = 2, dxa = 5, posa = 60, pordy = 5, dxy = 5, posy = 1943, bdeg = 3, forecast = 100.

Figure 35. Cohort life expectancy from age 65 under a variety of projection methods

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projection.[19] The *P*-spline projection is referred to as a median projection, as it represents the 50th percentile projection for mortality rates generated using the CMI's illustrative software — for further details on the construction of these projections see CMI WP27, CMI WP20 and CMI WP15.

12.2.5 The life expectancies under the medium cohort projections are considerably below those under the illustrative *P*-spline projections, although part of this difference will be due to the *P*-spline projections, reflecting the faster increases in the higher socio-economic classes prevalent in the CMI assured lives dataset. Further, simply introducing a minimum level to existing projection methodologies, actuarial calculations give life expectancies (and so annuity values) considerably lower than under the illustrative *P*-spline projection.

12.2.6 It is important, therefore, that, as a profession, we understand the relative merits of the different projection methodologies available — and *why* different methods produce considerably different answers. It also serves as a timely reminder of the need to communicate the uncertainty of future mortality to our clients when we are assisting them in choosing assumptions — since not to do so would leave the Actuarial Profession vulnerable to (further) criticism in the future. To this end, whilst this paper seeks to inform the debate on whether to apply a minimum to mortality improvements, and, if so, what level of minimum might be justifiable, it is important that our advice makes use of other projection methods (such as the *P*-spline and Lee-Carter methods) which are able to quantify the financial impact of this uncertainty for our clients.

12.3 *Other Considerations*

12.3.1 A question which I am often asked is from when the minimum improvements should be applied. In the context of the work presented here, the improvements have been assumed to start from 2006, to reflect the first

[19] In generating these illustrative projections, I have set the improvements at ages over 95 at the same value as predicted at age 95. I have done this because of the sparseness of the data in the CMI dataset for ages over 95 and the impact which this can have on the projected mortality curves. In particular, the CMI males dataset exhibits a phenomenon dubbed as 'old men are like fruit flies', in that raw mortality rates seem to reach a peak for males when they reach their mid 90s. The analogy arises from the fact that fruit flies reach a peak in mortality rates in mid-life. Although this effect might be a systematic data error rather than a true feature of male mortality, the *P*-spline projections detect the effect and project it into the future, resulting in 'humped' mortality curves. Although methods exist to avoid this (see, for example, Richards *et al.*, 2007), the methods require careful consideration of what, if any, terminal age and limiting mortality rates exist — as such, a full discussion is beyond the scope of this paper. However, it should be noted that the *P*-spline projections are sensitive to the method adopted, since they predict that a considerable percentage of 65 year olds will survive to age 95. Different methods explored by the author give a range of life expectancies (under median projections) from age 65 of between 31.4 and 37.2 years for males, i.e. always in excess of the underpinned medium cohort projections illustrated in Figure 35.

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valuation date to which they might be applied (see ¶5.4.1). In principle, the improvements can be applied from any year. However, if minimum improvements are applied to historic years, this should be taken into consideration when deriving the 'base table' (i.e. the table designed to reflect current mortality prior to any allowance for future improvements).

12.3.2 By suggesting that projections of mortality improvements should be subject to a minimum value, this paper is advocating an approach which, over time, reverts to a simple geometric model for improvements. Under such a model, the mortality rates ultimately tend (albeit very slowly) to zero at all ages, a feature with which some readers may have concern. In practice though, a modest level of improvement of 1.25% p.a. results in mortality rates halving once every *55 years* (and every 47 years at improvements of 1.5% p.a.). This means that even the youngest members of U.K. pension schemes are predicted to experience mortality rates no less than a quarter of current rates.

12.3.3 In Figure 23 we saw the survival curve from retirement at age 65 for an individual born in 1985 under a number of projection bases. Unsurprisingly, the introduction of minimum improvements causes further *rectangularisation* (concentration of mortality in the last years of life) — and, if borne out in practice, is likely to find the Actuarial Profession questioning the biblical terminal age of 120, as centenarians become increasingly common.

12.3.4 This is not to say that mortality improvements will not ultimately slow as we approach any limits which may exist. Indeed, the author is currently of the view that mortality improvements will ultimately slow down as we approach some limit to our capabilities of extending survival — either through the frailty of the human body or through prohibitive costs. However, mortality improvements are currently not slowing, and it seems unlikely that we will reach a limit to longevity within the lifetimes of existing members of pension schemes, i.e. the 21st century. This sentiment is echoed in Willets *et al.* (2004), where the authors write:

> "It is impossible to argue that we are close to hitting some kind of biological barrier that is going to prevent future improvements"

Consequently, I imagine that many trustees, concerned with using a 'prudent best estimate', would currently prefer to use a model which did not impose any lower limit to mortality rates, albeit that, over extended periods of time, it may predict very low death rates.

13. Conclusions

13.1 The analysis of Sections 5 to 7 suggests that, in order for projections to mirror long-term trends in England & Wales life expectancy (from age 65),

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the *annual rate of improvements in mortality* should be subject to a minimum of:

— 0.75% p.a. for females; and
— between 1.25% p.a. and 1.5% p.a. for males.

13.2 A higher minimum is likely to be necessary if:

— trustees or sponsors are seeking an assumption whereby improvements continue at the most recent levels;
— it is desired to maintain a constant ratio to life expectancies; for example, higher social classes are 'early adopters' of new health practices, and typically experience life expectancies which are 10% to 20% longer than the population as a whole; and
— the resulting assumption is to be described to be prudent in terms of national trends.

13.3 The minima suggested above represent a broad average of the historic level of improvements at the ages most critical to projections of *older-age life expectancy*; however, mortality improvements have a clear age and time dependency. This means that the use of any minimum is a pragmatic solution to an issue with existing projections, and the approach could be refined by using a minimum which varies with age.

13.4 Some factors which have influenced historic improvements may reasonably be expected to continue for some time (e.g. medical improvements), whilst others (such as the social-economic transition) may not occur so significantly in future, if at all (especially within occupational pension schemes).

13.5 Applying a minimum of 1.25% p.a. for men and women alike would increase the present value of benefit obligations by around 1% to 2% for pensioners and around 5% for actives and deferred pensioners, compared to using medium cohort projections without any minimum level of improvement.

13.6 I would hope that this paper encourages the use of some level of minimum improvement in mortality projections. Ultimately, any estimate of future longevity based on historic trends is no more than a reasoned guess, and experience will inevitably differ from these predictions. As such, it is important that, whatever projections we use ultimately, the uncertainty therein is conveyed to the recipients of our advice.

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APPENDIX A

A SUMMARY OF THE '92' SERIES PROJECTIONS AND THE INTERIM COHORT PROJECTIONS

A.1 *Original '92' Series Projections*

A.1.1 The '92' series of tables was first published in Continuous Mortality Investigation Reports (CMIR) Numbers 16 and 17 in 1998 and 1999 respectively. In CMIR 17 details were published of associated projections of how mortality might improve with the passage of time. The projection factors were designed to be used with the '92' series tables for pensioners, immediate annuitants, retirement annuitants and widows alike. The same projection factors were to be used with both the male and the female tables and on a lives and an amounts basis.

A.1.2 The '92' series projections assume that mortality rates at ages:

— over 80 could only halve compared to values in 1992 (or more precisely fall to 47.8% of 1992 values);
— over 90 could drop by no more than a third compared to values in 1992 (or more precisely fall to 65.2% of 1992 values); and
— 110 and over had already reached their natural limit in 1992.

A.1.3 Further, the '92' series projection model assumes that:

— at each age the rate of mortality decreases exponentially to a limiting value (i.e. at every age there is a non-zero rate of mortality beyond which further improvements are not possible); and
— the speed of convergence to the limit varies by age. A significant proportion of the fall in mortality rates (rising linearly from 29% at age 110 to 55% at age 60) happens in the first 20 years.

Figure A.1 illustrates the model graphically.

A.1.4 It is important to note that a consequence of this methodology is that the *annual rate of improvement in mortality* declines with time, with asymptote zero.

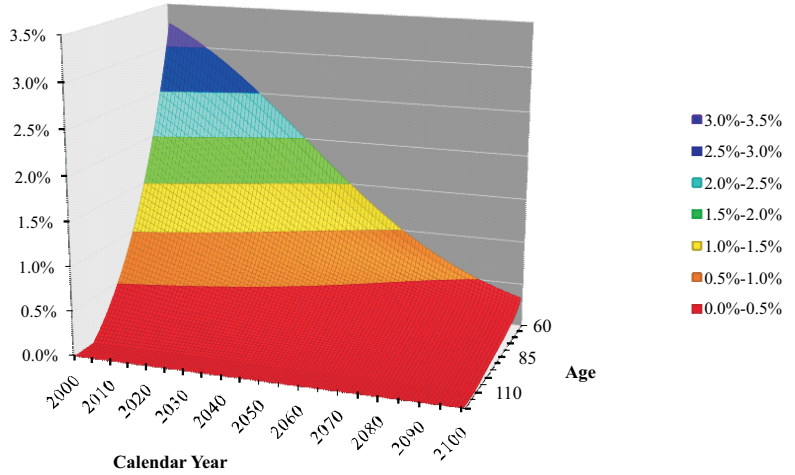
A.1.5 The weighting towards improvements occurring within the first 20 years means that, as we approach 2012, so the rate of future improvement contained with '92' series tables *declines rapidly*. Crucially, this continues to apply when using the interim cohort projections — see below.

A.2 *The Interim Cohort Projections*

A.2.1 In 2002 the CMI introduced, in CMI WP1, a set of interim projections for improvements in mortality rates known as the *interim cohort projections*. These projections were published in response to:

— an analysis of the experience of various CMI investigations;
— the recent population projections produced by the GAD; and

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Source: Own calculations and CMIR 17

Figure A.1. Annual rates of mortality improvement under the '92' series projections

— the paper by Willets (1999).

A.2.2 All of these provided evidence for a 'cohort effect', whereby a generation of people born broadly between the two World Wars is surviving in greater numbers to an older age than previously expected. Observations of this phenomenon led both the GAD (see GAD, 2001) and the CMI to revisit previous projections as to how mortality rates would improve in future years. A number of reasons are cited for the inter-war generation experiencing such rapid improvements, including:

— the introduction of the welfare state and, particularly, of the NHS;
— the first generation to benefit from the wide-spread use of antibiotics;
— the 'cabbage and carrots' lifestyle of the years immediately post World War II; and
— the decline in smoking being most rapid amongst this generation.

For a more detailed analysis of the cohort effect in population data see Willets (2004), and for the assured lives data see CMI WP1 and CMI WP2.

A.2.3 In formulating its revised projection factors, the CMI looked at the data which it held on the experience of assured lives and of life office pensioners. The model adopted by the CMI was to adjust the *annual rates of improvement in mortality* in the '92' series projections as follows:

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— Increased rates apply for a '*cohort*' born between 1910 and 1942, centred on 1926 (the width of this cohort being derived from the 'loyal office' pensioner data).
— Increases apply for the longest time to those born in the centre of the 'cohort'.
— Increased rates are to be in line with the experience of the 'all office' pensioner lives data from 1993 to 1999 (equal to the actual annual rate of improvement in mortality, based on mortality rates graduated to the experience data).
— From 2001, these increased rates are assumed to reduce linearly, ending for those born at the centre of the 'cohort' at a point known as the *end of the cohort period*.

A.2.4 The CMI published three illustrative values for the *end of the cohort period*, known as the *short cohort* (ending in 2010), the *medium cohort* (ending in 2020) and the *long cohort* (ending in 2040). Taking into account when these projections were published and that the cohort in question will be centenarians in 2040, one could interpret the projections as:
— *short cohort*: immediate tailing off of the cohort effect;
— *medium cohort*: a 'middle of the road' estimate; and
— *long cohort*: an assumption that we will continue to see accelerated improvements for near enough every year of life for the 1926 generation.

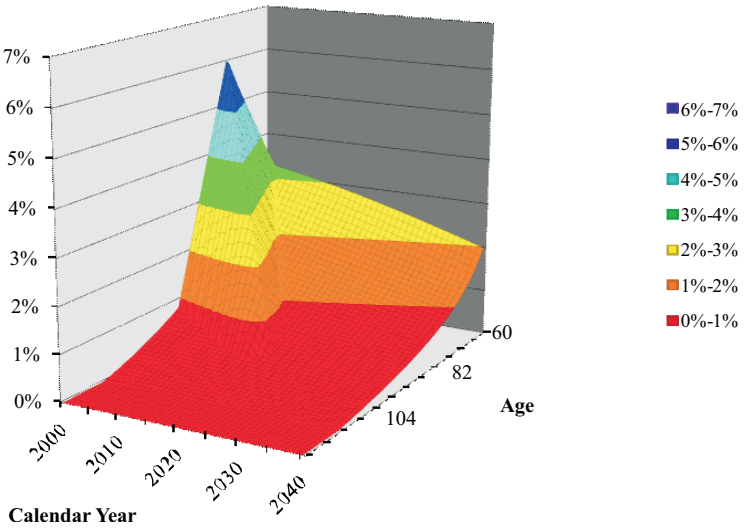
Figure A.2 illustrates the medium cohort improvements.

A.2.5 It is important to realise that CMI WP1 was published as work in progress — in particular, the paper makes it clear that it represented work done, and judgements made by the authors rather than by the Actuarial Profession.

A.2.6 Under the interim cohort projections, subsequent generations inherit the lower mortality rates and increased life expectancy from the cohort generation. This reflects the fact that the later generations also benefit from most of the factors believed to have driven the cohort effect (e.g. the existence of the NHS). However, the rapid and accelerating improvements seen during the 1990s are also assumed to have peaked in 1999, and from 2001 decline back to the improvements suggested by the original '92' series projections, i.e. the cohort projections ultimately rely upon the original '92' series projections to factor in a best estimate of ongoing general (period) improvements in life expectancy.

A.2.7 The CMI model differs from the cohort model adopted by the GAD in population projections. This is because the national population data show a concentration of the cohort effect around those born in 1931, and asymmetrically so (with relatively few birth years prior to 1931 impacted by the cohort effect compared to those after 1931). Since the membership of a typical U.K. pension scheme may share more in common with the national

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Source: Own calculations and data published in CMI WP1

Figure A.2. Annual rates of mortality improvement under the '92' series interim cohort projections (medium cohort)

population than with the life office pensioners on whom the cohort projections are based, there is potential for the cohort effect to have a delayed impact on pension schemes.

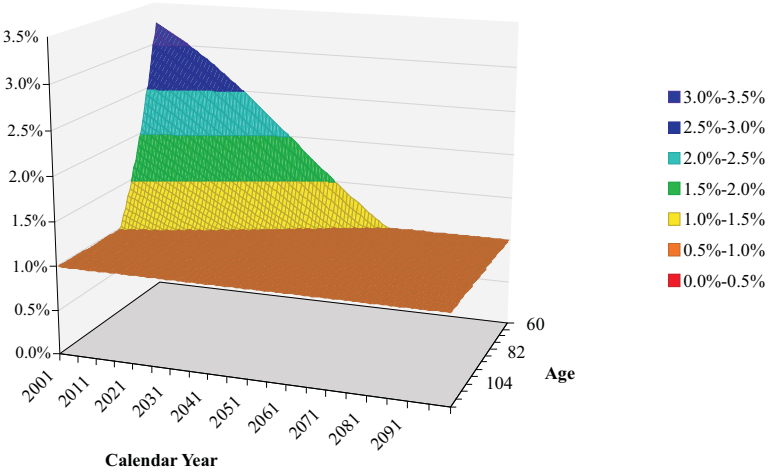
A.2.8 For actuaries advising on the post-retirement mortality assumptions to be used in funding defined benefit pension schemes, the author is firmly of the belief that the above paragraphs are important points — especially given the requirement that technical provisions be calculated with reference to prudent mortality assumptions.

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APPENDIX B

ILLUSTRATIONS OF APPLYING A MINIMUM TO PROJECTIONS OF MORTALITY IMPROVEMENTS

B.1 *Applying the Underpin to the Original '92' Series Projections*

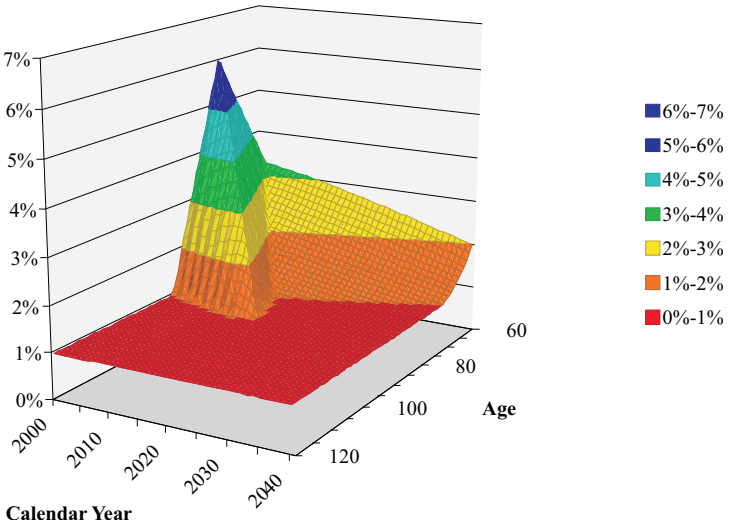


Source: Own calculations and CMIR 17

Figure B.1. Annual rates of mortality improvement under the original '92' series projections with an underpin of 1% p.a. at all ages

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B.2 *Applying the Underpin to the Interim Cohort Projections*



Source: Own calculations and data published with CMI WP1

Figure B.2. Annual rates of mortality improvement under the '92' series interim cohort projections (medium cohort) with an underpin of 1% p.a.

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APPENDIX C

STATISTICAL MEASURES FOR THE FITTED TRENDS

The tables below summarise key statistical measures for each of the trends fitted in the main body of this paper. The last three columns look at a number of statistical tests to see if the results are consistent with the data having come from the fitted trend line up to random noise.

Table C.1. Summary of functional forms fitted for females for a selection of different older ages

Analysis	Functional form	Parameters	Coefficient of determination	Signs test	Grouping of signs test
Female life expectancy (from 65, all data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 11.50, \beta = 0.07562, T = 1907$	97.6%	0.23	−2.90
Female life expectancy (from 65, pre 1996 data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 11.49, \beta = 0.07231, T = 1906$	97.1%	−0.56	−1.98
Female life expectancy (from 55, pre 1996 data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 17.46, \beta = 0.09358, T = 1899$	98.1%	−1.04	−3.21
Female life expectancy (from 60, pre 1996 data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 14.30, \beta = 0.08185, T = 1901$	97.7%	−0.08	−1.36
Female life expectancy (from 70, pre 1996 data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 9.06, \beta = 0.06480, T = 1914$	96.2%	−0.72	−3.58
Female life expectancy (from 80, all data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 5.35, \beta = 0.04548, T = 1932$	93.9%	−0.08	−2.90
Female life expectancy (from 90, all data)	$\alpha + \max(0, \beta(t - T))$	$\alpha = 3.08, \beta = 0.01963, T = 1941$	81.8%	0.86	−1.92

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Table C.2. Summary of functional forms fitted for males for a selection of different older ages

Analysis	Functional form	Parameters	Coefficient of determination	Signs test	Grouping of signs test
Male life expectancy (from 65, all data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 10.64$ $T_0 = 1909$ $\beta = 0.03570$ $T_1 = 1948$ $\gamma = 12.03$ $T_2 = 1974$ $\delta = 0.1404$	94.7%	0.08	−2.95
Male life expectancy (from 65, pre 1996 data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 10.64$ $T_0 = 1909$ $\beta = 0.03512$ $T_1 = 1948$ $\gamma = 12.01$ $T_2 = 1974$ $\delta = 0.1128$	91.1%	−0.56	−1.98
Male life expectancy (from 55, pre 1996 data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 16.19$ $T_0 = 1901$ $\beta = 0.05399$ $T_1 = 1948$ $\gamma = 18.73$ $T_2 = 1971$ $\delta = 0.1507$	94.0%	0.88	−3.90
Male life expectancy (from 60, pre 1996 data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 13.29$ $T_0 = 1904$ $\beta = 0.04308$ $T_1 = 1947$ $\gamma = 15.12$ $T_2 = 1971$ $\delta = 0.1271$	92.4%	−0.24	−3.29
Male life expectancy (from 70, pre 1996 data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 8.33$ $T_0 = 1915$ $\beta = 0.02390$ $T_1 = 1965$ $\gamma = 9.52$ $T_2 = 1975$ $\delta = 0.1008$	88.7%	−1.20	−0.27

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Table C.2. (Continued)

Analysis	Functional form	Parameters	Coefficient of determination	Signs test	Grouping of signs test
Male life expectancy (from 80, all data)	$LE_{men}(t) = \begin{cases} \alpha & t < T_0 \\ \alpha + \beta(t - T_0) & T_0 \le t \le T_1 \\ \gamma & T_1 \le t \le T_2 \\ \gamma + \delta(t - T_2) & T > T_2 \end{cases}$	$\alpha = 4.79$ $T_0 = 1933$ $\beta = 0.01899$ $T_1 = 1982$ $\gamma = 5.72$ $T_2 = 1983$ $\delta = 0.07204$	88.4%	−0.23	0.10
Male life expectancy (from 90, all data)	$\alpha + \max(0, \beta t(t - T))$ (see note 4)	$\alpha = 2.77$ $T = 1958$ $\beta = 0.01823$	62.9% (see note 5)	0.86	−1.35

Notes

(1) The coefficient of determination is a measure of goodness of fit where a perfect fit returns 100%.

(2) The signs test is a simple test for overall bias in a trend line. It caters for the fact that it is possible for a least squares approach to fit a trend line which is consistently above or below the actual data, owing to a small number of outliers. The value represents the (normalised) number of times the trend line lies above the actual data, and should be compared to the standard normal distribution when deciding whether or not to reject the null hypotheses that the trend line has no overall bias.

(3) The grouping of signs test considers whether, even if there is no overall bias in the trend, there are periods of consistent understating or overstating of the data. The test statistic is the number of distinct such periods, and considers if this is too few for the number of distinct data points (i.e. whether the true data follows the trend line up to noise). The test statistic should be compared to the lower tail of a standard normal distribution.

The fitted trends generally perform badly against this test, and would fail at most confidence levels. This is not surprising, as a premise of this statistical test is that noise about the central trend line is random. However, when fitting to period life expectancies, we might anticipate 'clumping' of the positive and negative deviations — for example, lower life expectancies in periods when winters are particularly harsh, when particular epidemics strike (e.g. influenza in 1918-1919) or during times of conflict (e.g. the Blitz years of 1940-41).

This is also consistent with the observation given in Section 5 that the fitted trend tends to be below the data points over the last couple of decades, i.e. female period life expectancy is currently increasingly more rapidly that the prevailing trend over the 20th century.

Further, this is, in many ways, a 'closeness of fit' measure, in that it ensures that the curve passes between the points. Since the approach in this paper is to adopt a pragmatic approach of looking at general overall trends, it is unsurprising that we have 'undergraduated'.

(4) Although the more complex model used for males was fitted to the male life expectancy from age 90, the least squares fitting reduced it to the simpler model used for females.

(5) Prior to the 1950s very few men reached the age of 90. This results in considerable volatility in the life expectancy of males from age 90 and a low coefficient of correlation.

APPENDIX D

AGES OTHER THAN 65

D.1 *Introduction*

D.1.1 Throughout this paper I have focussed on *older-age life expectancy*, defined as the life expectancy from age 65. This a reasonable proxy to life expectancy for future pensioners (who typically retire at 65), and so to those lives for whom future improvements have the greatest impact. However, it is important also to consider projections of period life expectancy from other ages.

D.1.2 The trend lines fitted to the historic England & Wales data, along with the results of identifying the level of minimum improvement (or 'underpin') needed for the projection of the '92' series to mirror the extrapolation of the trend lines, are illustrated in Figures D.1 to D.18 for ages 55, 60, 70, 80 and 90. Where:

— two underpin values are illustrated, the lower value is designed to *broadly* maintain the absolute difference between life expectancies, whilst the higher value is the ratio of life expectancies;
— one value is shown; it is the closest match for *broadly* maintaining both the absolute difference between life expectancies and the ratio of life expectancies; and
— a range was given for the underpins in Section 10 (e.g. 0.5% p.a. to 0.75% p.a. to maintain a constant difference at age 70 for females), the lower end of the range for maintaining the absolute difference and the upper end of the range for maintaining the ratio of life expectancies have been plotted.

In all cases the comparisons are made against the '92' series amounts-based pensioner tables projected forward with '92' series improvements.

D.1.3 For all historic graphs in this Appendix (odd numbered figures) the source is my own calculations using data from HMD (2006). All graphs showing projections of mortality from 2006 (even numbered figures) are based on my own calculations.

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D.2 *Age 55*

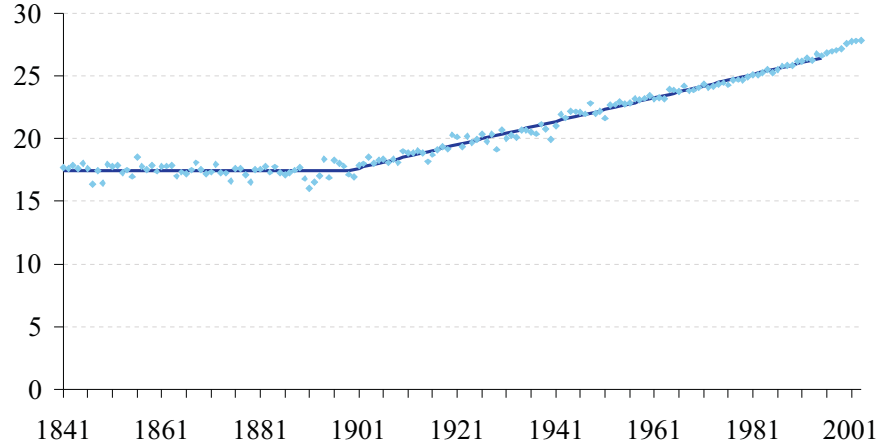


Figure D.1. Trend in female life expectancy from age 55

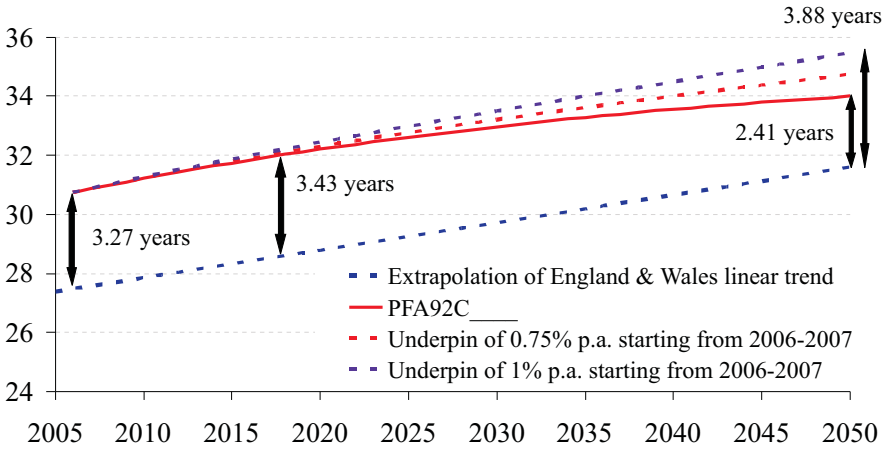


Figure D.2. Projected changes in female life expectancy from age 55 over time

No graphs are shown for male life expectancy from age 55, as the period of time over which the current increases in life expectancy occur, but which is prior to the potential distortions of the cohort effect, is too short to be reliable for extrapolation.

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D.3 *Age 60*

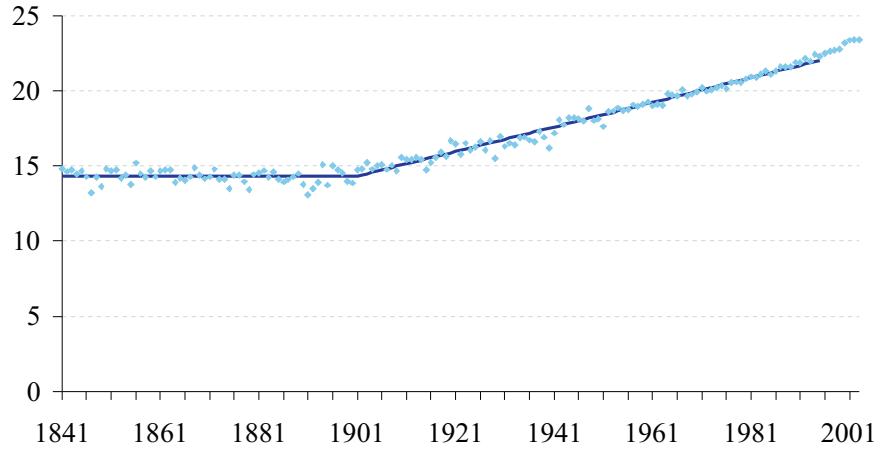


Figure D.3. Trend in female life expectancy from age 60

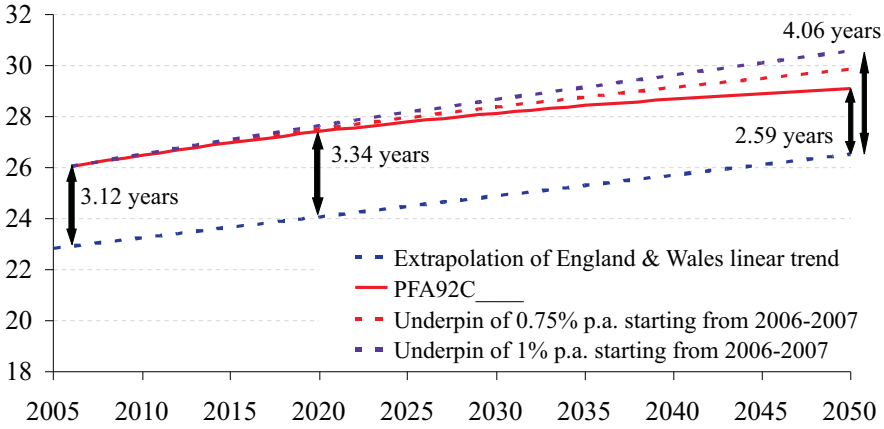


Figure D.4. Projected changes in female life expectancy from age 60 over time

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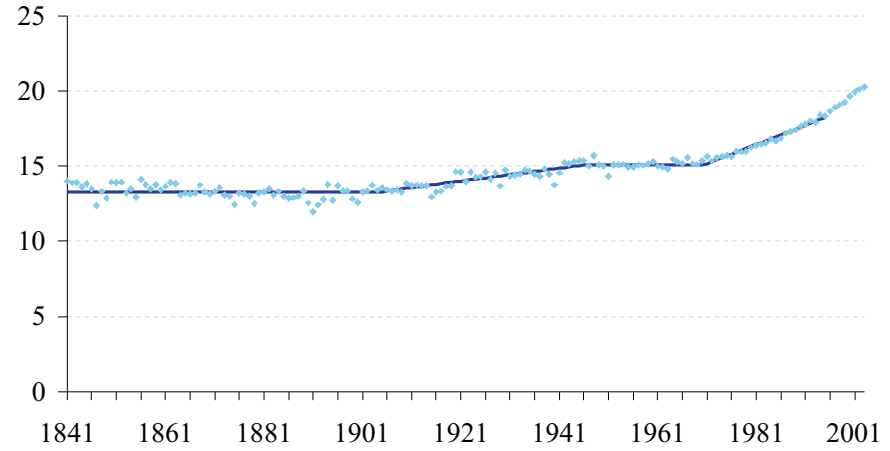


Figure D.5. Trend in male life expectancy from age 60

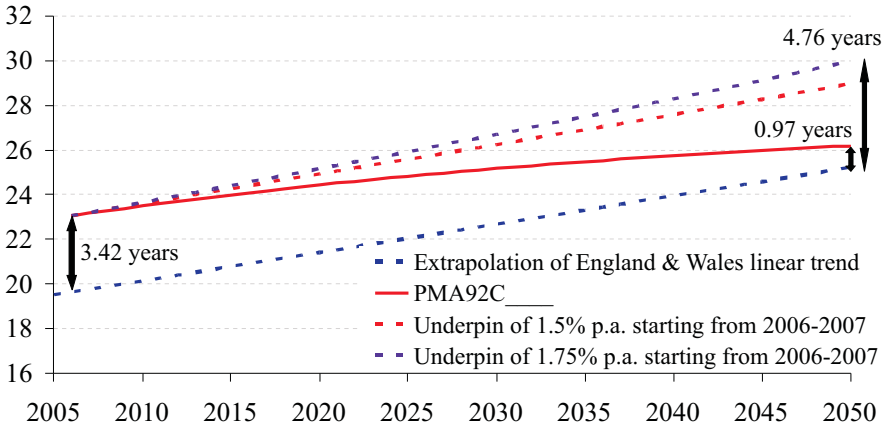


Figure D.6. Projected changes in male life expectancy from age 60 over time

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D.4 *Age 70*

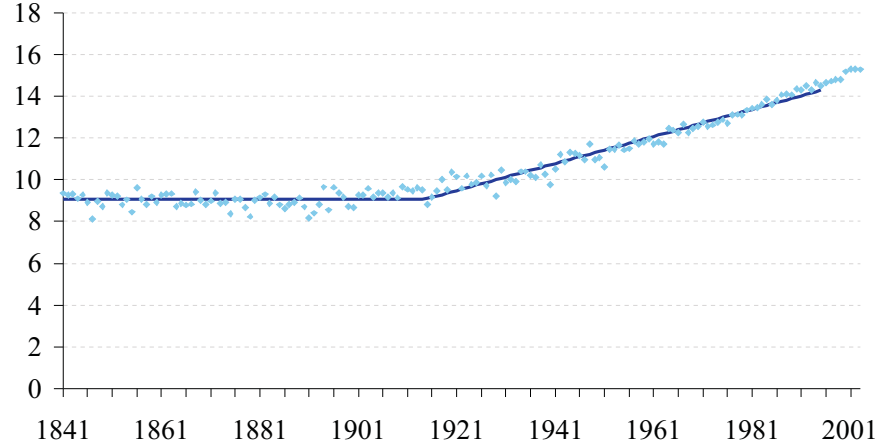


Figure D.7. Trend in female life expectancy from age 70

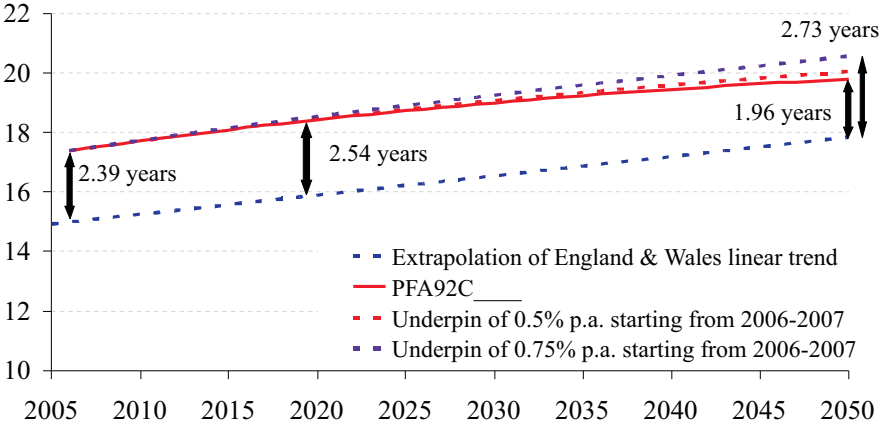


Figure D.8. Projected changes in female life expectancy from age 70 over time

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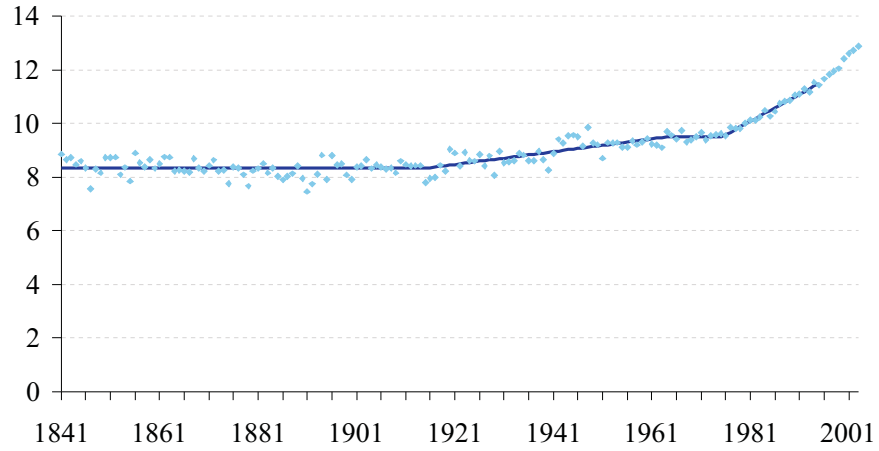


Figure D.9. Trend in male life expectancy from age 70

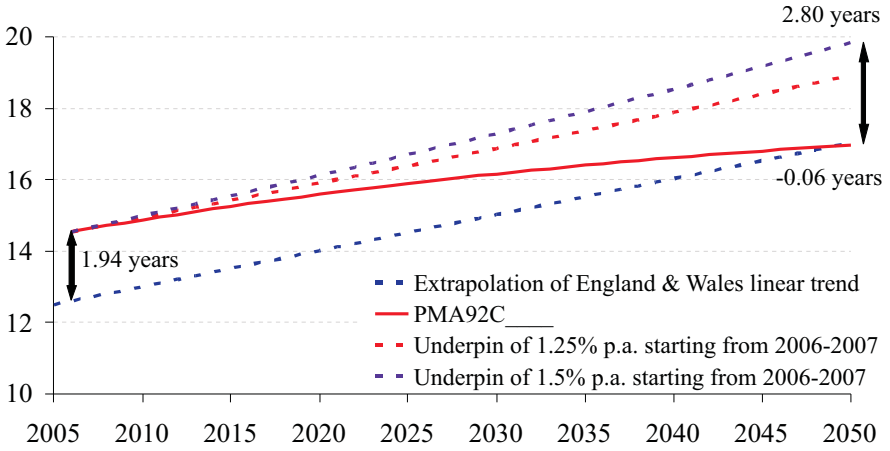


Figure D.10. Projected changes in male life expectancy from age 70 over time

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D.5 *Age 80*

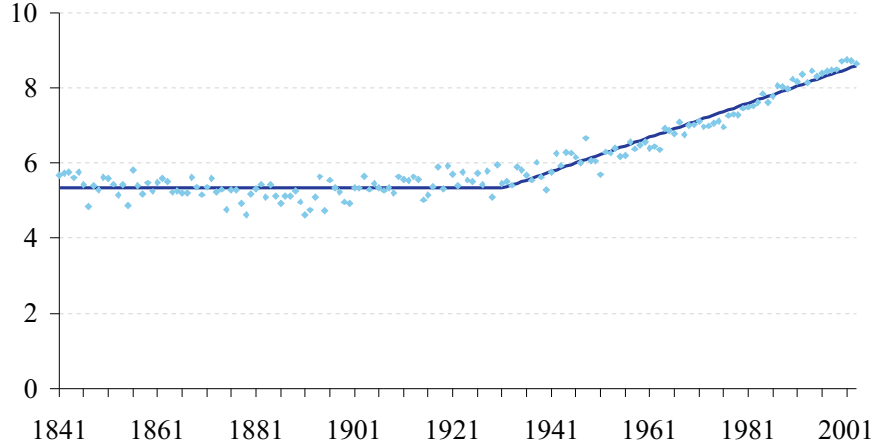


Figure D.11. Trend in female life expectancy from age 80

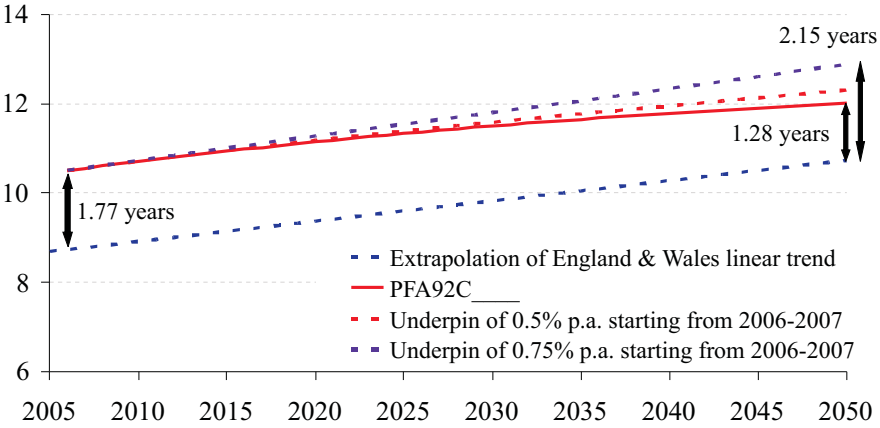


Figure D.12. Projected changes in female life expectancy from age 80 over time

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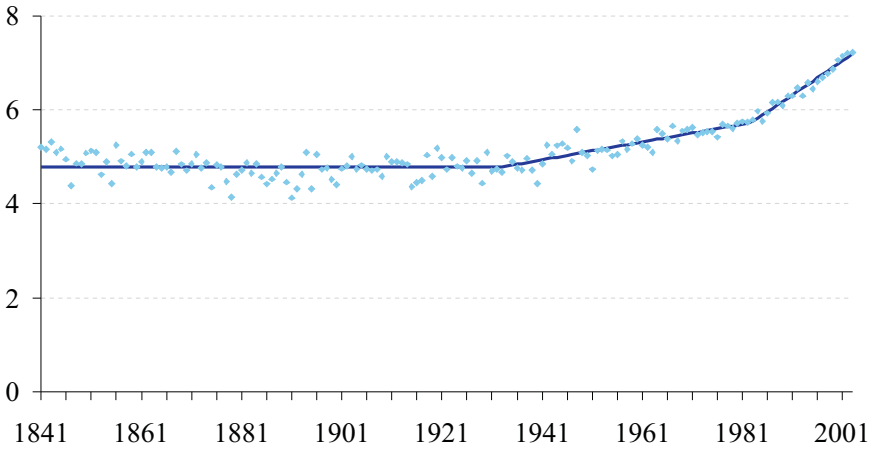


Figure D.13. Trend in male life expectancy from age 80

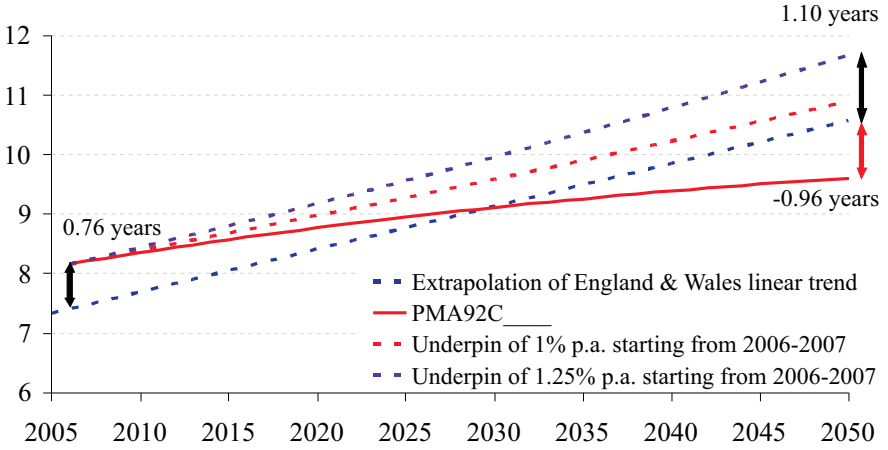


Figure D.14. Projected changes in male life expectancy from age 80 over time

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D.6 *Age 90*

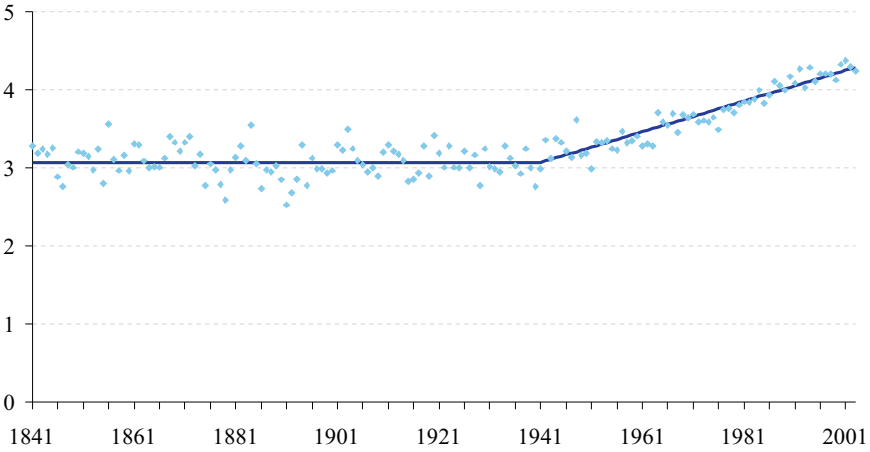


Figure D.15. Trend in female life expectancy from age 90

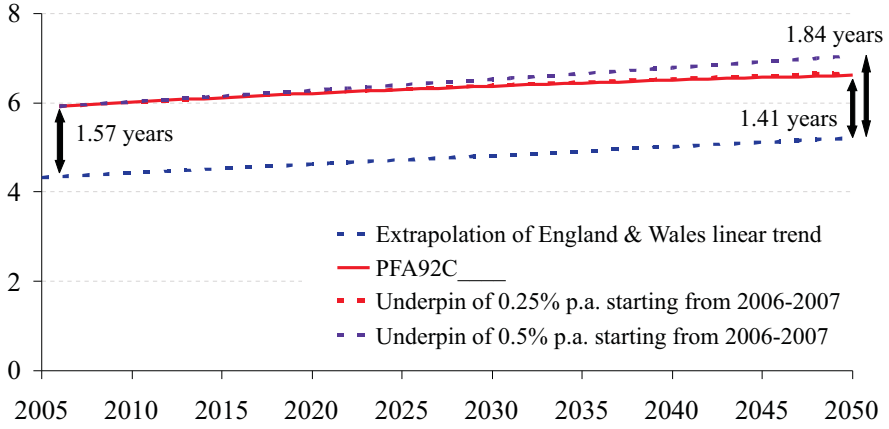


Figure D.16. Projected changes in female life expectancy from age 90 over time

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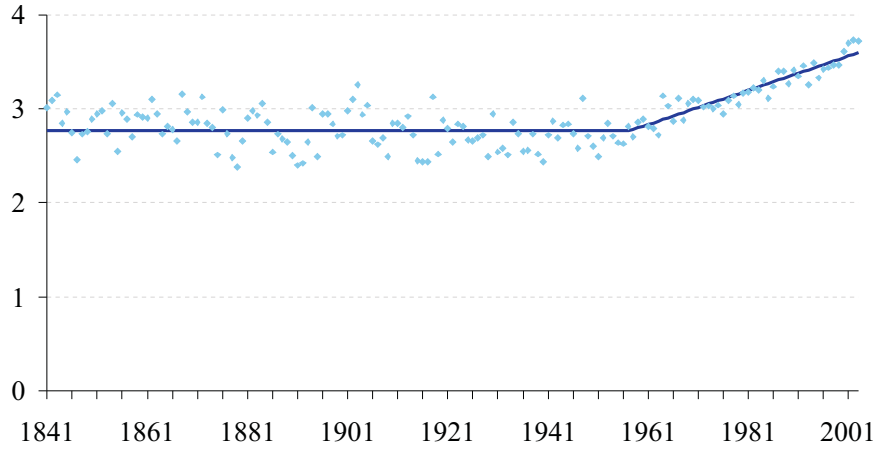


Figure D.17. Trend in male life expectancy from age 90

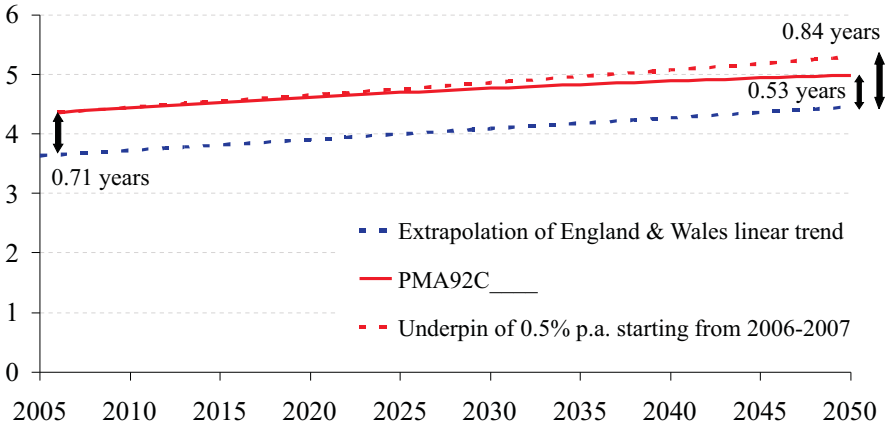


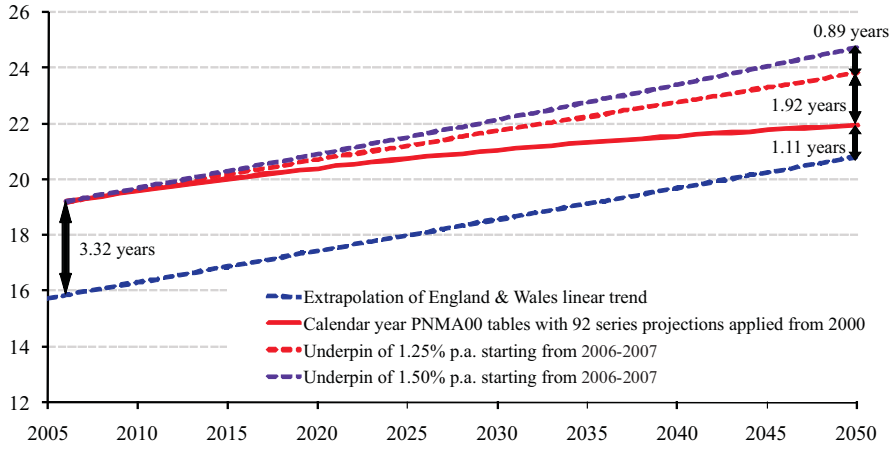
Figure D.18. Projected changes in male life expectancy from age 90 over time

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APPENDIX E

ADDITIONAL PROJECTIONS USING THE '00' SERIES OF TABLES

E.1 *Males — Amounts Basis*

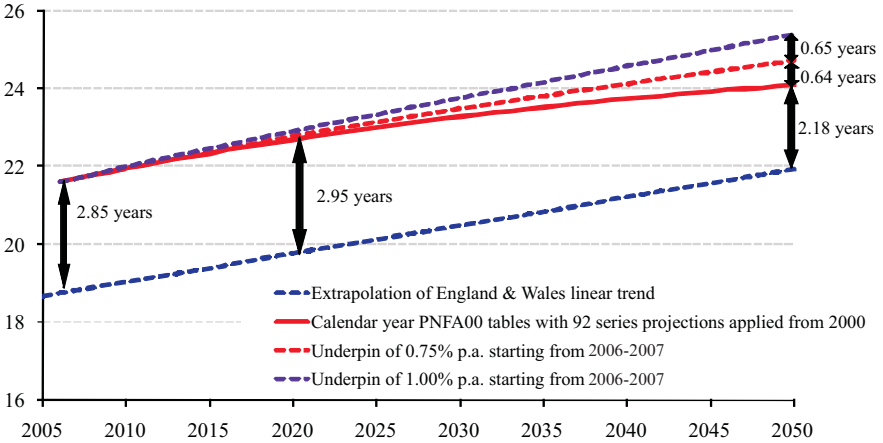


Source: Own calculations based on data in CMI 17 and CMI WP 22

Figure E.1. Projected changes in male life expectancy from age 65 over time (comparison with '00' amounts-based series projected using the '92' series improvements)

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E.2 *Females — Amounts Basis*

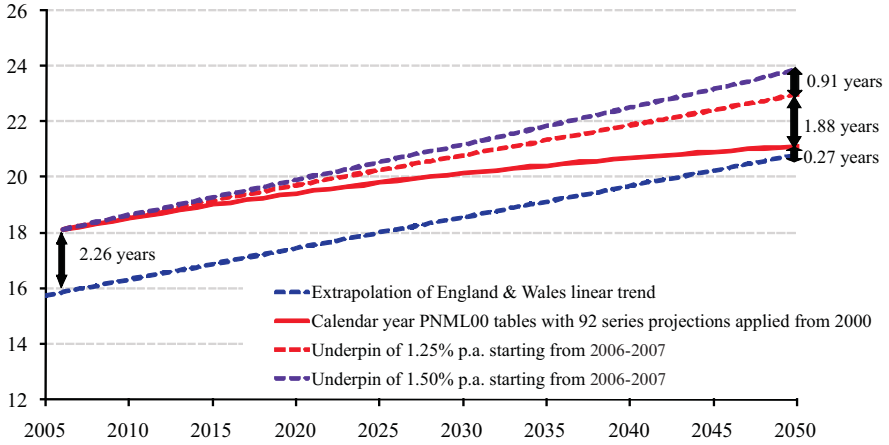


Source: Own calculations based on data in CMI 17 and CMI WP 22

Figure E.2. Projected changes in female life expectancy from age 65 over time (comparison with '00' amounts-based series projected using the '92' series improvements)

https://doi.org/10.1017/S1357321700001513 Published online by Cambridge University Press

E.3 *Males — Lives-Based Tables*

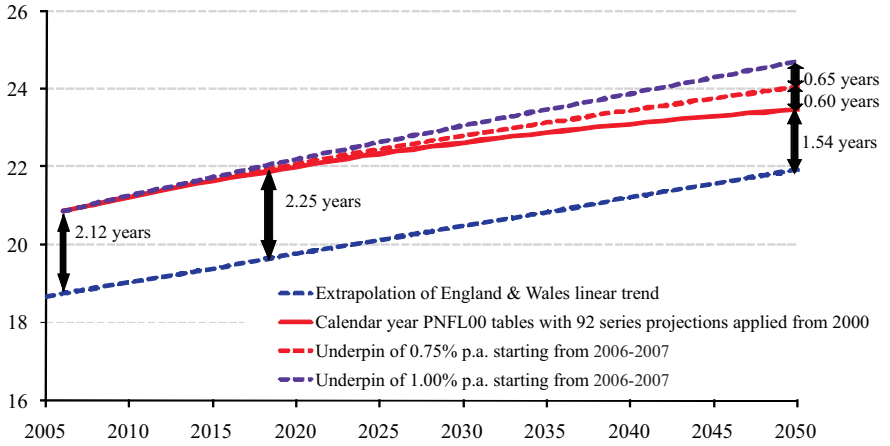


Source: Own calculations based on data in CMI 17 and CMI WP 22

Figure E.3. Projected changes in male life expectancy from age 65 over time (comparison with '00' lives-based series projected using the '92' series improvements)

https://doi.org/10.1017/S1357321700001513 Published online by Cambridge University Press

E.4 *Females — Lives-Based Tables*



Source: Own calculations based on data in CMI 17 and CMI WP 22

Figure E.4. Projected changes in female life expectancy from age 65 over time (comparison with '00' lives-based series projected using the '92' series improvements)

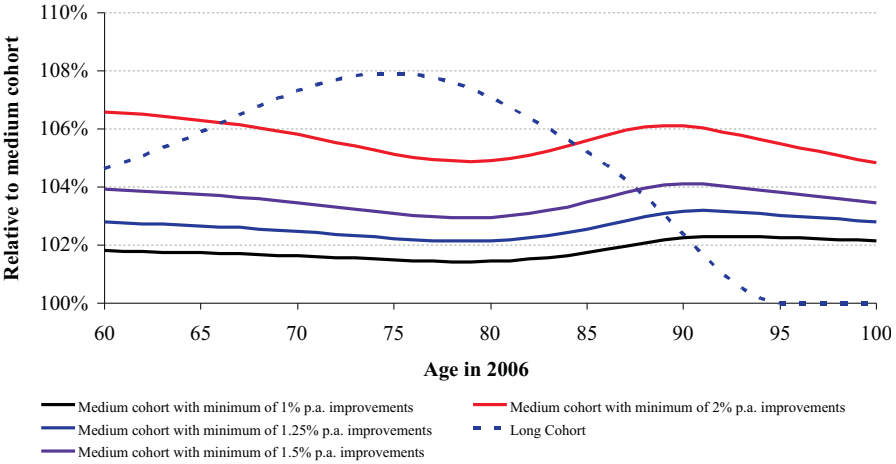
Please note that, in all of the graphs in this Appendix, the higher of the two underpins maintains the ratio of the life expectancy under actuarial projections and the extrapolation of the national trend line constant.

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APPENDIX F

FEMALE VALUATION ANNUITIES

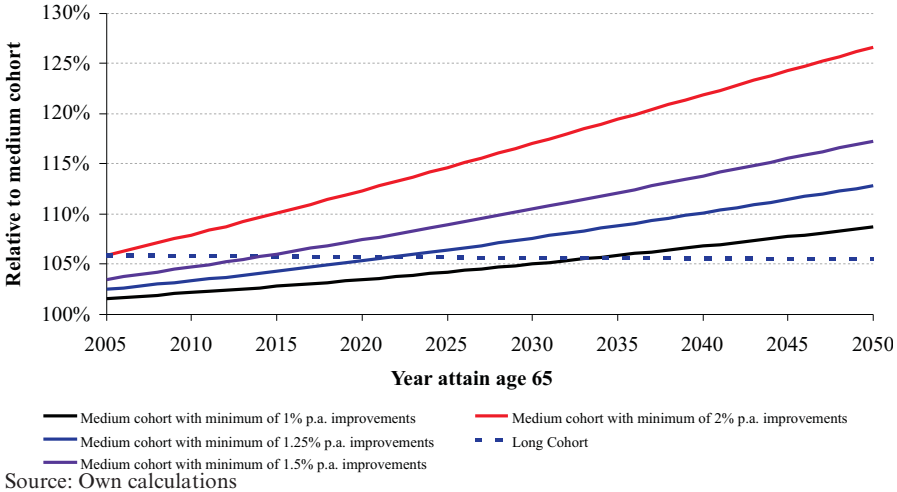
In each of Figures F.1 and F.2 the valuation annuities are cohort annuities, comprising a single life annuity and an attaching contingent life annuity, based on a net discount rate of 2%. In each case the widower's benefit is taken to be 50% of the member's pension, with 90% of members assumed to be married and the male spouse assumed to be three years older. Further, the same minimum level of improvement in mortality is applied to the projections of male and of female mortality, along with a terminal age of 120, for simplicity.



Source: Own calculations

Figure F.1. A comparison of (female) valuation annuities — current pensioners

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Source: Own calculations

Figure F.2. A comparison of (female) valuation annuities — future retirees

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