Review of longevity trends to 2025 and beyond

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Key trends in longevity to 2025 and beyond

Continuing mortality improvements at older ages

Mortality rates in the UK are declining at all ages and for both sexes, just as they are in the rest of the developed world. With every year that passes, there is an increase in the proportion of successive birth cohorts that reaches retirement age[1], and an increase in the likelihood of surviving to enjoy that retirement for several years[2]. Declining mortality at older ages is one of the main drivers of the growth in the relative size of the older population. By 2025 one in five people in the UK population will be aged 65 years or more. By 2050 it will be almost one in four.

Since most deaths now occur in later life, it is the continuing improvement in late life mortality that is contributing most to increasing life expectancy at birth. Over the last 20 years in the UK, male life expectancy at birth has increased by 5.6 years, ie at an average rate of more than three months per year, with most of the gain accruing to men past the age of retirement. Four of those additional life years have been added to life expectancy at the age of 65. Death rates in older men have not only fallen sharply in this time - by almost one half in the 60-69 age group and one third in the 70-79 age group - and from relatively high levels, but the decline in death rates has actually been *accelerating*, which accounts for the more or less linear increase in life expectancy.[3] The

[1] Premature mortality among males (<65) declined from 24.4% in 1984-6 to 16% in 2004-6; and among females from 14.9% to 11.1% over the same period.

[2] Over the last 20 years the chances of a 65 year-old women reaching the age of 80 have improved from 61% to 71%. Although the odds for a 65 year old man are not so good, they are still better than evens (59%), and much better than they were 20 years ago (41%).

[3] This is not true for all developing world. Some countries, such as the USA and Netherlands, have experienced relative stagnation in mortality improvement, especially among women (Mesle and Vallin).

average annual rate of improvement between 2000 and 2005 was twice as high as it was in the late 1980s. Death rates among older women have followed a similar trend, though the gains have been not quite so large.

Is this pattern of accelerating mortality improvements apparent in the data for the oldest-old - the population aged, say, over 80 years – as well as for people in their 60s or 70s? For men aged 80 to 90 years, it seems that it is, but not for men in their 90s, or indeed for women in either the 80-89 age group or the 90-99 age group (Pensions Commission, 2005). However, contrary to the expectations of some analysts writing in the 1980s and 1990s, there is no sign yet of a stagnation in mortality gains among the oldest segment of the population, certainly not in the UK (or Japan or France), nor even of a slowdown in the rate of improvement. Clearly then, there is no evidence in these data for the view that life expectancy in affluent countries is approaching any kind of limit, let alone the limit of 85 years estimated by Fries (1980) and reaffirmed by Carnes and Olshansky (2007).

It is these recent trends in mortality that form the basis of current official forecasts for future life expectancy, and they have been sufficiently striking to prompt the Government Actuary's Department (GAD) to change its assumptions about the trajectory of future mortality improvements. Where the 2000-based projections assumed that annual improvements in mortality rates would converge toward ½% at each age for both males and females by the year 2032, the latest forecasts reckon that annual rates of improvement will converge to 1% for most age groups, which is equivalent to the average annual rate of improvement for the 20th century.

Earlier forecasts were further shaped by the assumption of an eventual slowdown in mortality improvements, which has now been dropped. Hence we find that forecasts of future life expectancy have been revised upwards *both* in the medium term *and* in the longer term. Over the next twenty years female life expectancy at age 65 is forecast to grow even more quickly than it has done over the last 20 years (3.4 yrs as against 2.6); and there will be only a slight dip in the rate of increase for men over the same period (3.6 years as against 4 years). Thereafter the projected trend in mortality improvements entails a marked slowdown (and convergence) in the rate of increase for both sexes. Between 2028 and 2048 life expectancy at age 65 years will increase by 1.8 years for men and 1.7 years for women.

Variations and inequalities in mortality risk

The gender gap in life expectancy is narrowing

The life expectancy of a 65 year old woman in the UK is now 19.7 years, almost 3 years longer than that of a 65 year old man. It is not surprising, then, that among the oldest age groups in the population (eg 85 years+) women outnumber men by more than two to one, nor that nine out of every ten centenarians in this country are female.

Over the course of the 20th century, in common with most other developed countries, the gender gap in life expectancy in the UK first widened, and then in the 1970s and 1980s started to narrow (Gjonca et al, 2005). Mortality rates for men are falling faster than mortality rates for women. If these trends continue, which is what GAD expects[4], the ratio of men to women in the older population will of course increase, and this means that an increasing proportion of older women will have surviving husbands. Japan and Russia are notable exceptions to this pattern (ie the sex gap in life expectancy has

[4] In 1981, the gap in life expectancy at birth was 6 years. In 2006 it was 4.3 years, which is relatively low for a rich country at the beginning of the 21st century.

increased over the last 20 years). In Japan, the widening gap appears against a background of improving life expectancy for both sexes whereas in the Russian Federation life expectancy has actually declined.

Social inequalities in life expectancy are widening

One of the most notable features of recent trends in mortality in affluent countries is that a pattern of international convergence in life expectancy overlays a pattern of widening within-country variation of age at death, much of which is thought to be explained by socioeconomic differences in mortality risk (Edwards and Tuljapurkar, 2005). In the UK, as in most of Europe (Mackenbach et al, 2003) and the US (Meara et al, 2008) over the last couple of decades, the increase in life expectancy has been accompanied by widening socio-economic inequalities in mortality [5]. Although mortality rates have been decreasing at both ends of the social scale, they have been decreasing much more quickly in the upper socio-economic groups.

Here in the UK, data from the ONS Longitudinal Study show that, in the years between 1972-5 and 2002-5, the gap in life expectancy at age 65 between men in manual and non-manual occupations doubled from 1 to 2 years. The gap between men in the highest and lowest of the Registrar General's occupational classes now stands at 4.2 years, with unskilled manual workers having more or less the same life expectancy at pensionable age (14 years) as professionals did in 1972-5 (ONS, 2006). The trends for women are the same.

A similar pattern is apparent in analyses of deaths in the British Regional Heart Study (Ramsay et al, 2007), as well as in many studies of trends in geographical inequalities in mortality. Although the risk of premature mortality (< 75 yrs) has declined everywhere in the UK over the last 25 years, the difference between the authorities with the highest and lowest probabilities of surviving beyond 75 has increased (Wells and Gordon 2008). A similar conclusion is reached by Leyland et al (2004), though he uses a lower threshold to define premature mortality (< 65 years). Between 1979 and 1998, premature mortality decreased by 36% in Great Britain as a whole. Over the same period inequalities in the risk of premature mortality increased not only *between* regions, but also *within* most regions of the country. The excess premature mortality associated with living, for example, in London increased from 14% to 19%.

Changes in cause-specific mortality

One common factor in analyses of trends in cause-specific mortality over the last half-century, not only in the UK, but in all of the developed world, is the contribution of declining mortality from cardiovascular/circulatory diseases to overall mortality decline. It has been estimated, for example, that reduced CVD mortality contributed more than 5 of the 8.8 years added to life expectancy at birth in the USA since the middle of the 20th century (Cutler, 2004). In the USA, as in the UK, it is the decline in mortality from heart disease that has contributed most of the decline in CVD mortality – mainly because a much larger proportion of deaths were (and still are) caused by heart disease than by stroke[6].

[5] The relative gap in death rates between upper and lower socio-economic groups has grown more in northern Europe (inc. the Nordic countries) than in the south.

[6] Although analysis of mortality by 'underlying cause' suggests that stroke mortality in the UK has been declining more slowly than CHD mortality in recent years – indicative perhaps of a slowdown in the well-recognised long-term secular decline in stroke mortality – Goldacre *et al* (2008) have argued that a revision of these estimates may be

In the UK, over the last ten years (1995-2005), the age-standardised mortality rate for CHD fell from 94 to 48 per 100,000; with death rates falling by about one half in both the 55-64 year age group and the 65-74 age group. If these trends were to continue, we could expect to see the end of premature mortality from CHD. Whether or not that will happen over the next few decades is unclear. A recent analysis of trends in CHD mortality in younger adults – they appear to be flattening out – suggests that increases in obesity may be starting to offset the decline in other risk factors among younger cohorts (O'Flaherty et al, 2008).

For the other main cause of death in the UK, cancer, the picture is quite different, and more complicated. Taken as a whole, age-standardised mortality from cancer changed very little in the second half of the 20^{th} century (Quinn et al, 2001), although more recently, mortality rates have declined substantially (10-15%) among both men and women (Westlake and Cooper, 2008). Cancer incidence, however, declined by only 1% between 1993 and 2004, and it actually increased among women (with breast cancer accounting for much of the increase). For men, the main source of the downward pressure on cancer mortality is the fall in mortality from lung cancer, and this is due to declining incidence. With breast cancer in women and prostate cancer in men, on the other hand, the drop in mortality has occurred in spite of *increasing* incidence.

Increasing healthy life expectancy

In the early 1970s it was feared that a combination of increasing longevity and the intractability of the major degenerative diseases of later life would lead to an expansion of morbidity (eg Gruenberg, 1977). If gains in life expectancy at older ages were being driven mainly by the increasing capabilities of medicine to postpone death in people with serious illness, then the average person should expect to spend more years living with a heavy burden of disease and disability. What is now clear is that age-related disease is not as intractable as was then supposed. There are established and effective strategies to reduce the risk of onset for many kinds of chronic disease as well as effective interventions to delay the progression of disease and minimise associated disability. There is also growing evidence that the onset of age-related ill health and disability is in fact being postponed to older ages across whole populations. What is being postponed, in other words, is the *need* for medical intervention to deal with the more serious problems of age-related disease and disability. At least this is what seems to be happening in *some* developed countries and for *some* forms of age-related disease and disability.

There are distinct questions to ask here. We can ask, for example, whether or not the number of years that we can expect to spend in a healthy (or active) state is increasing. We can also ask whether it is increasing as fast as life expectancy. Or is it increasing even faster, which would mean that there is a compression of the time spent in serious ill-health or disability at the end of life?

The evidence for ongoing improvements in healthy life expectancy in the UK (ie the first question) is now quite strong. Or at least this is the case for cardiovascular disease, which is, after all, not only the main cause of death in later life but also a major cause of late-life disability. Trend data for the age-specific incidence of disease (eg first coronary attacks or first strokes) confirm that the average age of onset is climbing up (Davies, 2007; Rothwell, 2004). Estimates of the relative contribution of medical care and

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in order (at least for the UK), since mortality based on underlying cause alone misses about one-quarter of all stroke-related deaths.

changing levels of population risk factors to declining mortality from CHD tell the same story, though from a slightly different angle. The kind of evidence that can give us a more rounded picture of health status is, however, more equivocal. Data from the General Household Survey, for example, on self-perceived health suggest that we are keeping our health for longer (although it seems that increases in healthy life expectancy are not keeping pace with improving life expectancy). There is, on the other hand, quite a lot of evidence to suggest that the prevalence of chronic disease and related health problems is increasing in the older population, and this is not just because the older population is itself ageing. A recent analysis of the MRC CFAS dataset found that the prevalence of chronic disease is increasing in successive cohorts of the younger-old (65-69 years), though it is admittedly very difficult to be sure that most of this change cannot be explained by improved detection and earlier engagement with medical care (Jagger et al, 2007).

The evidence on trends in late-life *disability* is, if anything, even more problematic. Although there are some affluent countries which do show clear evidence of favourable trends in late-life disability (often in spite of an increasing prevalence of self-reported health problems and diseases), the UK is not one them (Lafortune et al, 2007). And since there is no firm evidence for increasing disability-free life expectancy in the UK, there can be no firm evidence to suggest that the functional status of the older population is improving enough to bring about a compression of disability.

Key uncertainties and potential discontinuities in longevity trends

Demographic uncertainty

Demographic forecasters make errors, not because their methods are inadequate to the task in hand, but rather because the future trajectory of mortality is inherently uncertain. We may be confident, and reasonably so, that mortality rates in the older population will continue to decline over the 20 years, but we cannot be so sure of the accuracy of our estimate for the average annual rate of improvement, that it will be 2%, for example, rather than 1.5% or 2.5%. GAD, which for many decades has persistently under-estimated mortality improvements in the older population, captures some of the uncertainty in forecasts of life expectancy through its use of variant projections. Since the likelihood of forecasting error increases with the length of the projection period, the gap between the high and low variant forecasts for life expectancy increases over the course of the century. In the 2006-based projections, there is a 2.6 year gap in 2025 between the upper and lower estimates for life expectancy at birth for men; by 2050 it opens up to 8 years (and for women it increases from 1.6 years to 6.3 years). Although the trend line for the principal projection lies of course between these limits, GAD's current methodology gives us no mathematical handle on the probability that it will in fact fall within that range. All we can say is that it most probably will (and, of course, that the future is more likely to correspond to the principal projection than to either of the variants).

It seems very unlikely, for example, that life expectancy will start to decline after 2038, which is the boundary set by the *low variant forecast* (ie it assumes that life expectancy remains constant after that date). But it is not altogether inconceivable that it might start to fall some time between 2025 and 2050, and precisely this outcome has been assigned to a worst-case scenario for the obesity 'epidemic' in the USA (Olshanksy et al, 2005). Nor does it take much casting around to find other potential causes of such an outcome, such as a catastrophically bad influenza pandemic. As for the *high variant forecast*, this corresponds quite closely to a continuation of the more or less linear trend in improvements in life expectancy noted by Oeppen and Vaupel (2002) for a times series of data from so-called 'best practice' countries. If, however, we assumed that the trend in *life expectancy* projected for the UK for the next 20 years were to continue up to 2050 (ie an average annual increase of about 3 months per year), then life expectancy at birth in 2050 would exceed the high variant forecast[7]. Once again this may be an unlikely outcome, but it is not altogether inconceivable.

Optimists and pessimists

We cannot be sure that future changes in mortality rates will be the same as those we have seen in the recent past, but unless we have any reason to think otherwise, our best bet is to assume that they will. This may be a good rule-of-thumb, but when it comes to deciding on its application to the future of human mortality in the 21st century, it leaves some important basic issues unresolved. In particular, there is the question whether we have good reason to think that future changes in mortality rates will *not* be the same as those we have seen in the recent past. And this question may in turn be asked in various ways depending on which stretch of the recent past we are considering for extrapolation into the future. Do we have any reason to think that gains in life expectancy in the 21st century will be less than those seen in the 20th century? Do we have any reason to think that the pattern of gains in life expectancy seen in the UK over the last 20 years will not continue? More generally, we can ask whether we have any reason to think that the rate of mortality improvements at older ages is more likely to slow down than continue on its present trajectory[8]. The kinds of answers that demographers and experts on human mortality give to these questions may be divided into four broad categories. At the extremes there are two scenarios which 'foresee' a fairly radical departure from recent trends, or at least they argue that such a discontinuity is much more likely than most demographic forecasters are inclined to suppose.

The *pessimistic* scenario assumes that the increasing prevalence of obesity in cohorts that are still relatively young or in middle age will have a very substantial impact on their mortality in later life, large enough in fact to reverse the long-term trend in life expectancy. We are to suppose that the full impact of obesity on mortality will turn out to be not very different from the impact of smoking on mortality. What distinguishes this particular pessimistic scenario from the risk of catastrophes that hit us, as it were, 'out of the blue', is the availability of evidence on current trends in obesity as well as estimates of the impact of obesity on mortality, which together enable a projection to be made. The basis for the scenario, in other words, is found in present trends. What makes it an especially pessimistic scenario (rather than a merely realistic assessment of the likely impact of obesity on life expectancy) is (i) the choice of the most pessimistic of the range of current estimates of the relative mortality risk associated with obesity and overweight, and (ii) a likely under-estimate of the effect of countervailing changes in lifestyle, especially the decline in smoking prevalence.

At the other extreme there is what we might call a *super-optimistic* scenario, which reckons on our ability to develop and apply the means of overcoming whatever limits the process of biological ageing puts to human longevity *soon enough to have an impact on the evolution of human longevity in this century*. Should this happen, then (so the argument goes) we should expect to see a rapid acceleration in gains in life expectancy, and there is no reason why the average age at death should not exceed the maximum observed human lifespan (approximately 125 years) before the end of the century. What makes this a *super*-optimistic scenario is that it offers us a reason to think that the future trends in mortality will depart quite radically from historical trends. The gains in

[7] Combined life expectancy at birth would reach 100 years before the end of the century.
[8] Though we should not underestimate the difficulties and disagreements involved in determining what the 'present' trajectory is.

mortality that would be required to achieve this scenario exceed anything that could be derived from the extrapolation of current trends.

Even among the majority of demographers who would reject these 'extreme' scenarios as highly unlikely, there remain important differences of opinion on the question whether life expectancy in affluent countries is approaching a limit; and if it is, whether this has any relevance for attempts to forecast the short- to medium-term future for mortality. For the sake of simplicity, and following Carnes and Olshansky (2007), they may be divided into *realists*, who argue that the rate of mortality improvements is more likely to slow down than continue on its present trajectory, and *optimists*, who forcefully reject the idea that we have any reason to suppose that this will happen in the foreseeable future.

The difference in practical terms between realists and optimists is large. Where Carnes and Olshansky think that combined life expectancy is unlikely to exceed 85 years, Oeppen and Vaupel (2002) puts it at 100 years by the end of the century. The key to this difference lies in differing assessments of the relevance of what is known about the ageing process to the assumptions that demographers make about the future of mortality. Carnes and Olshansky (2007) argue that humans, like other organisms, "are subject to the biological equivalent of a warranty period". This is not to say that we cannot survive beyond our 'warranty period'; the point is rather that the probability of death increases sharply the longer we survive beyond it. What the optimists dispute in this is not just the rate at which the probability of dying increases in later life, or the estimate of the 'warranty period' for humans, or indeed whether the idea of a warranty period is at all useful. The fundamental division of opinion turns on the question whether the constraints that biological ageing imposes on human longevity are going to become apparent in the mortality data soon enough at least to influence the assumptions of demographic forecasters.

Convergent or divergent trends in differential mortality risk?

Will social inequalities in life expectancy continue to increase?

Uncertainty about what is going to happen to social differentials in mortality risk is presumably at least as great as the uncertainty about overall trends in future mortality. If we suppose that there are practical limits to life expectancy which rich countries like the UK are fast approaching, then we would expect soon to see a slowdown in the rate of increase in the mean age at death *and* a compression of mortality around the mean (Fries 1980). In effect, most of the future increase in the mean would be achieved by a narrowing of social inequalities in mortality. It is assumed, on this view, that the benefits for life expectancy of good early life nutrition and healthy living have been more or less fully realised by a substantial minority of the population. Future cohorts in similar circumstances may still gain more in this way, but not much. There is, however, still a large gap to be closed between them and the rest.

The problem with this view, however, is that it is not supported by the evidence. To be sure, GAD forecasts a slowdown in the rate of increase in life expectancy between 2025 and 2050, and this *may* be accompanied by a compression of mortality (and a narrowing of social differentials). As we have already noted, however, current trends in social differentials provide no evidence for this. Quite the contrary. And this is despite a considerable effort on the part of government to do something about it. If we decided to follow, for this particular case, GAD's standard approach to projection, we would presumably forecast a further widening of social inequalities in mortality. Given the determination of government to reverse this trend, the question we have to ask is this: how confident can we be that government efforts to narrow social inequalities in mortality will be successful before 2025 or 2050? Or should we suppose that they will be no more successful over the next 20 years than they have been over the last 10 or 15?

The future of the gender gap in life expectancy

The gender gap in life expectancy decreases by about 20% in GAD's principal projection for 2050, and by more than a third in the high variant. Only in the low variant does it actually increase. If we take the high and low variants as the outer limits for likely outcomes, then the gender gap in life expectancy could be anywhere between 2.4 and 4.2 years by 2050. It is worth noting, moreover, that the continuing decrease seen in the principal projection happens in spite of an assumed convergence between male and female rates of mortality improvements: gains in female life expectancy will accelerate as gains for men will slow down (ie without this assumption the convergence would be much greater).

Since male-female life expectancy fails to converge only in the low variant forecast, it is perhaps worth asking how unlikely it is that we will have much greater gains in life expectancy than are forecast in this variant *along with* a lack of convergence in male and female life expectancy. The point has already been made that GAD's methodology does not allow us to assign a number to the probability of this kind of outcome. However, as with Olshansky's pessimistic scenario for the impact of obesity on future trends in life expectancy or Vaupel's best-bet forecast of linear increases in high-performing countries, such an outcome does not seem so unlikely as to fall outside the limits of serious consideration (wherever they are).

Are we on the verge of an epidemic of frailty?

Just as there are optimists and pessimists about the future of mortality over the next few decades, so also are there optimists and pessimists about the likelihood of achieving a compression of morbidity (or disability) when life expectancy is continuing to increase by more than two months per year. Although current trends in old-age disability in the USA give grounds for optimism, here in the UK they look less favourable (Lafortune, 2007).

Even in the USA, however, it would be unwise for policy-makers to discount the risk of a slowdown in current rates of improvement in the prevalence of disability. Nor is it sufficient that disability rates continue to decline for there to be no expansion of disability (ie the amount of time that the average person spends in a disabled state at the end of life). If future increases in life expectancy outpace future increases in active (or disability-free) life expectancy, there will be an expansion of disability. The prospects for a compression of disability depend, therefore, not only on what happens to disability rates, but also on what happens to life expectancy. An increase in the prevalence of disability may look unlikely on current trends, but there is a risk, for example, that the effects of obesity will be sufficient to reverse them; and there is *also* the risk that gains in life expectancy at older ages exceed the current 'best estimate' of forecasters.

Useful as it is, however, to make this kind of broad distinction between a future compression of disability and a future expansion of disability, there are other possible scenarios for the evolution of the relationship between increasing life expectancy and increasing *active* life expectancy. It is possible, for example, that increases in active life expectancy will keep pace with increasing life expectancy, so that there will be neither a compression nor an expansion of disability.

It is also important to take proper account of the distinction between more and less severe states of ill-health and disability. If we suppose that current gains in life expectancy are strongly dependent on improvements in the secondary prevention of fatal chronic disease in later life, then although we should expect an expansion of morbidity, this will result from an expansion of the time spent with relatively mild and 'manageable' health problems, not from an expansion of time spent in a severely disabled or seriously ill condition.

The original prediction of an imminent compression of morbidity (Fries 1980) was based on the conjunction of two hypotheses: firstly, that the main driver of the current gains in life expectancy at older ages was an underlying improvement in health which has enabled people to remain free of potentially fatal chronic disease for longer; and secondly, that life expectancy was approaching its limit. As we have seen, there is no evidence yet of a slowdown in gains in life expectancy. Even, therefore, if the first hypothesis is right, there is no reason *in theory* to predict a compression of morbidity in the foreseeable future unless we also predict a slowdown in gains in life expectancy[9].

Suppose, then, as seems quite likely, that most of the current gains in life expectancy at older ages are due to a combination of improved secondary prevention of fatal chronic disease and underlying improvements in health. Can we be reasonably confident that *if* this is true, there will be no expansion of (severe) disability? According to Manton et al (1991), and the hypothesis that increasing life expectancy is in a state of 'dynamic equilibrium' with morbidity and disability in later life, we can. Not everyone, however, would agree. A good deal turns on the relationship between patterns of delayed onset and progression for different categories of chronic degenerative disease. If age-specific patterns of risk for the major *fatal* chronic diseases of later life (eg circulatory disease) are changing faster than the patterns of risk for severely disabling but *non-fatal* conditions, then the prospect of extended survival is likely to expose individuals to an increasing risk of disabling and age-related functional loss[10].

How longevity trends intersect with developments in science and technology

The drivers of mortality decline

"Gains in longevity are the result of a complex array of changes (standards of living, public health, personal hygiene, and medical care), with different factors playing major or minor roles in different time periods" (Wilmoth, 2000). Most analysts would accept that medicine made a relatively small contribution to declining mortality until the second half of the century, or perhaps even as late as the 1970s, after which it started to make a big difference (Bunker, 2001). It seems clear, for example, that the secondary prevention of heart disease through more effective medication and improved surgical techniques has had a substantial impact on the mortality of people with diagnosed heart disease (Jeune, 2007), and they are, after all, a large proportion of the older population. Whether or not medical interventions have contributed more to declining mortality over the last 20 years than social change or lifestyle change is not so clear. Certainly for heart

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[9] This is not to say that the *data* on recent trends might not indicate that there has *in fact* been a compression of disability over, say, the last 20 years; and this trend may provide the basis for a 'best-bet' projection for the future.

[10] When this argument was first developed, dementia was classified as a non-fatal degenerative disease. It now appears as a cause of death on death certificates. Although this change weakens the force of the distinction between fatal and non-fatal degenerative disease, the essential point remains the same.

disease there is an impressive body of analysis which argues that improvements in medical care account for less than half the decline in mortality in recent decades (Unal et al, 2004), though a rather different view of the impact of medical intervention emerges from some recent analyses of the contribution of pharmaceutical innovation to mortality decline (Lichtenberg, 2007).

What is at issue in these different estimates is the balance between the various components in the array of forces driving down mortality *in the recent past*, and even if we were to suppose this issue settled, we would still have to consider how this balance might change in the foreseeable future. There are two broad questions we might ask here. Firstly, how much life expectancy can we expect to gain in rich societies *without* the ever more intensive application of expensive medical interventions? Secondly, should we expect over the next few decades an increase in the life expectancy gains made as a result of the widespread application of biomedical innovation (and if so, how)?

Social change and changing lifestyles

The question of how much life expectancy we can expect to gain in rich societies without the intensive application of new medical technologies has been tackled in various ways. One approach involves an assessment of the impact of the increasing diffusion of what Carey (2003) calls 'healthful living' on mortality. Although Carey himself argues that social and lifestyle change probably has a rather small and diminishing contribution to make to future longevity gains, there are others who take quite a different view. The effects of the continuing recession of the 20th century smoking epidemic may be the most obvious candidate for this kind of exercise, but there are of course other factors besides smoking which have a measurable impact on mortality risk. It has been estimated, for example, that a modest reduction in risk factor levels for CHD in the general population could reduce CHD deaths in the UK by nearly one half within a policy-relevant time frame (Kelly and Capewell, 2004). An alternative approach would be to estimate the effects on population life expectancy of the elimination or narrowing of social inequalities in mortality. What would happen, for example, to population life expectancy if standardised mortality ratios for the lowest income groups were the same as those for the highest (Manton et al, 1990)? More generally, we could assess the impact of narrowing the gap in life expectancy by eg 50% or 75%.

The role of smoking

Smoking is the single largest cause of preventable deaths in the UK (Davy, 2007), accounting for approximately one in six of all adult deaths in England in 1998-2002 (Health Development Agency, 2004). Since the gap in life expectancy at birth between the average non-smoker and the lifelong smoker is estimated at about 10 years (Doll et al, 2004)[11], it not surprising that smoking should be widely regarded as the largest single determinant of the substantial variations in mortality that are found (i) between men and women (see eg Pampel, 2003), (ii) between different socioeconomic groups (see eg Law and Morris, 1998), and (iii) between different geographical areas (see eg Mackenbach et al, 2008). It is hard to exaggerate the importance attached by many demographers and epidemiologists to smoking behaviour in explaining changing patterns of mortality in the developed world in the second half of the 20th century.

Smoking patterns that appear early in life of a cohort have very large effects on mortality several decades later. In many countries the spread of smoking in cohorts born at the beginning of the 20th century acted as a substantial drag on the mortality declines

[11] This compares with the estimate of 6-7 years of life lost at age 40 for obese non-smokers in the Framingham cohort (Peeters et al, 2003)

that might have been expected from post-war improvements in living standards and health care (Janssen et al, 2007). As the smoking epidemic recedes, we should therefore similarly expect an acceleration of mortality declines in places where the proportion of smokers in cohorts reaching later life continues to fall. There are good reasons, therefore, to think that the continuing decline in smoking prevalence is likely to be one of the main drivers of gains in life expectancy in the developed world over the next 50 years.

Human and physiological capital

There are two other potentially important sources of continuing gains in life expectancy which are largely (but not entirely) independent of innovation in biomedical technology; firstly education, and secondly what economist Robert Fogel (2003) has called the accumulation of 'physiological capital'.

The idea that improvements in the general level of education in society is a important driver of increasing life expectancy has its origins, partly in the well-established link between socioeconomic status and differential mortality risk, and partly in the idea that higher levels of education are associated with an increased ability to negotiate the challenges and hazards of modern life in a highly urbanised and technologically-oriented society (ie more 'know-how'). What is gained from more education is not just a higher standard of living. Better educated individuals are more in control of their lives, which means *inter alia* that they are more in control of the various factors in the social and material environment which influence their own health status (Cutler et al, 2006).

The idea that the accumulation of 'physiological capital' early in life has large benefits for late-life health and mortality builds on the now familiar idea that nutrition *in utero* and in early childhood has a substantial and long-lasting impact on health *via* their influence on the formation of essential physical structures in the developing organism (Barker, 1995). As a result of improved nutrition in early life, more recent cohorts in the developed world are not only better able to resist infectious disease than their parents and grandparents, but also benefit from a delay in the onset of the chronic diseases that cause ill-health and death later in life. One of the key pieces of evidence to which Fogel appeals in developing these views is trend data on birth weights and adult heights. Essentially we are getting taller - which is a good marker for the improved development of internal organ systems - and there is, he thinks, a demonstrable link between adult height and mortality risk (see eg Langenberg et al, 2005). The fact there is no evidence of any deceleration in this particular trend, certainly in Europe, suggests furthermore that we should expect no weakening in the force of this source of mortality reductions (Fogel and Costa, 1997). At the very least, we might look forward to a narrowing of socioeconomic differences in adult height, and given the link between adult height and mortality risk, this would lead us to expect a narrowing of social inequalities in life expectancy.

Innovation in medicine and biotechnology

Most deaths in old age are caused by cancer, heart disease and stroke. Individualised interventions which aim to delay or halt the progression of these life-threatening diseases account for much of the medical care that is now provided in our society, and an enormous amount of research effort is devoted to developing more effective interventions. Innovations in new fields such as pharmacogenomics and nanotechnology clearly have the potential to provide *some* of the additional power that is needed to maintain current momentum in what Carey (2003) calls 'disease prevention and cure' as a driver of mortality improvements in later life. The magnitude of the gains in life expectancy that may be achieved by such developments should not be over-estimated, however. If we suppose that more effective treatment were to reduce cancer mortality as dramatically over the next two decades as mortality from heart disease has fallen over the last 20 years (ie by about 50%), this would add not much more than a couple of years to life expectancy at birth[12].

Can we expect to find therapeutic innovation anywhere *other* than in the development of technologies which offer the prospect of improvements in disease prevention and cure? Carey (2003) himself answers this question by identifying two quite distinct potential drivers of future improvements in mortality: regenerative medicine; and age-retardation. The implication of the distinction is that the development of these technologies would represent an important 'step-change' in the capabilities of biomedicine to extend healthy lifespans. How likely is it that gains in life expectancy can be maintained on their current trajectory without such a step-change? Olshansky and Carnes (2007), for example, take the view that we should expect a slowdown in mortality improvements *unless* there is a radical breakthrough in our ability to control the process of biological ageing. They doubt whether Oeppen and Vaupel's optimistic forecasts for the future of life expectancy in this century can be realised simply by the wider diffusion of healthy living and improved disease prevention and cure.

Since the aim of regenerative medicine is to develop therapies which will restore lost, damaged or ageing cells and tissues in the human body, it seems clear that it has the potential to make a significant contribution to future increases in life expectancy at older ages. As ever in such cases, it is important to distinguish between outputs that might reasonably be expected in the short term, and the more speculative long term promise. The hope that stem cell therapy might be used, for example, to repair damaged heart tissue or to 'cure' diabetes lies in the longer term future (DHHS, 2006).

'Age-retardation', as it is now generally understood, would represent a step farther even than the ability to repair ageing or damaged tissue and cells in various body systems. Effective age-retarding interventions would stand to regenerative medicine rather as prevention stands to cure. Where regenerative medicine aims to remedy age-related decline in cell and tissue function by repair or replacement, age-retarding interventions would aim to prevent or slow down the processes that underlie that age-related decline in function (President's Commission on Bioethics, 2003). Once we assume that such interventions are feasible, there is no reason why life expectancy should not eventually[13] exceed the current maximum observed lifespan, and it is this conclusion which has prompted discussion of their social and ethical implications.

Range of potential futures these trends might point to from present to 2025 and 2050.

Greater or smaller gains in life expectancy

What are the main scenarios for longevity *apart from* the range of trajectories for life expectancy that is bounded by the high and low variant forecasts made by GAD? If we follow Oeppen and Vaupel (2002) in thinking that it is feasible that there should be a more or less linear increase in life expectancy in best-practice countries for most of this century, then it is important to add this ***optimistic*** scenario to the range of possible futures for longevity. By the same token, though this does depend on contested assessments of the likely impact of the so-called obesity epidemic on mortality, it seems excessively complacent to discount altogether the risk of a ***pessimistic*** scenario in which life expectancy actually starts to fall as younger (and more obese) cohorts start reaching later life, say from 2030 onwards.

[12] Olshansky et al (1990) estimated that the elimination of mortality from cancer would add 3.2 years to life expectancy at birth in the USA.

[13] Though presumably it might take quite some time to have this kind of population-wide effect.

A rather different approach to the construction of possible futures for life expectancy in the UK was adopted by the Wanless review on the future of NHS spending (Wanless, 2002). The key variables in this case were (i) the public's engagement with their own health (ii) the achievement of public health targets, and (iii) health service productivity. ***Solid progress*** in these respects would produce life expectancy gains in line with what was then GAD's high variant forecast. ***Slow uptake*** would lead to gains in life expectancy that correspond to GAD's principal forecast. The fully ***engaged scenario***, however, is associated with mortality improvements beyond what is achieved even in the high variant forecast. The interest of this set of scenarios lies partly, therefore, in the fact that one of the projected outcomes falls outside the boundaries set by GAD's high and low variants, and partly in the way that movements in mortality trends are connected with opportunities for policy action by government.

Variability in mortality risk

Quite distinct from the question of the magnitude of the gains in life expectancy that might be achieved between now and 2050 is the question of variability in mortality risk. What will happen to (i) the gender gap in life expectancy, and (ii) socioeconomic disparities in life expectancy?

In the GAD variant forecasts male-female life expectancy fails to converge only when life expectancy gains stagnate. In view of this fact, it would seem desirable at least to consider a scenario which combined moderate gains in life expectancy with an increase in the gender gap in life expectancy. In other words, life expectancy would continue to increase for both men and women, but there would no significant increase (or perhaps even a decrease) in the ratio of men to women in the oldest-old population.

The GAD variant forecasts have nothing to say about future trends in socioeconomic disparities in life expectancy. The present government target for reducing inequalities in life expectancy at birth runs to 2010 (a 10% reduction between 2003 and 2010 in the life expectancy gap between local authorities). Whether or not it is likely that our society will achieve proportionately ambitious targets for 2025 and 2050 is open to question. These are nonetheless the benchmark scenarios against which governments should presumably measure their long-term success in reducing socioeconomic disparities in life expectancy. The worst-case scenario is that the relative difference in mortality rates between high and low socioeconomic groups will continue to increase.

More or less disability and ill-health in later life

There are two ways of constructing scenarios for the future of disability and ill-health in the older population. If we want simply to clarify the range of possible outcomes for the interaction between changing life expectancy and changing active life expectancy, we should think in terms of the expansion or compression of disability and ill-health as worst- and best-case scenarios. The most commonly discussed ***intermediate scenario*** foresees some increase in the time spent with mild (and relatively manageable) health problems and a stable or decreasing amount of time spent in a severely disabled state.

The approach adopted by most *projections* for the future of disability and ill-health in the older population is different from this. The scenarios generated by these projections involve an estimate of the numbers of severely disabled or dependent older people in the population based on combinations of alternative trajectories for (i) trends in life expectancy and (ii) trends in age-specific prevalence rates for disability and dependency. This is the kind of approach taken by the PSSRU model for projecting future expenditure on long-term care (eg PSSRU, 2004), and the recent OECD projections on the future of old-age disability (Lafortune, 2007). We can ask, for example, what happens *if* age-specific prevalence rates:

- remain unchanged and life expectancy grows more quickly than GAD's principal projection (this is the most common worst-case scenario)
- follow current trends (which generates a positive scenario if rates have been decreasing as they have done in the USA over the last 10 or 20 years)
- decrease in line with optimistic expectations about improving health (eg at an average rate of 1% per year).

A more sophisticated approach to generating the same kind of outcome is used in the scenarios prepared by Jagger *et al* (2006) for the Wanless review of social care. They outline three basic scenarios:

- a ***no change*** scenario which assumes that the age-specific prevalence of disabling chronic disease will remain unchanged. This is not to say that preventive efforts will be ineffective. They will be effective, but only enough to offset the negative impact of obesity on the health and functional status of cohorts that are now still relatively young.. The incidence of dependency will stay the same and mortality rates will decline in line with GAD principal projections.
- a ***poorer health*** scenario assumes that current trends in obesity will continue (which means an increase in prevalence of about 2% per annum). This problem will be compounded by the ageing of large ethnic minority populations, which will add to the prevalence of CHD and stroke. Preventive strategies will only partially offset these trends.
- an ***improving health*** scenario, which is not that different from the ***fully engaged*** scenario for life expectancy. There will be a decline in smoking prevalence and obesity as individuals take their own health more seriously. Health services will be responsive to demand with high rates of technology uptake for disease prevention and excellent rates of diffusion of treatment. Mortality will decline more quickly than in the GAD principal projection.

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