# Abstract

**Background**

All-cause age-specific mortality risks have tended to be decreasing in England & Wales for more than a century. The period 2008-2015 has seen both a global recession, and since 2010, two Conservative-led governments pursuing an ‘austerity’ agenda of reduced investment in public services.

**Aim**

To estimate trends in age-specific mortality risks from 1990 to 2010, use these trends to produce estimated age-specific risks over the period 2010 to 2015, and compare actual against projected numbers of deaths by various ages to produce estimates of total excess deaths up to age 95 years in each year from 2010 to 2015.

**Methods**

Office for National Statistics (ONS) data on population counts and death counts at each age in single years from birth to age 95 years (2010 to 2014 data) or to age 89 years (2015 data) were used to construct linear regression models of mortality risk against year for each age in single years from 1990 to 2010, including dummy variables to control separately for effects of the New Labour (NL) government (1997-2010) and the 2008-2009 global financial crisis (GFC). The models were used to estimate the mortality risks that would have been expected if mortality trends during the New Labour period had continued. The number of age-specific deaths at each age in each year from 2011 to 2015 were estimated given population counts in each year, and compared with observed number of deaths in each year.

**Results**

There were slightly fewer deaths than predicted from the models in 2010 and 2011, but from 2012 to 2015 there have been an additional 42,800 deaths in England and Wales than predicted up to age 90, and an additional 61,000 additional deaths up to age 95 years, than would have occurred had the previous (1997-2010) rate of improvement continued. Most excess deaths occurred after retirement age, and were more likely among males than females.

**Discussion**

Falling levels of investment in social and health care services in England & Wales since 2010 may be responsible for mortality rates at older ages either increasing or falling more slowly than would have been expected if previous improvements had continued. Mortality for males was improving rapidly before 2010 so had that trend continued many older men would have been alive by 2015. The actual rise in mortality was greater for older women, but we should be aware that mortality improvements among older men slowed most abruptly after 2010.

# Introduction

## Austerity and elderly mortality

In their 2013 book The Body Economic, summarising dozens of academic papers [1–3], Stuckler & Basu argued that the fiscal responses of the Obama administration in the US (starting May 2009), and the Conservative-led administration in the UK (starting October 2010), to the 2008 global financial crisis (GFC) can be thought of as a ‘natural experiment’ to assess the comparative effects of austerity versus economic stimulus on population health. [4] Since 2013, the experiment has continued, and disturbing results have started to emerge about the possible effects of austerity on elderly mortality. In 2016 a paper published in the Royal Society for Medicine explored the correlation between falls in Pension Credit and social care budgets in the UK, and changes in mortality rates in pensioners aged 85 years and older, within the period 2007 to 2013. It found that each 1% fall in social care spending was associated with a statistically significant 0.08% rise in elderly mortality, with similar but weaker rises in persons aged 75 to 84 years. [5] This focus on elderly mortality was prompted by a 2014 *New Statesman* article by Danny Dorling, commenting on provisional estimates by Public Health England, leaked in the online Health Services Journal in 2014, of deaths amongst over 75s in England, suggesting increased deaths in this age group occurred in both 2012 and 2013. [6]

The official Public Health England report, published in 2015, considered three possible explanations for the trends: influenza, cold weather, and a statistical artefact. [7] If either influenza or cold weather were the main causes of these rises then the following can be expected: firstly, that the mortality rate rises would be spatially patterned, and secondly that the rises would be a ‘blip’ associated with a single year rather than continuing from one year to the next. Evidence of spatial patterning of elderly death rates have now been explored, both visually using choropleths and statistically through calculation of the Moran’s I statistic of spatial auto-correlation, and suggests that these explorations are unlikely. [5,8,9] Artefactual explanations could relate to uncertainty about population structure within a given year, or to aggregation biases caused by inadequately controlling for changes in age-composition within an age group for which mortality rates are calculated. Recently it was pointed out that an aggregation bias could be responsible for much of the rise in middle-aged mortality rates in the USA over recent years, reported in a highly influential paper by Case & Deaton, as the average age of US populations aged between 45 and 54 years rose slightly between 1999 and 2013, meaning some rise in average mortality rate within this strata should be expected. [10–12] However, this type of explanation is unlikely to explain similar changes in multiple population age strata, such as multiple five or ten year age groups, occurring over the same time period, which have been identified in English population records. [5,8] The scope for such biases also reduce as more age-disaggregated data are used. [12] In contrast Dorling, along with Loopstra and colleagues, have suggested that the rises are more likely due to austerity. [5,6,13]

On 23 June 2016, mid-year population estimates for England & Wales (covering 1 July to 30 July) were released by the ONS.[14] These data, disaggregated by age in single years up to age 89 years, provide further evidence with which to assess and compare between competing explanations for rising elderly mortality. If the elevated mortality rates continued in 2015, as they had in 2012, 2013 and 2014, then influenza, cold weather, and statistical artefact become less plausible as explanations, and the evidence supporting austerity as a predominant explanation mounts.

## Slower improvements are still falls against expectations

The fact that death rates in some elderly age groups have risen in recent years should be of great concern given that the tendency and expectation for many decades has been for the risk of death at most ages to continue to decline. Reasons are multifactorial and include both specific medical innovations, and broader improvements in living conditions such as improved housing and sanitation. [15,16] Though the fastest improvements in longevity occurred during the epidemiologic transition, reductions in mortality risks at most ages have continued in the decades since. [17–19] Even a falling age specific death rate, but at a markedly lower rate than the long-term average, should be of concern, as the consistency and duration over which these declining death rates have occurred sets up an expectation that steady increases in longevity should be the norm rather than the exception, and that only a severe and prolonged shock and assault to the factors which contribute to such steady improvements can do much to alter these long-term dynamics. A comparison with economic growth is illustrative. Figure 1 shows how per capita GDP (not inflation adjusted) has risen since 1950 in England & Wales, using total annual GDP estimates from the ONS, and total population estimates extracted from the Human Mortality Database (HMD). [20] The line shows the trend of log per capita GDP against time over the period 1950 to 2008 inclusive, which is then extrapolated to 2015. Over the period 1950-2008 the statistical fit of this trend line is extremely high (R2 of 0.98) but after 2008 the shaded region, showing the difference between actual and projected per capita GDP, has grown ever larger. In 2009 the gap amounted to around £6,800 per person; by 2015 it had grown to more than £13,400 per person. Before the 2008 recession, all previous recessions had been followed by one or more years of catch-up, of faster-than-trend growth in per capita GDP. Nothing similar occurred after 2008, and instead per capita GDP in 2015 has barely recovered to pre GFC levels. Although a similar down shift in the fundamental rate of economic growth has occurred in many rich countries, prompting discussion amongst economists of a ‘secular stagnation’, [21,22] the disparity between current and projected levels in the UK are especially severe.

Long-term trends in human longevity are somewhat similar. Trends in life expectancy at birth in the UK and other rich nations have been repeatedly underestimated because the downwards trends in the mortality risks at most ages have not been accounted for in projections, leading to large underestimates of the size of the elderly population and the level of public expenditure in social security and healthcare required to maintain a given standard of living amongst the less infirm elderly and a given standard of care amongst the more infirm elderly. One way of seeing this is to consider figure 2, which shows, for England & Wales, how 12 month mortality rates at different ages have changed between consecutive birth cohorts, presenting these data as if they are orienteering maps, with a series of contour lines. [23–25] In an orienteering map contours represent height above sea level; in this demographic map the contour lines indicate the age at which different birth cohorts first experience a given 12 month mortality risk. Most of these contour lines have been moving steadily to the right, to be faced at ever older ages, which is equivalent to saying that the 12 month risk of death at any of these ages in single years has tended to decline. Population projections involve, amongst other things, making assumptions about how the trends in these age specific mortality rates will tend to develop over time. In this map, different assumptions about changing mortality risks may be thought about as different ways of extrapolating the contour lines into the ‘unobserved’ region in the top right quadrants of the maps. (For example, the 12 month mortality risks of the 1950 birth cohort when they are 70 years of age.) A standard simplifying assumption made in many population projections is that the age-specific mortality rates observed in the last year will simply continue in future years. (An important exception to this simplifying assumptions is in a recent spatiotemporal model published in the Lancet, which models both linear age-specific trends in mortality rates as well as spatial variations. [26]) Within this map this is equivalent to assuming that each of these contour lines, which at almost all older ages have been moving steadily to the right since birth cohorts born in the 1920s, will suddenly stop moving and become vertical instead, which does not appear a plausible assumption except perhaps for males born between around 1870 and 1900.

Like the need to compare per capita GDP levels in 2015 against the long-term trend, rather than simply against the level in 2007 or 2008, estimating the possible effects of austerity on elderly mortality involves not just looking for absolute increases in mortality rates at some ages, but comparing actual rates at various ages against rates that would reasonably have been expected if previously observed trends had continued. This is one of the key motivations for the model developed.

# Methods

## Data

Mid-year population estimates and registered deaths in England & Wales, for each year from 1961 to 2014, were downloaded from the ONS website. [27] These data are presented for each age in single years up to 104 years, though mid year population estimates for ages 90 and above are produced using the Kannisto-Thatcher survival ratio method, and so subject to more model dependence than estimates at some younger ages. [28] However it is also known that migration propensities are low at these older ages (and highest in early adulthood), and without high levels of migration amongst nonogenerians and centenarians population sizes can likely be reasonably inferred given registered deaths at different ages. [29]

Mid-year population estimates and registered deaths for 2015 were released on 23 June 2016 for England & Wales. These are disaggregated by age in single years up to the age of 89 years rather than 104 years. [14]

## Modelling strategy

The precise details of the modelling strategy are detailed in the appendix, but the intuition is as follows. The approach involves two stages: a ‘statistical stage’, in which counterfactual death rates at different ages over the period 2011 to 2015 are produced, then an ‘actuarial stage’, in which these death rates are applied to the populations at different ages to produce ‘expected deaths’, and compared with the recorded deaths at each age and in each year.

The issue of how best to model mortality risk over age, time and other attributes is being actively debated by demographers and statisticians, with modelling strategies such as intrinsic estimator model [30,31] and more recently the hierarchical age-period-cohort model [32,33] being proposed, contested, [34,35] defended [36] and contested once again. [37] At the heart of this debate is what is known as the ‘identifiability problem’, [38] in which it is recognised that cohort effects often have influence on rates in addition to age and period effects, but it remains mathematically impossible to separate out age, period and cohort effects in a single model, despite certain birth cohort effects, such as the 1918 birth cohort effect in many Western European countries, being relatively easy to identify visually.[24,25]

Our approach does not aim to engage with these debates, but simply to see value in models which formalise intuitions developed through visual inspection of shaded contour plots of the type shown in Figure 2. These suggest to us that there have been long-term trends towards reduced 12 month mortality risks throughout much of later life. It is also well known that mortality risk rises log-linearly with each additional year of life throughout much of adulthood. [39] We formalise these intuitions by producing separate linear regression models for both sexes and for each age in single years, using ONS data over the period 1990 to 2010, from birth (‘0 years’) to 94 years of age. This means a total of 190 separate linear regression models were produced. The start period of 1990 was used because we expected the assumption of a linear trend would be reasonable over this period, whereas it may be more nonlinear and complex over a much longer period of time. (A structural sensitivity analysis was also performed to see whether the overall results were similar if a nonlinear trend specification were used.)

Within each of these models the response variable is the log mortality rate for a particular age and sex, and in a particular year. Predictor variables include an intercept at the start of the time series, a linear trend term with year, and separate intercepts and trend terms for both the years of New Labour government (1997-2010), and for the peak years of the GFC (2008-2009; the GFC terms were included to avoid biasing any intercepts and trends associated with the Labour period).

In the second, actuarial stage of the modelling strategy, counterfactual age and sex specific mortality rates are produced by predicting age and sex specific mortality rates under the assumption that the New Labour terms (intercept and trend with year) apply for the years 2011 to 2015 (i.e. setting these dummy variables to ‘1’ in the models). The actual population counts for each age and sex, for each year from 2011 to 2015, are then applied to these counterfactual age-specific mortality risks in order to produce counterfactual estimates of the numbers of deaths that would be ‘expected’ at each age and for each sex for each of these years. These counterfactual age and sex-specific death counts are then compared, for each year, with the actual numbers of deaths reported for both sexes at different ages.

To show the age distribution of the differences between actual and expected levels in each year from 2011 to 2015, graphs are produced showing the summed differences in total deaths by different ages in each of these years. For example, the value on the vertical axis when the horizontal axis is age 50 shows the sum of differences between actual and expected deaths in that year from birth up to age 50, the value at age 60 is the sum of differences from birth to age 60, and so on. This means that the summed differences up to certain ages can be negative if there are fewer than expected deaths at some ages.

## Extrapolation in 2015

For the 2015 population data, population sizes were available disaggregated by age in single year up to the age of 89 years, whereas for previous years they were disaggregated up to age 104 years. For 2015 the relationship between total excess deaths and age was extrapolated up to age 95 based on the linear trend over ages 84 to 89. Total excess deaths for each year at age 89 and age 94 are discussed in the results section and it should be noted that the estimates up to age 89 years will be slightly less model dependent than those up to age 95 years in 2015 due to this extrapolation.

## Sensitivity analyses

Two forms of sensitivity analysis were conducted. Firstly, a structural sensitivity analysis in which a non-linear specification of the trend in age specific mortality rates over time, by including year squared terms as well as year terms. Secondly, a probabilistic sensitivity analysis, using a quasi-Bayesian statistical simulation approach [40] similar to those used in UK health economic modelling [41], was conducted to allow estimation of uncertainty intervals around estimates of excess deaths by various ages in each of the years from 2011 to 2015. Full results from these sensitivity analyses are presented in the appendix and summarises of these results are discussed in this paper.

# Results

## Description of model coefficients

Figure X in the appendix shows the regression coefficients for males and females of each age from the first year of life up to 94 years. The dark line in each of the subfigures shows the point estimate for a particular parameter, which is surrounded by a grey band indicating plus or minus two standard deviations (i.e. around a 95% coverage of estimates). Given the model contains a number of interactions it is not possible to directly infer the substantive implications of the model estimates to changes in mortality, but a number of findings are noteworthy.

The top row of the figure shows the intercept for each of the models, arranged by age and shown separately for males and females. This plot of model intercepts reveals the Gompertz Makham Law, also known as the ‘bathub curve’, which has been well known in demography and actuarial sciences for over a century, suggesting the model is appropriately specified. The ‘left side’ of the ‘bathtub’ is infant mortality. After this first year the risk of dying in the next 12 months then falls sharply, reaching very low levels throughout much of childhood, before rising rapidly on the onset of adulthood, then appearing to plateau during young adulthood. For females from their late twenties onwards, and males from their early to mid thirties, the intercept line then rises linearly with age, which given the response variable is log mortality implies an exponential increase in mortality risk with each additional year of life.

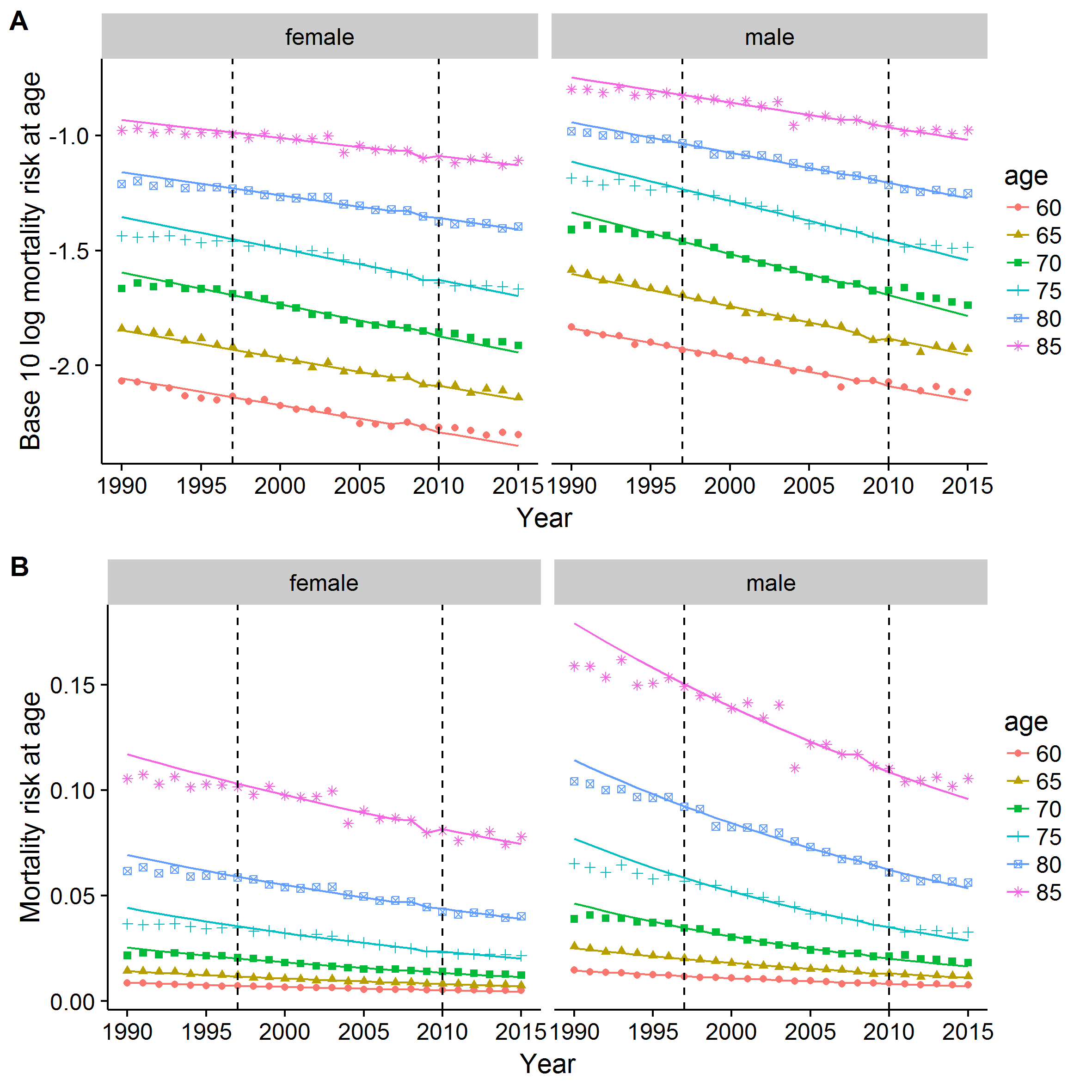
In effect, the top row in figure X shows the mortality risk at different ages in 1990. Other model parameters help to show how this mortality risk profile changed in subsequent years. The parameter ‘year’ shows the linear trend over subsequent years, having controlled for specific changes observed during New Labour and that may be due to the GFC. This ‘year’ parameter shows a reduction in log mortality at all ages, with the fastest falls in annual log mortality risk occurring in childhood, including infancy, but also at around the age of 65 years. Conversely, trends in log mortality risk reduction are slowest around the age of 40, and the rate of decline becomes smaller after around 65 years of age, suggesting a compression of highest mortality risk within the oldest pensioner age groups.

The New Labour years were associated with modest changes in the shape of the mortality risk reduction at most ages, with statistically significant effects for both sexes around the age of 70 years, and trends towards reduced mortality risk at older ages.

## Illustrative model projections

Figure 3 shows both actual ASMRs for select ages in different years from 1990 to 2015 as points, and the levels predicted by the model as a line, if the New Labour effects on intercept and trend were projected to both the pre- and post- New Labour period. The projections tend to be above the observed values for the pre Labour period, and below the observed values for the post Labour period, indicating that during the New Labour years ASMRs at these older ages tended to decrease at a faster rate compared with the earlier and later period. This seems particular the case for older ages in the series, especially on the identity scale (Figure 3B) rather than log10 scale (Figure 3 A), as would be expected given the higher baseline mortality risk at these higher ages. Equivalent ASMR trends at younger adult ages, as shown in the appendix, appear to show a contrary effect, but as the absolute mortality risks at these ages are much smaller the effects of elevated mortality in earlier adulthood are much smaller than the increased mortality risks compared with forward projections in at older ages. Greater numbers of excess deaths overall should therefore be expected in the post New Labour period than during New Labour.

Figure Forwards and backwards model projections of select ASMRs. (A) log10 mortality; (B) absolute mortality



## Total Estimated Excess Death, 2010-2015

Figure 4 shows the total ‘excess’ deaths in each year from 2010 to 2015, between birth and the age indicated on the horizontal axis, if the New Labour trends and intercepts were projected forwards and applied to age-specific population counts in each year. A vertical dashed line is added at age 65 years, because within these figures this age seems to mark an important turning point in the excess deaths by particular ages.

It appears from these figures that, for each year from 2010 to 2015, there tends to have been somewhat fewer deaths than expected between birth and the start of retirement age, but a much increasing number of excess deaths after retirement age, such that by ages 89 there were many more deaths than expected in total. These differences and worsening tendencies become evident from 2012 onwards, and appear have been getting worse, moving further from the New Labour trends, in each subsequent year. For the years 2010 to 2014 inclusive, population counts and death rates are also available at the ages of 90 to 95 years, but for 2015 only population and death counts disaggregated by age in single year up to the age of 89 years were made available by the ONS. The trends in total deaths by given ages are therefore projected to ages 90 to 95 years in 2015 for comparison with other years, using a linear regression of trends observed between ages 85 to 89 years. Even if only the trends in total excess deaths up to the age of 89 years were taken into consideration, however, then it appears 2015 saw a greater number of total excess deaths than the years 2012 to 2014.

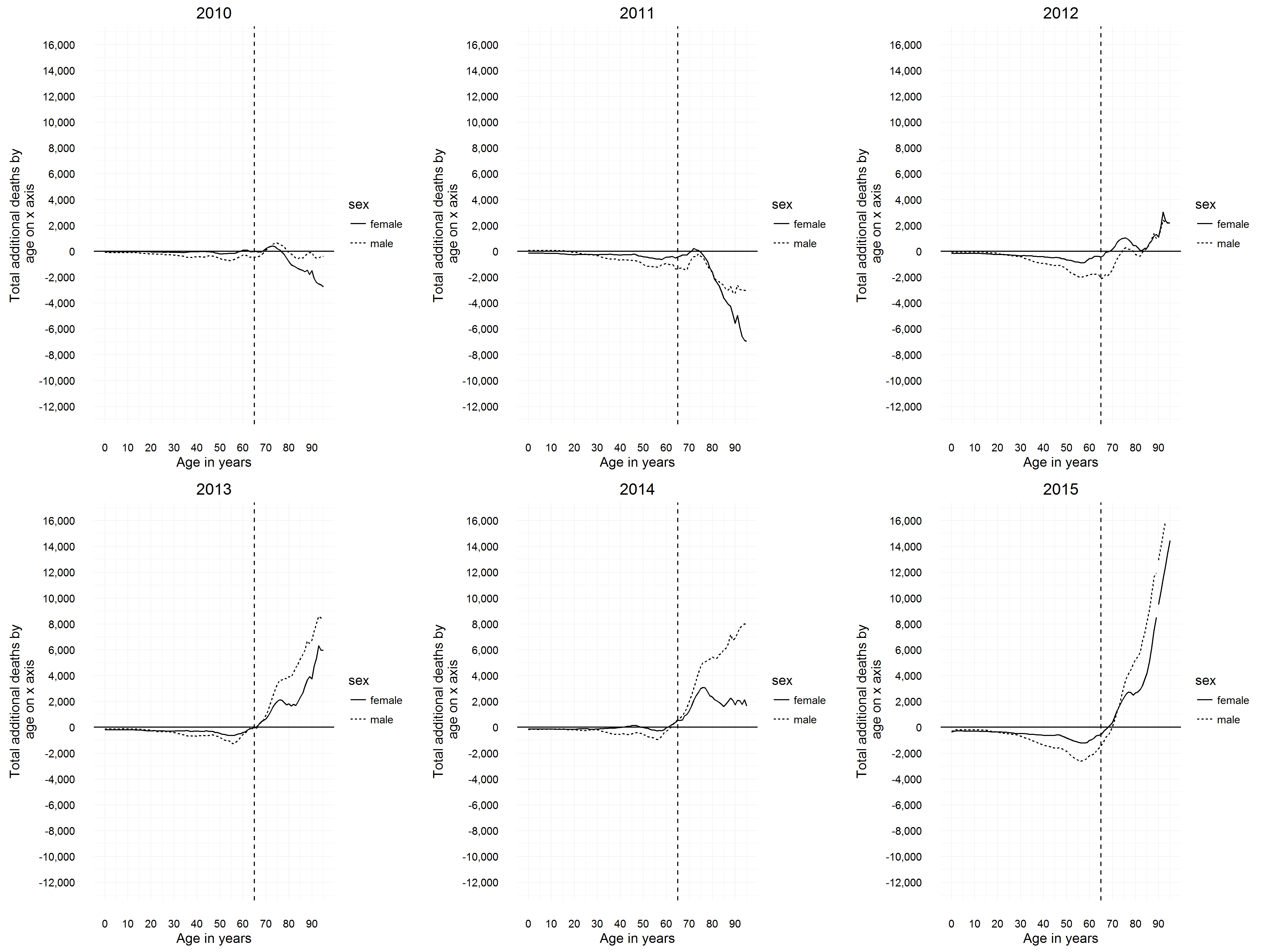
The models suggest that, between birth and the age of 89 years, there were around 20,000 excess deaths in 2015 (12,000 excess male deaths, and 8,000 excess female deaths), up from around 9,000 excess deaths in 2014 (7,000 male and 2,000 female), 11,000 excess deaths in 2013 (7,000 male and 4,000 female), and around 2,000 excess deaths in 2012 (1,000 male and 1,000 female). This produces a total of around 42,000 excess deaths by age 89 years in these four years. If the trend extrapolation to age 95 years in 2015 is accurate, then the total number of excess deaths by age 89 in these four years rises to around 60,000 excess deaths. However even if there are no additional excess deaths in 2015 after the age of 89 years, this total number of excess deaths over the four years only reduces to around 55,000 excess deaths.

## Sensitivity analyses

For the structural sensitivity analysis, an alternative model specification was produced which included year squared terms as well as year terms, allowing nonlinear trends in reductions in age-specific mortality risk to be captured. This model specification indicated fewer total excess deaths during 2010 and 2011, but more deaths per year from 2012 onwards, with increasingly more deaths for each year after 2012 compared with the standard model specification. Compared with this alternative model specification, the standard model specification therefore produced more conservative estimates of total excess deaths.

The probabilistic sensitivity analysis suggests a 95% credible range of excess deaths by age 89 of XXX to XXX in 2011, rising to between XXX and XXX in 2012, XXX and XXX in XXX in 2013 and XXX and XXX in … [etc]. It indicates an XX% probability that there were more rather than fewer deaths by age 89 in 2010, rising to an XX% probability of more rather than fewer deaths in 2015.

Figure Total 'excess deaths' (actual - projected) in England & Wales, for each year from 2010 to 2015.



# Discussion

The patterns of excess deaths produced by the modelling approach are consistent with what might be expected from a country that has been subject to both the longest decline in long-term economic growth rates, and longest period of lack of investment in healthcare and social care services since World War 2. This is both in terms of much increased and increasing levels of excess deaths amongst the elderly, but paradoxically also with somewhat reduced levels of deaths within working ages, in particular for males. It is known, for example, that mortality inequalities between people living in the most and least deprived quintiles of England tend to be lowest in late adolescence, and in the late 1990s briefly equalised around 17-19 years of age, [42] i.e. when disproportionately more young adults from the least deprived quintile would be both inexperienced at driving and first have access to a car than those from the most deprived quintile. Similar findings were also identified using more recent English data and morbidity measures. [43] Difference in ‘risk appetite’ may also help to explain particularly high ratios of male to female mortality in young adulthood, [44] reflected in the more ‘plateaued’ appearance of the age-mortality schedule in early adulthood for males compared with females. (Top row, figure XXX.)

The idea that both recessions and responses to recessions (‘austerity or stimulus’) can have differential effects, on different types of mortality, over different time scales, and at different ages, is not new, and in fact a central claim made in the Body Economic and elsewhere. [2,4] A sudden fall in vehicle related deaths after 2008, disproportionately affecting young adults, and in particular White Non-Hispanic males, is clear from publically available mortality data, which also hint at the 2008 recession leading to falls in violent deaths amongst Black Non-Hispanic males. [12] Similarly, amongst the many findings reported by the Global Burden of Disease (GBD) Study for England was a rapid fall in Road Injuries as a leading cause of death by years of life lost (YLL), from 10th place in 2005 to 16th place in 2013. [45], with Self-harm remaining at 9th place in the rankings in both years.

**Period-responsiveness: deaths from specific causes amongst working age; all-cause mortality amongst the elderly**

As evidence from the GBD and elsewhere indicates, within working age changes in death rates due to specific external causes, such vehicle related deaths, and ‘despair related’ deaths such as drug overdoses and suicides (broadly ‘Self harm’) tend to rise fairly quickly in response to changing ‘environmental stimulus’. This period responsiveness appears more acute in the USA than in many other rich nations, likely because healthcare and systems of social security are less effective than in most comparable nations. Changes in these specific causes of death amongst people of working age are unlikely to greatly affect changes all-cause mortality, however, as most deaths do not occur within working age. However, changes to the funding and functioning of social care and healthcare are likely to influence all-cause mortality amongst the elderly. After people get beyond working age, and in particular once they become increasingly dependent on healthcare and social care services to continue living well, with a reasonable quality of life, then the level of investment in these services can be expected to have an effect on their mortality risks. This is exactly what the excess death estimates, and their concentration at older ages, indicate. The people most affected are likely to be particularly old and frail, and so to know the true cost of such cuts on cutting many lives a little shorter, accurate and highly disaggregated population and death count data need to be made available for persons aged more than 90 years of age. It is therefore not surprising that we have seen increases in all-cause death rates amongst the elderly but not the working age population.

**Lagged effects, lifecourse disadvantage, and cohort-responses to changing socioeconomic environments**

Death rates from specific external causes amongst the working age, and changes in all cause mortality amongst the elderly, both respond relatively quickly to changes in economic conditions and investment in public services. They are both epidemiologic ‘canaries’ suggesting conditions have changed for the worse. But the death of a canary is usually not the first indicator that it is experiencing distress, and other people, unlike canaries, can tell us of this distress directly, if we choose to listen. The Coalition government introduced annual measurements of subjective wellbeing in 2010, and in each successive year scores have fallen within most age groups. [46–48]

If lower subjective wellbeing scores at most ages, a few fewer vehicle related deaths and a few more suicides amongst the working age, and a large number of additional deaths amongst the elderly, lagged by a couple of years, are the shorter-term consequences of the GFC and the austerity experiment, longer-term mortality consequences can be expected, especially if …

The finding that, in the USA, despair-related deaths rose after 2008 amongst middle-aged White Non-Hispanics has been widely reported and covered. [10,12] Visual exploration by sex, ethnicity and age suggests rates due to suicides and poisonings appeared to rise sharply after 2008, but had been rising previously since at least 1999; [12] statistical modelling suggests in the USA suicides rates …

… There is also some evidence that suicide rates there is evidence of more subtle and lagged effects The Trends in deaths due to suicide and poisonings in this age group rose quite sharply in the US, mainly affecting in the USA is clear from the public health

## Limitations

Population estimates for ages over 90 years are not routinely available disaggregated by age in single years as part of standard UK population estimates, and are estimated by the ONS within the main dataset used in these analyses based on population and mortality rates at younger ages. Given that our results indicated that much of the additional burden of excess mortality has been at some of the oldest ages, however, we considered it important to produce estimates of total excess deaths which include ages up to 95 years, despite these limitations. These limitations in the quality and availability of highly disaggregated data at some of the oldest ages are not just limitations affecting our analyses, but limitations which may hide some of the greatest mortality excesses which have occurred in England & Wales within the previous decade. Effective measurement and dissemination of age-disaggregated population and death counts at and above the age of 90 years should therefore be a national record keeping priority.

As has been noted many times before, “all models are wrong, but some are useful”. [49] This model is clearly ‘wrong’ in the sense that it applies projected mortality rates to observed population counts for a number of consecutive years, and of course different mortality rates at any particular age would affect the number of people alive and thus exposed to the mortality rate of people one year older in the following year. However, we argue this approach is appropriate for aggregate quantification of harms or benefits, because otherwise sufficiently large premature mortality could give the impression that deleterious trends are actually positive. For example, if there were a sudden rise in deaths due to cardiovascular events occurring in populations in their late sixties there may then be a fall in deaths due to cancer amongst people in their seventies a few years later, but this should not be considered evidence of improvements in cancer treatment and care. For similar reasons, we have not altered the population sizes exposed to age-specific mortality risks in each of the years, only the degree of risks such populations are exposed to at each age.

The issue of how to accurately estimate the counterfactual is intrinsic to quantifying the consequences of different actions or clusters of actions. In this case these consequences are measured in deaths, and the cluster of actions these deaths are thought to have occurred in response to is known as ‘austerity’. Alternative, and arguably more sophisticated, statistical modelling strategies could have been used, and the actuarial estimates of excess deaths produced would change. However we argue that the modelling approach used represents a reasonable operationalisation of intuitions about age specific mortality trajectories developed from exploring very large amounts of demographic data from throughout the affluent world, and that these intuitions are relatively straightforward to explain and justify. The assumptions built into the modelling approach are likely to be slightly less appropriate at some younger ages (e.g. between around the ages of 3 and 40 years) but these are unlikely to greatly affect the total numbers of excess deaths estimated as most deaths occur in the elderly.

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# Appendices

## The modelling approach

## Model

For each sex, and for each age in single years, a, from birth to 95 years old, a separate linear regression model was fit with the following specification:

|  |  |
| --- | --- |
|  | (1) |

Where is the mortality rate (death count divided by population count) in year t, at age a, and for sex s; t is year; L is a dummy variable indicating the years, 1997 to 2010, in which New Labour were in government; R is a dummy variable indicating 2008 and 2009, the years in which the UK economy entered a recession as a result of the GFC, and is an error term. The R term is included to capture any additional short-term changes in mortality rates to be captured in a separate term rather than influence the coefficients including New Labour years, and . The use of interaction terms Lt and Rt allowed for the gradients of change in log mortality rates over time to be different over the New Labour and GFC recession periods.

The above model specification was fit to ONS data for each year from 1990 to 2010 inclusive. Redefining , projected log mortality rates were calculated for years 2011 to 2015 inclusive by setting t to these year values and L to 1, i.e.

|  |  |
| --- | --- |
|  | (2) |

Predicted numbers of deaths at each age, for each sex, and in each year from 2011 to 2015 were therefore calculated by multiplying the relevant age-year-sex specific population counts by the requisite projected mortality rates, i.e.

|  |  |
| --- | --- |
| or equivalently | (3) |

Where is the projected mortality rate rather than log rate.

The age-sex specific differences in deaths are therefore , and the total difference in deaths by age A, shown in figures xxx, is .

As death and population counts from the ONS for the year 2015 was aggregated for years 90 and above rather than disaggregated by age in single years, for ages 90 to 95 years was estimated by extrapolating over ages 84 to 89 years.

