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Estimation of future cases of dementia from those born in 2015

This report was commissioned by Alzheimer's Research UK

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1. Executive Summary

OHE were asked to estimate the number of people born in 2015 who would likely develop dementia during their lifetime. Based on conservative assumptions¹ for future life expectancy we estimate that:

- **27% of males born in 2015 in the UK will develop dementia²;**
- **37% of females born in 2015 in the UK will develop dementia²;**
- **32% of people born in 2015 in the UK will develop dementia².**

Given the conservative nature of these estimates – that life expectancy will not improve in the future – then it would not be unreasonable to communicate these results as **one out of every three people born in 2015 will develop dementia during their lifetime**. These are our recommended estimates, but because there is considerable uncertainty in the data a range of additional estimates are also provided. Note that due to a paucity of robust data we have only considered the onset of dementia in people aged 60 or above, which also makes our above estimates potentially conservative.

2. Introduction

The proposal to Alzheimer's Research UK (ARUK) is embedded below. The key task was to produce estimates of the number of people born in 2015 that would develop dementia in their lifetime.



Three components are needed: i) estimates of how many people born in 2015 will survive to a given age; ii) age and sex specific estimates of the incidence of dementia; iii) an epidemiological model capable of measuring the flow of people between non-dementia and dementia, while mimicking overall population dynamics consistent with survival data. All analyses were conducted in Mathematica software, and the Mathematica workbooks used for the calculation are embedded in the Appendix as both PDF format (for readability) and also the original format to allow analyses to be repeated (requires access to Mathematica 10+).

Note that throughout we are considering only dementia in people aged 60 and over. This is because there are insufficient good quality data to allow for age-based calculations on the onset of dementia in younger ages.

¹ In terms of the choice used of projected improvements in life expectancy provided by the Office for National Statistics

² In our analysis we only consider late onset dementia, i.e. dementia in those aged 60 and over.

3. Data sources

The Demographic Analysis Branch within the Office for National Statistics (ONS) publishes “Period and Cohort Life Tables”. These detail how many of 100,000 people born in a given year (in our case born in 2015) survive to a given age (estimation stops at age 100). We use the “principal projection” estimate because this is the primary estimate used for government planning. There are two very different methodological variants, period mortality and cohort mortality. Period mortality projects survival forward from 2015 applying current estimated age-sex specific mortality rates (e.g. as at 2015). In contrast, cohort mortality incorporates projections which assume mortality will change (be lower) in the future, and compared to period mortality many more people are estimated to survive at each age. Survival based on cohort mortality is much less certain as it extrapolates beyond current data making implicit assumptions about how much longer people will live projecting forward 100 years into the future. We include analyses for both period and cohort mortality survival as these give very different results.

The second source of data used was CFAS I³ which provides estimates of age and sex specific incidence of dementia. These data are rather old but are arguably still the best available before incidence estimates from CFAS II are published. It has been agreed that we will update the main estimates once incidence from CFAS II is available (prevalence estimates were published in 2013, but not incidence).

A third data source is used, again from the ONS, and this is the number of death registrations in England and Wales due to all causes, and specifically due to dementias (ICD10 F01/03). This is to compute the relative proportion of deaths which are due to dementia. The reason why these data are relevant is discussed in section 4.

Finally, we assume that the age-sex specific rates from CFAS I apply to the UK, similarly for age-sex specific dementia mortality rates from the ONS for England and Wales.

4. Epidemiological Model

Basic model

We have a survival curve with age, i.e. how many people out of an original 100,000 born in 2015 survive to age x (or equivalently how many are still alive at year 2015+ x). We can construct a system of two ordinary differential equations:

$$\frac{dS}{da} = -\mu(a)\frac{S}{S+I} - \lambda(a)S; \quad (1)$$

$$\frac{dI}{da} = -\mu(a)\frac{I}{S+I} + \lambda(a)S; \quad (2)$$

where:

- S and I are the number of people of age a without-dementia and with-dementia respectively;
- $\lambda(a)$ is the age-sex specific per capita rate of onset – this is the per capita incidence rate, which is taken from CFAS I; and

³ <http://www.cfas.ac.uk/pages/hincidence/index.html>

- $\mu(a)$ is the total age-sex specific death rate.

These two equations define the flows in the population – at each age a an individual can either leave the population due to death (this is the $\mu(a)$ rate) or else move from without-dementia into the with-dementia cohort (flow from $S \rightarrow I$). In order to maintain the correct demography we require that the solution $N(a)=S(a)+I(a)$ exactly matches the data estimates from the ONS life tables. By adding the two equations above together we get

$$\frac{dN}{da} = -\mu(a), \quad (3)$$

which ensures that the total population size exactly matches the life table estimates from the ONS⁴. The total flow from without-dementia into with-dementia – which is what we require, as this is the **total number of people who develop dementia during their lifetime** - is the number

$$N_{dementia} = \int_{a=60}^{a=\infty} \lambda(a) S da, \quad (4)$$

which can be calculated by solving (1) and (2) above to get S and evaluating the integral in (4) (which is simply the sum of the total flow of people of all ages 60 years and above from S into I).

Improved model

The model in (1)-(2), while attractive in its simplicity, does make a less than optimal assumption; in order to ensure the demography is correct we have apportioned the total number of deaths at each age pro-rata across both the S (without-dementia) and I (with-dementia) cohorts. All else being equal there should be a higher number of deaths in the with-dementia cohort compared to the without-dementia cohort. We address this by adjusting the death rate *downwards* in the model by multiplying the estimated per capita death rate by a factor $\theta(a) < 1$, which is estimated from ONS deaths registrations and is the proportion of deaths due to reasons other than dementia. This then reduces the death rate in the S cohort due to excluding mortality from dementia, and thus means that there are now more S in the population at all ages compared to the existing model (in (1)-(2)), and therefore the flow from without-dementia into with-dementia will be greater⁵. This improved model is

$$\frac{dS}{da} = -\mu(a)\theta(a)\frac{S}{S+I} - \lambda(a)S; \quad (5)$$

$$\frac{dI}{da} = -\mu(a)\theta(a)\frac{I}{S+I} + \lambda(a)S. \quad (6)$$

⁴ by construction because we fix $-\mu(a)$ to be the derivative of the survival curve from the life tables – see Mathematica workbook for technical implementation

⁵ Technical note: in this adjustment the death rate in the with-dementia cohort will now be too low (as we use the same death rate parameter $\mu(a)$ in each of S and I) but this does **not** affect our estimate of the total number of people born in 2015 who develop dementia, but will result in a slight underestimate in the prevalence of dementia, $I/(S+I)$ from the model but we are not using this value in any analyses.

We use the model in (5)-(6) to estimate (4), the total number of people born in 2015 who will develop dementia.

Entirely separate data and models are used for males and females due to their very different life expectancies and incidence of dementia.

5. Results

Life tables

We start with presenting the life table data (Figures 1-2) which shows how the very different assumptions of period and cohort mortality affect the future survival prospects of males and females born in 2015. We can also see that, as expected, females have longer life expectancy than males (there are more females alive at each age than males). For example it is estimated that 4% of females born in 2015 will survive to age 100 applying period mortality, whereas applying cohort mortality this increases to 40%. The corresponding values for males are 2% and 31%.

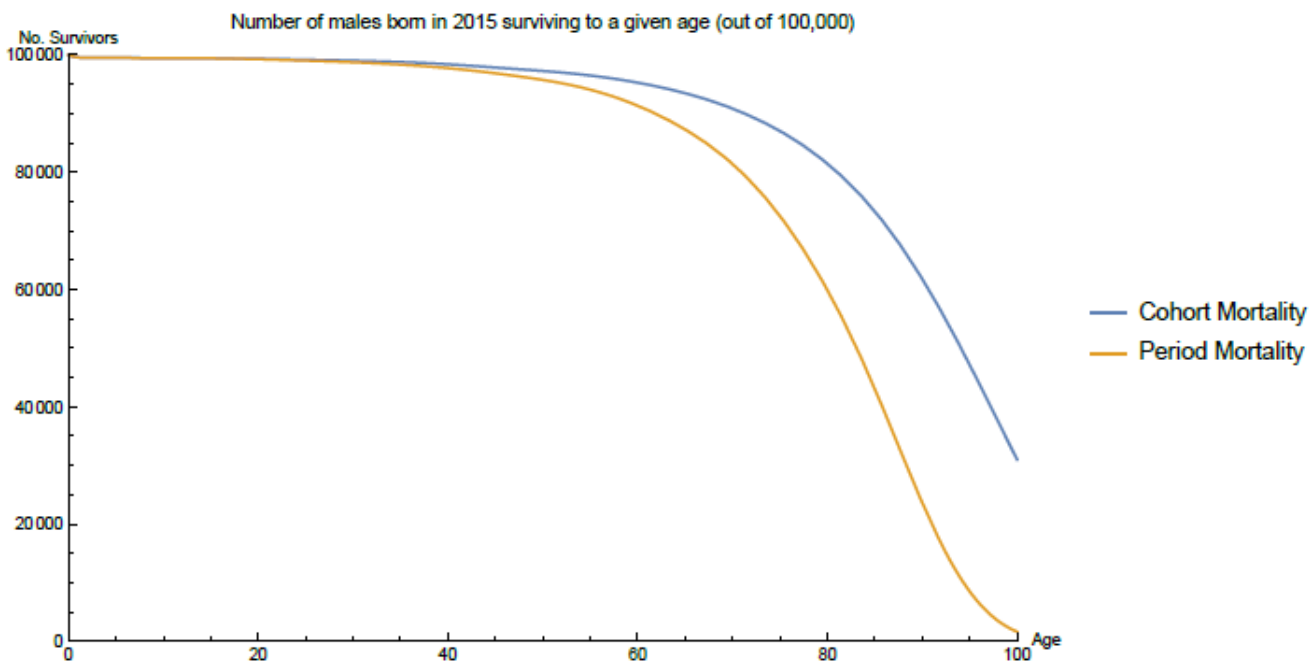


Figure 1. Male survival from 2015. Source: ONS.

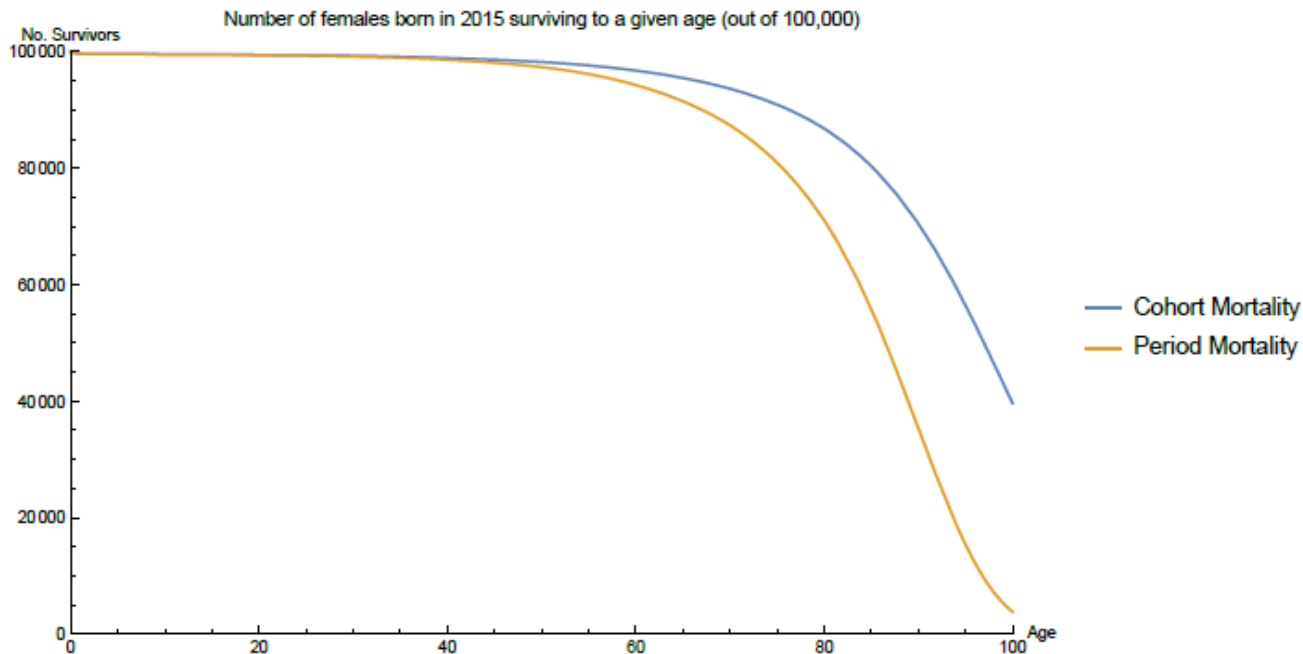


Figure 2. Female survival from 2015. Source: ONS.

CFAS incidence

Figure 3 shows the estimated age-specific incidence of dementia in males using CFAS I data. This curve is not smooth because it joins together⁶ statistical point estimates from wide age bands. This uses mean estimates and assumes a constant incidence from age 85+. The female incidence curve is similar in shape (not shown).

⁶ Technically we create an interpolation function across the various point estimates, only linear interpolation is used because there are so few point estimates which is why the curve is rather "lumpy". More data points would allow for a smoother curve.

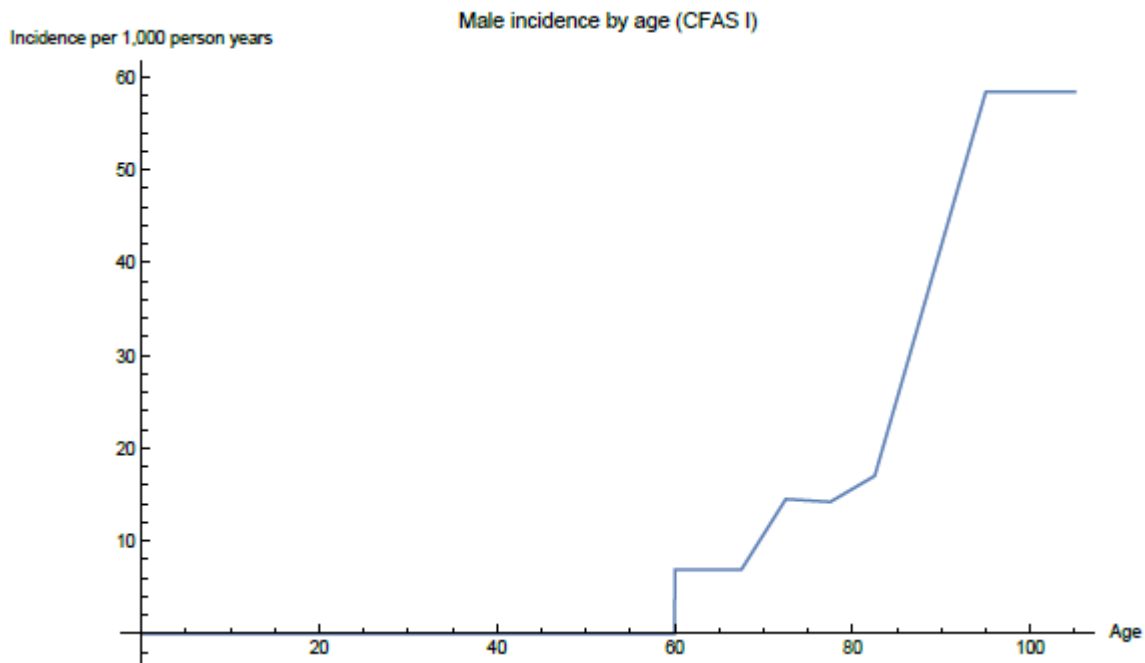


Figure 3. Incidence in males (mean estimate), number of cases per 1,000 person years. Source: CFAS I.

Model output

Figure 4 shows the resulting S and I values over age for the improved model for males. Figure 5 is similar but for females. An observation here is to note that the prevalence of dementia in the figures is larger than current (e.g. CFAS I) prevalence estimates, e.g. at the very oldest ages this is above 50% (yellow line is above blue line). We are applying current estimates of (per capita) incidence to the future UK population which has a very different demographic (i.e. mortality) profile from the existing UK population - in the future many more people live longer meaning that they have a greater chance of developing dementia before they die.

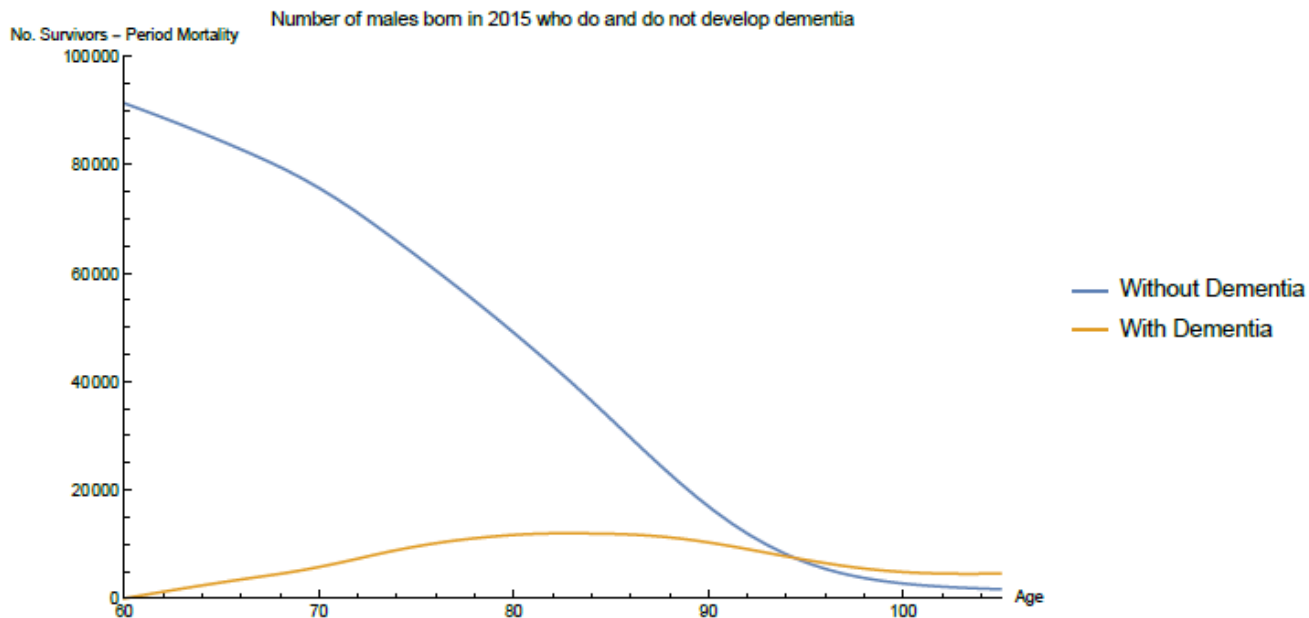


Figure 4. Number of males without and with dementia using period mortality. Source: OHE Consulting analysis.

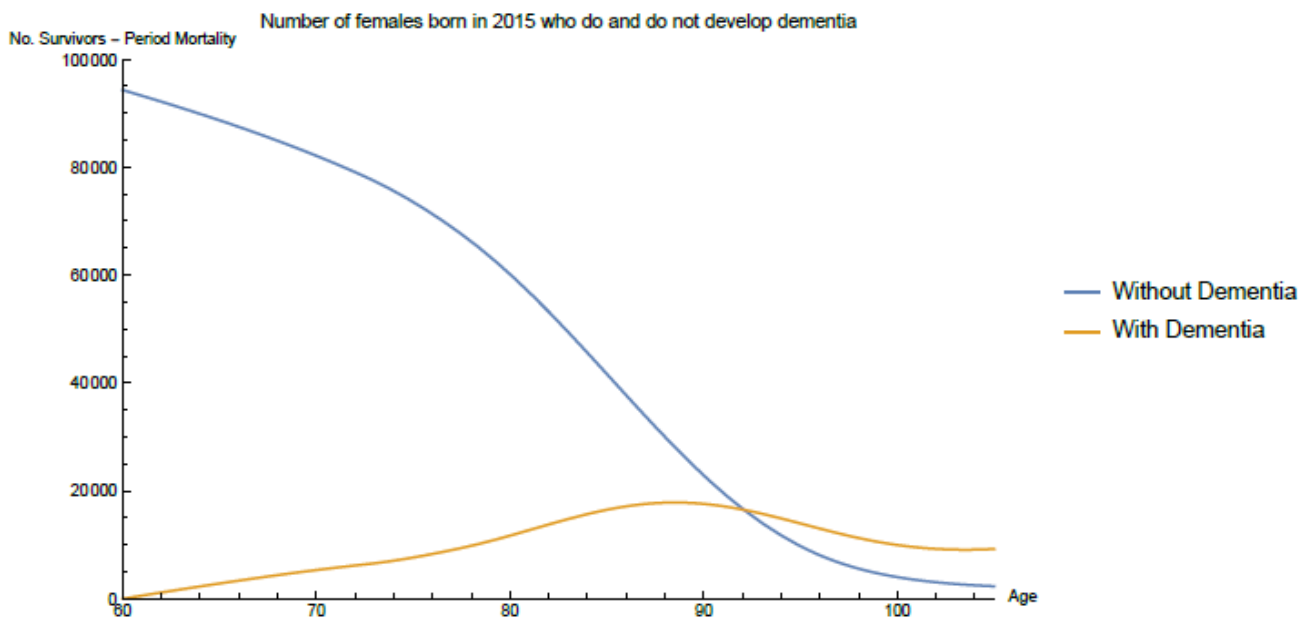


Figure 5. Number of females without and with dementia using period mortality. Source: OHE Consulting analysis.

Numerical summary of results

Table 1 provides numerical estimates for $N_{dementia}$, the % of males (females) born in 2015 who will develop dementia during their lifetime. Two sets of variants are shown, results using period mortality and cohort mortality separately. Within each of these we show results using the mean per capita incidence estimates from CFAS I (our recommended results), and also estimates using the lower and upper 95% confidence interval estimates⁷ of per capita incidence from CFAS I. The estimates using cohort mortality are considerably larger than those using period mortality, e.g. 27.4% versus 46.6%. The estimates based on cohort mortality are given as "At least 46.6%". The reason for this is explained below.

We suggest that results based on period mortality are more reasonable, if potentially conservative. A justification for this is twofold. Firstly, projecting future improvements in mortality rates 100 years into the future is highly uncertain, requiring therefore considerable caution in the use of cohort mortality based estimates. Secondly, available incidence estimates have considerable uncertainty themselves, i.e. have wide confidence intervals and use broad age bands. In cohort mortality some 40% of the population are still alive at age 100, and estimates of their survival beyond this point are not provided by the ONS. We have attempted only to extrapolate up to age 105 (in incidence, survival and mortality rates adjustment using deaths registrations), as beyond this the extrapolation becomes highly unstable. The life table data stops at age 100, the incidence estimates at age 85+ and the deaths registrations at age 95+. This is why the results for cohort mortality say "At least" as these estimates do not include new cases of dementia in those aged above 105. This would require moving sufficiently far beyond all available current data that these results would be – in our view - unreasonably unreliable.

We recommend reporting our preferred estimates of 27.4% of males developing dementia in their lifetime and 37.2% of females as simply 27% and 37% respectively for the reasons above regarding extrapolation. There are a (very) small number of males and females without dementia still alive beyond age 105 using period mortality – see the blue line in Figures 4 and 5 - which could still develop dementia and these have not been included in our estimates using period mortality (for reasons of stability given above). Sensitivity analyses suggest that the magnitude of this impact is very minor, possibly adding one or two tenths of a percent onto the final estimate. In addition, reporting estimates down to a tenth of a percent implies a level of accuracy which is arguably not appropriate given all the uncertainties present in the estimation process.

	% of males born in 2015	% of females born in 2015
Period Mortality – mean	27.4	37.2
Period Mortality – lower	14.8	27.5
Period Mortality – upper	43.0	47.9
Cohort Mortality – mean	At least 46.6	At least 57.5
Cohort Mortality – lower	At least 27.1	At least 45.9
Cohort Mortality – upper	At least 64.1	At least 67.8

Table 1. Numerical summary of proportion of males and females (aged 60 and over) who will develop dementia during their lifetime. Source: OHE Consulting analysis.

⁷ See table with 95% CI here <http://www.cfas.ac.uk/pages/hincidence/index.html>

We conclude by presenting selected results aggregating across sex. According to analyses by the UK Department of Health⁸ the gender ratio in the UK is approximately 105 male births to 100 female births. To calculate the percentage of persons born in the UK in 2015 who will develop dementia, we simply weight the estimates in Table 1 appropriately (i.e. $(105 * \text{Males} + 100 * \text{Females}) / 205$). These results are given in Table 2. As above we recommend reporting results as 32% rather than down to one decimal place.

	% of persons born in 2015
Period Mortality – mean	32.2
Period Mortality – lower	21.0
Period Mortality – upper	45.4

Table 2. Numerical summary of proportion of persons (aged 60 and over) who will develop dementia during their lifetime. Source: OHE Consulting analysis.

6. Appendix

Additional results

Table 2 reports additional results using the 'basic' rather than the 'improved' model. These estimates are, as should be the case, less than those in Table 1 as the basic model assumes a higher mortality. These values should not be very different from those in Table 1 as deaths due to dementia (as reported by the ONS) are a small proportion of all deaths.

	% of Males born in 2015	% of Females born in 2015
Period Mortality – mean	25.1	33.3
Period Mortality – lower	13.2	23.7
Period Mortality – upper	40.8	44.3
Cohort Mortality – mean	At least 45.0	At least 55.1
Cohort Mortality – lower	At least 25.9	At least 43.6
Cohort Mortality – upper	At least 62.7	At least 65.7

Table 3. Numerical summary of proportion of males and females (aged 60 and over) who will develop dementia during their lifetime using basic model. Source: OHE Consulting analysis.

Embedded files

Below are PDF and native Mathematica versions of the workbooks used for all the modelling results contained in this report. These contain all the technical details, models, and data.

⁸https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200527/Gender_birth_ratio_in_the_UK.pdf



males



females



males.nb



females.nb