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Assumptions on mortality

The growth of Australia's very elderly population: past estimates and probabilistic forecasts

Tom Wilson and Wilma Terblanche, Australia[1]

Summary

Official population estimates in Australia are overstated at the very highest ages, resulting in inaccurate mortality rates, and unreliable forecasts. Official population forecasts are not accompanied by information about their uncertainty, and do not extend into the centenarian ages. The aim of this paper is to present more accurate estimates of the very elderly population of Australia (those aged 85+) from 1971 to 2014, and probabilistic forecasts out to 2051 by sex and single years of age up to age 110+. Population estimates were calculated from death counts using Extinct Cohort and Survivor Ratio methods, the latter being a newly-refined version. Population forecasts were produced using a probabilistic cohort-component model. The 85+ population of Australia grew from 69,000 in 1971 to 456,000 in 2014, in large part due to mortality reductions. It is forecast to increase to 1.90 million by 2051, with the 95% prediction interval spanning 1.51 to 2.37 million. The future growth in centenarians is proportionally far greater, but relatively more uncertain. Although the extent of future growth cannot be forecast precisely, huge increases in Australia's very elderly population will eventuate.

[1] [Prepared by Tom Wilson, Principal Research Fellow, Charles Darwin University, and Wilma Terblanche, Assistant Professor, Bond University].

I. Introduction

1. In common with other industrialised countries, the substantial growth of the elderly population is one of the most prominent features of contemporary Australian demography. Conventionally defined as those aged 65 years and over, the elderly component of the population has increased in number from 1.09 million in 1971 (8.3% of the total population) to 1.95 million in 1991 (11.3%) and 3.45 million in 2014 (14.7%) (ABS 2015). However, for many service providers, planners and policymakers, it is the very elderly – often defined as those aged 85 years and above – who are of greatest significance. They are the fastest growing age group in the population and have considerable needs in terms of health, accommodation, income support, and aged-care services (Chomik & MacLennan 2014). They comprise a rapidly growing, and thus increasingly influential, group of consumers and voters.

2. There is no shortage of research examining population ageing internationally and in Australia, including its characteristics, drivers, and multitude of consequences (e.g. Beard et al. 2012; Cubit & Meyer 2011; Christensen et al. 2009; Productivity Commission 2013; Rowland 2012; Terblanche & Wilson 2014). Neither is there a lack of political awareness of the topic. The Australian Government's Treasury is keenly aware of the implications of population ageing, and every few years produces an 'intergenerational report' focusing primarily on the budgetary consequences of the nation's future population ageing (Treasury 2015). The Productivity Commission, an Australian Government research agency, has also published several major reports on population ageing (e.g. Productivity Commission 2013). But much of this work tends to discuss the 65+ population in fairly homogenous terms. From a policy perspective, those at the very highest ages have greater needs, and there are fewer studies which specifically concentrate on the past and future trends of this important section of the population (but see, for example, McCormack 2010, and Terblanche & Wilson 2014).

3. Many studies which do focus on Australia's very elderly population tend to be limited by at least one of three key issues. First, they often use official population estimates and forecasts. As has been shown for Australia (Terblanche & Wilson 2014) and many other countries (Thatcher et al. 2002), official population estimates at the highest ages are not as accurate as they could be. This is due to mistakes in reporting age on census forms as well as errors introduced in census editing and processing. The published population estimates tend to be overstated from somewhere in the mid-90s upwards, with the problem increasing in severity with increasing age, and worse for males than females (Terblanche 2015a). Consequently, mortality rates, which use these population estimates as denominators, are understated. Mortality forecasts at the highest ages, and hence population forecasts themselves, are therefore also affected.

4. Second, existing studies often use a final age group of 85+ or 90+, and sometimes 100+, which is the final age group of official Australian Bureau of Statistics (ABS) Estimated Resident Populations (ERPs). Forecasting a mortality rate for the 90+ population, for example, would not account for the changing age distribution within that age group and its impact on the mortality rate. With a rapidly growing and heterogeneous very elderly population, it is wise to extend the estimates by single years of age up to an age where the final open-ended age group has fewer people in it than the previous single year age group.

5. Third, few forecasts of the very elderly are accompanied by any indication of their uncertainty, yet many studies have demonstrated that population forecasts always contain some degree of error (e.g. Keilman 2008; Wilson 2012). The traditional way of representing forecast uncertainty is to produce alternative high and low projection variants. But this approach is beset with problems (Lee 1999; Wilson & Bell 2004). There is usually no information supplied on the likelihood of future population lying within the high-low range; the high and low variants are often produced by changing fertility and/or migration assumptions, which will clearly understate uncertainty for the elderly population because of the dominance of mortality at these ages; and the high-low range tends to be inconsistent over time and across variables. Probabilistic population forecasts overcome these limitations, and illustrate the uncertainty of forecasts with internally consistent prediction intervals. Such forecasts have received considerable research attention in demography over the past 20 years (e.g. Alho et al. 2008; Bell et al. 2011; Bijak et al. 2015; Keilman et al. 2002; Wilson & Rees 2005). But the very top end of the age distribution has not been prominent in this work.

6. This paper presents new estimates and forecasts of Australia's very elderly population which attempt to overcome these limitations. New population estimates, extending from 1971 to 2014, were created using a combination of Extinct Cohort and Survivor Ratio methods. These two methods have been shown to yield far more accurate population numbers than census-based estimates (Terblanche & Wilson 2015b; Thatcher et al. 2002; Wilmoth et al. 2007). Our estimates also extend to higher ages than the official ERPs: they are broken down by sex and single years of age up to 109, with a final age group of 110+. The estimates were then used as denominators for mortality rates, which provided the input data to forecast mortality. The future growth and uncertainty of Australia's very elderly population is shown by probabilistic forecasts extending out to 2051. Particular attention is given to future centenarian (100+) and semi-supercentenarian (105+) populations.

II. Data and methods

a) Population estimates

7. Population numbers for 1971 to 2014 by sex and single years of age from 85 to 109 and 110+ were estimated from death counts using the Extinct Cohort (Vincent 1951) and Survivor Ratio methods (Dépoid 1973). Population estimation methods which make use of deaths have been found to produce more accurate very elderly population estimates than those based on census counts because of more accurate information on age in deaths data (Coale & Caselli 1990; Jdanov et al. 2005; Thatcher 1992; Thatcher et al. 2002). These methods are described below.

<u>Extinct Cohort method</u>

8. The Extinct Cohort method was used to calculate historical population numbers for cohorts for which all members have died. A population estimate for an extinct cohort for any year and age is obtained by summing subsequent cohort deaths (Coale & Caselli 1990; Kannisto et al. 1994; Vincent 1951). The population of the cohort c aged x last birthday on 31st December of year t $P_{x,t}$ is:

$$P_{x,t} = \sum_{i=1}^{\omega-x} \mathrm{D}_{t+i}^{c}$$

where w is the age of extinction, and D^c_{t+i} is the number of deaths in year t+i from cohort c, which are people born in the year t-x. In line with Thatcher et al. (2002) w is estimated as the highest age at which there was expected to be only one survivor. w did not exceed 110 in any year. The Extinct Cohort method was used to estimate population numbers from 1971 to 2014 for cohorts born in 1903 and earlier.

9. Death counts by single year of age for individual calendar years from 1971 to 2014 were obtained from the ABS. Deaths were split between cohorts based on relative birth numbers and estimated survival probabilities (Terblanche & Wilson 2015a). In applying this method an implicit assumption is made that deaths are the only source of population flows, and thus that international migration at these ages is negligible and can be ignored (Thatcher 1992).

Survivor Ratio method

10. For cohorts that are nearly extinct, population numbers were estimated using the Survivor Ratio method (Dépoid 1973; Thatcher et al. 2002). The Survivor Ratio method was used to estimate population numbers for cohorts aged between 85 and 110+ at 31st December 2014, or cohorts born between 1904 and 1929. Cohort populations in earlier years were then obtained by adding deaths as for the Extinct Cohort method.

11. The survivor ratio R_x is defined as the ratio of a cohort's population at the calculation date to its size k years ago, and can be expressed as:

$$R_x = \frac{P_{x,t}}{P_{x-k,t-k}}.$$

12. According to the Extinct Cohort method, the number of survivors from a particular cohort k years earlier can be written as:

$$P_{x-k,t-k} = P_{x,t} + \sum_{i=0}^{k-1} D^c_{t-i}$$

so that the survivor ratio for this cohort over k years is:

$$R_x = \frac{P_{x,t}}{P_{x,t} + \sum_{i=0}^{k-1} D^c_{t-i}}.$$

The estimated population aged x at 31st December of year t is thus:

$$P_{x,t} = \frac{R_x}{1 - R_x} \times \sum_{i=0}^{k-1} D^c_{t-i}.$$

13. Based on a retrospective assessment of the accuracy of various nearly extinct cohort estimation methods for Australia, it was found that survivor ratios based on a 5-year age range and 5 older cohorts produced accurate results (Terblanche & Wilson 2015b). Terblanche & Wilson (2015b) furthermore found that survival improvement across cohorts is best allowed for indirectly by constraining the total nearly-extinct population at the calculation date to the total official population estimates for ages 85+. Official Estimated Resident Populations (ERPs) are provided by the ABS (2015) for single ages

85-99 and in aggregate for ages 100+. ERPs at 30th June were interpolated to 31st December. This method differs slightly from that used by the Human Mortality Database (HMD) in that the HMD applies a constraint of 90+ ERP rather than 85+ ERP. While the Survivor Ratio method with results constrained to 90+ ERP was found to produce very accurate estimates for Australian females, applying an 85+ ERP constraint was found to produce more accurate estimates for Australia on average across age ranges and the sexes (Terblanche & Wilson 2015b).

14. Period and cohort life tables were constructed using the death data and population estimates at ages 85-110+ for 1971 to 2014 derived using the Extinct Cohort and Survivor Ratio methods, and ERPs for ages below 85 from the ABS (2015). These were supplemented with estimates for earlier periods using Australian death data from the Human Mortality Database (HMD 2015), and, for the younger ages, by historical life tables published by the ABS (2008).

b) Population forecasts

Forecasting model and program

15. Forecasts of the very elderly population were prepared using a probabilistic cohort-component model. Probabilistic models explicitly incorporate uncertainty about the demographic future and produce forecasts as predictive distributions rather than the single set of numbers which are output by conventional deterministic models. These distributions are created by running a cohort-component model several thousand times with randomly generated sample paths of fertility, mortality and migration, usually from time series models. The thousands of forecast outcomes are then sorted from highest to lowest so that prediction intervals can be marked out. For example, a 95% prediction interval in a set of 5,000 ranked forecasts extends from the 125th value to the 4,875th.

16. The forecasting program used in this study was PROBPOP (PROBabilistic POpulation Projections), developed by the first author of the chapter for earlier research (Bell et al. 2011). A minor refinement was made for the present study by adding uncertainty in the initial populations. The model operates in single year intervals with the population disaggregated by sex and single years of age up to 109, ending with age 110+. Time series models are used to generate sample paths for the Total Fertility Rate, life expectancy at birth by sex, total immigration, and total emigration. The varying male and female life expectancy paths, and immigration and emigration trajectories, are correlated in the forecasts to mimic historical trends. The calculations of PROBPOP are performed by a fortran 95 program, though data inputs, assumptions and parameters are read in from an Excel workbook. In this application the jump-off and final dates were set as 30th June 2014 and 30th June 2051 respectively, and 5,000 simulations were chosen. As the simulations are generated, forecasts are progressively written to output files which effectively comprise a large unsorted output database. A separate program then reads and sorts the thousands of forecasts and presents selected outputs in Excel.

Input data and assumptions

17. The forecasts begin with the newly-created 30th June 2014 population estimates, calculated using the approach described above in section 2.1. These initial jump-off populations were subject to random variation in each of the 5,000 forecast simulations because in Australia these numbers are population estimates, not precise counts.

18. The long-run Total Fertility Rate (TFR) assumption used was 1.90, approximately the level of fertility recorded in Australia for the last few years (ABS 2015). Sample paths

for the TFR were created from a random walk with drift model subject to ceiling and floor limits.

19. Immigration and emigration sample paths were generated with ARIMA(1,0,0) time series models, with correlated random numbers for errors obtained by Cholesky decomposition of the variance-covariance matrix. For the first few years of the forecasts short-term predictions from the Department of Immigration and Border Protection (2015) were used. From 2019-20 onwards slight increases in both immigration and emigration totals were assumed, resulting in Net Overseas Migration rising from 247,000 in 2019-20 to 267,000 by 2050-51.

20. Past mortality rates by age and sex were calculated using the newly created population estimates as denominators. Mortality and life table forecasts were created by geometric extrapolation of age-specific death rates from 1971 to 2014. Rates were smoothed across most ages using cubic splines and in the centenarian ages with a fitted logistic curve. A detailed evaluation by Terblanche (2015a) concluded that the geometric method yields forecasts which are just as accurate as far more complex approaches. Life expectancy at birth was forecast to increase at a gradually decelerating pace, rising from 84.7 years in 2013-14 to 90.0 in 2050-51 for females, and from 80.6 years in 2013-14 to 88.0 in 2050-51 for males. Sample paths for life expectancy at birth were generated using random walk models. Correlated random numbers for male and female life expectancy at birth errors were produced by Cholesky decomposition of the variance-covariance matrix. For each life expectancy at birth value generated by the random walk model the forecasting program interpolated the forecast life tables to obtain a corresponding set of age-specific death rates. By way of illustration, Figure 1 shows the median female life expectancy at birth forecast, 95% prediction interval bounds, and a small selection of the 5,000 life expectancy sample paths that were created.

III. Estimates of Australia’s very elderly population

a) 85+ population

21. Australia’s very elderly population has grown almost seven-fold over the 1971-2014 period, from 69,000 to 456,000. This exponential growth is clear from Figure 1, which shows male and female very elderly population estimates over the study period. The very elderly population has grown at an average annual rate of 4.5% compared to 1.4% per annum for the total population. As a result, the very elderly increased their share of the total population from 0.5% in 1971 to 1.9% in 2014.

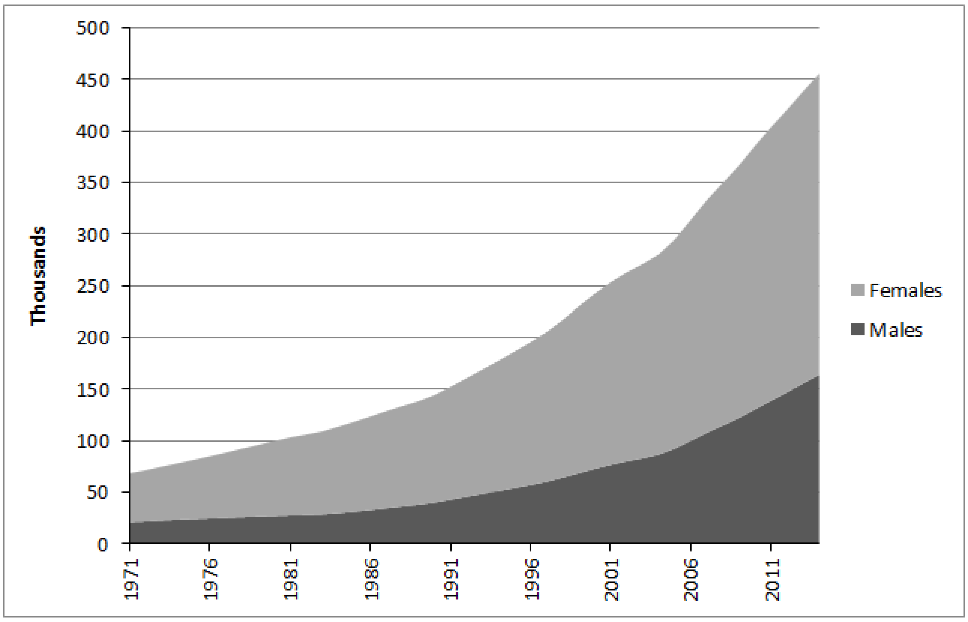

Figure 1: Very elderly population estimates by sex, 1971 to 2014 (Source: authors' calculations)

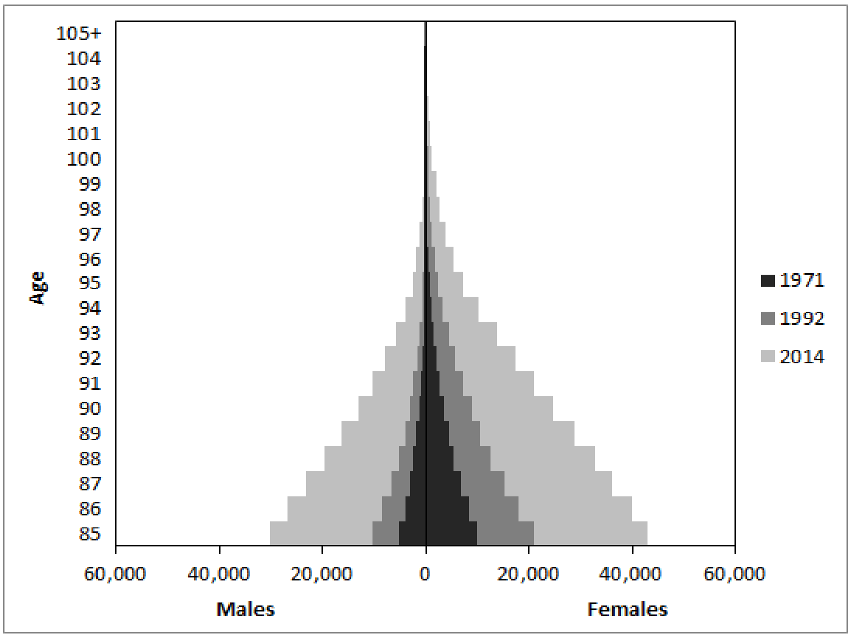

Figure 2: Very elderly population age-sex structure, 1971, 1992 and 2014 (Source: authors' calculations)

22. Estimated numbers of males and females at single ages 85-104 and in aggregate for 105+ in 1971, 1992 and 2014 are shown in Figure 2. It is clear from the graph that male and female numbers at all ages increased substantially. Between 1971 and 1992, growth in female numbers increased with age and exceeded that of males at all ages. Over this period, growth in male numbers at ages up to 100 did not show a similar pattern of

increase with age. Male numbers at most ages increased much more over 1992 to 2014 compared to the period 1971 to 1992, and their growth increased with age up to 93.

23. Centenarian numbers increased more than 17-fold, from 210 in 1971 to around 3,650 in 2014. The number of semi-supercentenarians (ages 105+) increased from only 3 in 1971 (all female) to about 155 in 2014 (137 female and 18 male).

b) 2. Drivers of growth

24. The relative contributions of changes in births, survival and net migration to the growth in nonagenarian numbers from 1971 to 2014 are shown in Figure 3. Figure 4 shows the contribution of these factors to the growth in centenarian numbers from 1981 to 2014. An initial year of 1981 had to be chosen because of data constraints relating to the earliest cohorts for which cohort life tables could be constructed.

25. The numbers of centenarians in each of 1981 and 2014 were expressed as the product of births, cohort survival from birth to age 65, age 65 to 85, age 85 to 100 and beyond age 100, and a factor representing the impact of net migration (Vaupel and Jeune 1995; Thatcher 1999, Terblanche 2015b). The factor increases shown in Figures 3 and 4 represent the ratios of these factors at the two dates. For example, the factor increase in male births of 1.7 shown in Figure 4 represents the ratio of birth counts in 1905-1914 compared to 1872-1881. Survivors from these cohorts were aged 100+ in 2014 and 1981 respectively. For nonagenarians, improvements in cohort survival between ages 65-85 contributed most to the increase in their numbers from 1971 to 2014, followed by an increase in birth numbers. By far the largest driver of centenarian growth between 1981 and 2014 was an improvement in cohort survival from age 85 to 100.

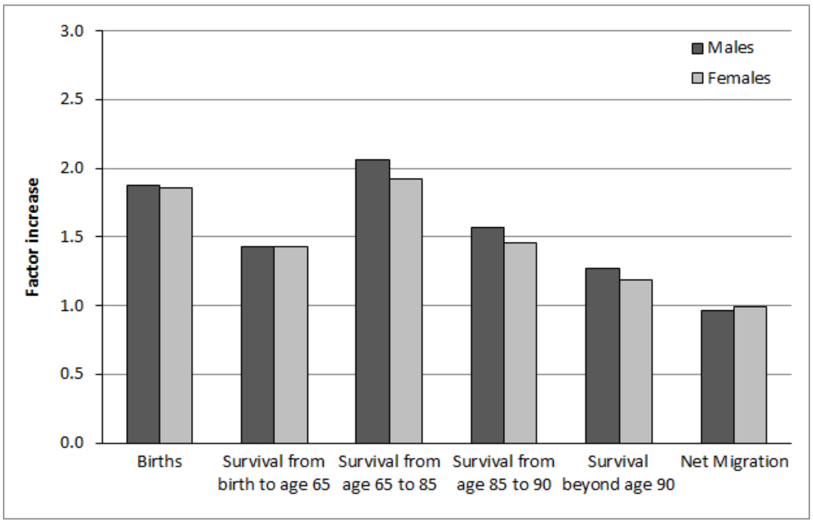

Figure 3: Factor increases in births, survival and net migration for the population aged 90-99 from 1971 to 2014, by sex (Source: authors' calculations based on own estimates, ABS (2008, 2015) and HMD (2015))

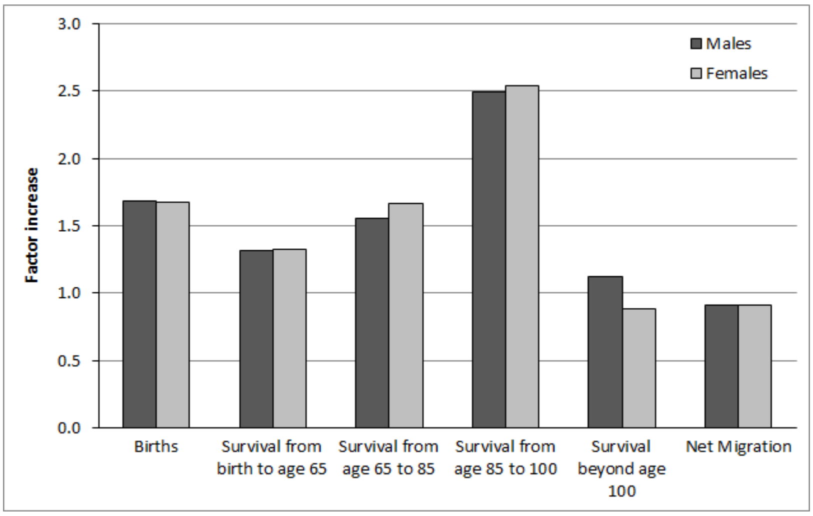

Figure 4: Factor increases in births, survival and net migration for the population aged 100+ from 1981 to 2014, by sex (Source: authors' calculations based on own estimates, ABS (2008, 2015) and HMD (2015))

c) 3. Comparison of centenarian numbers with those of ABS

26. The differences between our estimates and those of the ABS are most marked in the centenarian ages. A comparison of the two sets of figures from 1971 to 2014 is shown in Figure 5.

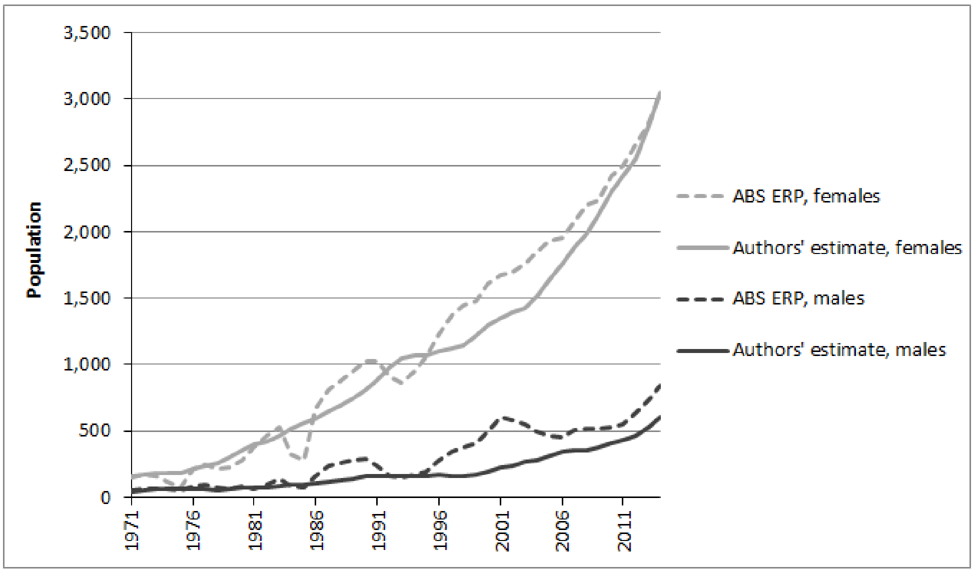

Figure 5: Comparison of ABS and authors' estimates of the centenarian population, 1971 to 2014 (Source: authors' calculations and ABS (2015))

27. Recall that ABS ERPs are derived from census counts, while the authors' estimates are derived from death counts using the Extinct Cohort and Survivor Ratio methods. ERPs show a more volatile and less plausible pattern over time. Up to around 1985, 100+ ERPs for females were lower than our estimates but since then, with the exception of

1992-1995, they have exceeded our estimates by around 20%. Since around 2006, the gap between female ERPs and our estimates has gradually reduced and in 2014 the two sets of numbers were very close. In the case of males, ERPs were generally higher than our estimates, especially during 1997-2003. The largest difference was observed in 2001, with ERP of 610 compared to our estimate of 223. At 30th June 2014 the ERP for males aged 100+ was 842, compared to our figure of 600.

IV. Forecasts of Australia's very elderly population

a) 85+ population

28. Australia's very elderly population will increase substantially in the coming decades, as Figure 6 shows. From an estimated 456,000 in 2014, the 85+ population is forecast to increase substantially over the next 16 years, with 95% of simulations lying between 778,000 and 975,000 by 2031, and with the median of the distribution at 871,000. Over the following 20 years growth will accelerate as the 1946-65 baby boom generation enters the 85+ age group. By 2051 the median of the predictive distribution is set to reach 1.90 million with the 95% prediction interval spanning 1.51 - 2.37 million.

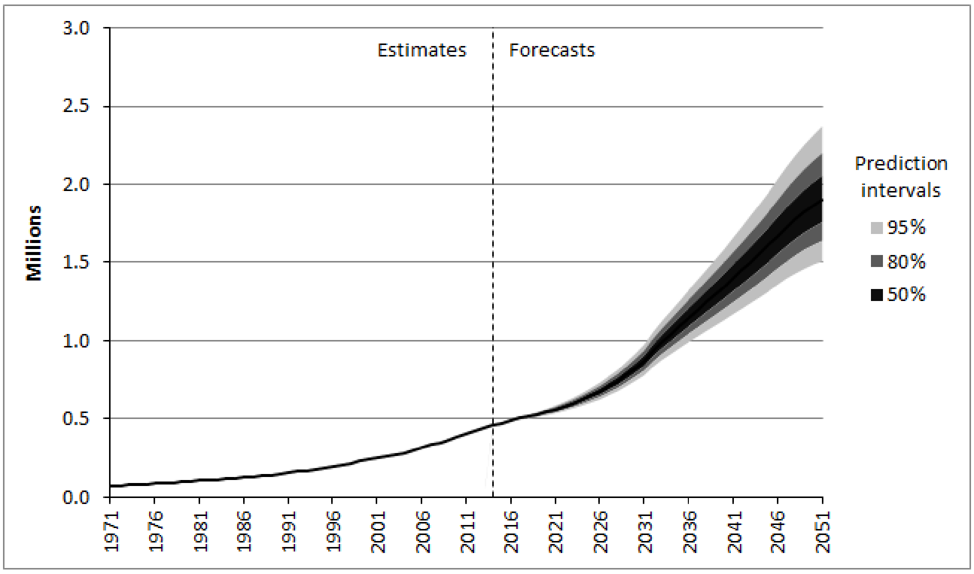

Figure 6: The growth of Australia's very elderly (85+) population, 1971-2051 (Source: authors' calculations)

29. The strength of these probabilistic forecasts is that they show how the demographic future of the 85+ age group is quite certain for the next decade or so but becomes increasingly uncertain further into the future. But they also demonstrate that huge growth is assured: by 2051 even the lower bound of the 95% prediction interval is more than triple the population in 2014. Prediction intervals in probabilistic forecasts are generally calculated for population ranges, but they may also be used to describe time periods for the passing of particular population milestones. For the 85+ population, the 95% interval for achieving 1 million extends from 2032 to 2037.

30. How do these forecasts compare to the latest 2012-based population projections for Australia prepared by the ABS (2014)? Although the ABS produce a large number of projection variants their publications focus mostly on just three, which they label Series A, B and C. Series A contains high fertility, high life expectancy and high net overseas migration assumptions, Series B has medium assumptions for all components and is widely interpreted as the principal series, and Series C contains low fertility, medium life expectancy and low net overseas migration assumptions. For the 85+ population Series B and C are almost identical and project a very elderly population of 805,000 by 2031 and 1.58 million by 2051. Series A projects 843,000 by 2031 and 2.15 million by 2051. The range between the highest and lowest of these series covers about a quarter of our predictive distribution by 2031, but about 80% of it by 2051 with Series A close to the upper bound of the 80% prediction interval and Series B and C close to its lower bound.

b) 2. Centenarians

31. For Australia's centenarian population, forecast growth is far more dramatic than for the 85+ population as a whole, as Figure 7 shows. Centenarian numbers are forecast to grow from about 3,600 in 2014 to between 9,000 and 11,700 by 2031 (95% interval) and to between 19,500 and 39,500 by 2051 (95% interval). The medians of the forecast distribution for these two dates are, respectively, 10,200 and 27,200. The milestone of 10,000 centenarians is expected to be passed sometime between 2028 and 2037 (95% interval).

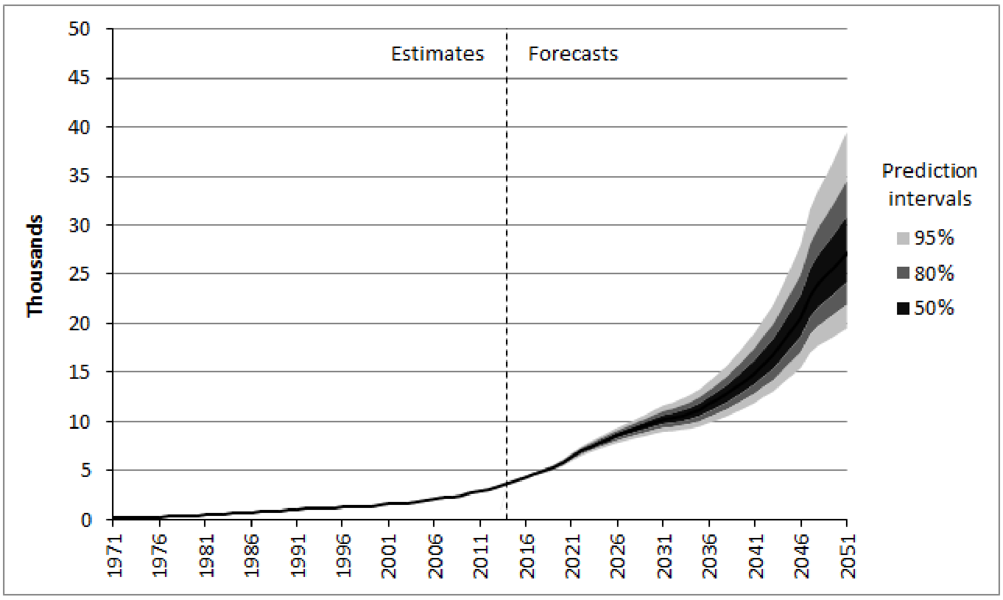

Figure 7: The growth of Australia's centenarian (100+) population, 1971-2051 (Source: authors' calculations)

32. Compared to the 85+ population as a whole, there is more uncertainty about the future of the centenarian group. Relative uncertainty can be measured with the Relative Inter-Decile Range (RIDR) which is defined as the 80% prediction interval divided by the median (Lutz et al. 2004). By 2051 the RIDR for the 85+ population forecast is 0.29 whilst for the centenarian population it is 0.46. The greater uncertainty about the

centenarian population is the result of higher death rates than the 85+ population as a whole.

33. How do our forecasts compare to those of the ABS (2014)? The latest ABS projections of the centenarian population begin higher than ours and remain above the upper 95% prediction interval bound of our forecasts through the forecast horizon. Series B and C track a few thousand above the upper 95% bound but move in line with it. Until the late 2030s, the high life expectancy Series A projection does the same, but after this time it increases exponentially, soaring to 94,000 by 2051. The ABS projections are much higher than our forecasts because they are based on forecast mortality rates which are too low, which in turn is the result of historical mortality rates being calculated using population estimates which are too high, as mentioned earlier.

c) 3. Semi-supercentenarians

34. People aged 110 years and above are described as supercentenarians. Supercentenarians in Australia are very few in number even at the end of the forecast horizon, so instead we focus here on semi-supercentenarians, those aged 105 and above. Figure 8 shows their past and forecast growth out to 2051. From a population of about 150 in 2014, semi-supercentenarian numbers are forecast to increase to between 480 and 590 by 2031 (95% prediction interval) and then on to between 950 and 1,800 by 2051 (95% prediction interval). The medians of the forecast distribution for these two dates are, respectively, 530 and 1,290.

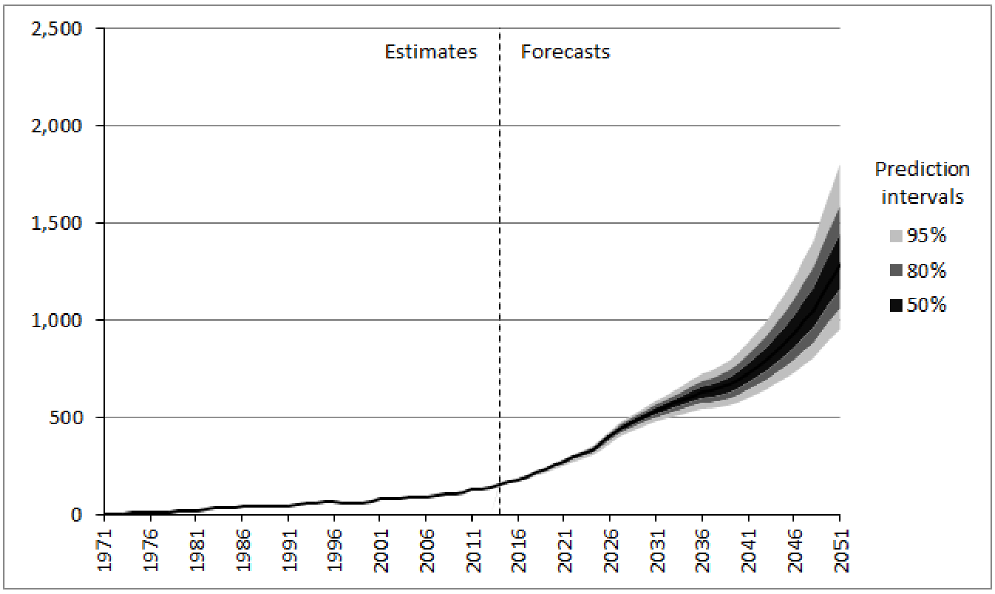

Figure 8: The growth of Australia's semi-supercentenarian (105+) population, 1971 to 2051 (Source: authors' calculations)

V. Summary and conclusions

35. This paper has presented updated estimates of Australia's very elderly population and the first set of probabilistic forecasts focusing on the very highest ages. Population estimates, created using the Extinct Cohort and Survivor Ratio methods, are far more accurate than those derived from census counts, especially at the centenarian ages.

These more accurate estimates were used to calculate more reliable death rates, which in turn permitted the preparation of more accurate mortality forecasts. Our probabilistic forecasts illustrate the extent to which growth in Australia's very elderly population is uncertain, and quantify it through prediction intervals. These intervals reveal there to be very little uncertainty in the coming decade, but increasing amounts the further into the future one goes, and relatively more for some variables (e.g. centenarians) than others (e.g. the 85+ population as a whole). What is certain, however, is that huge growth in population numbers at the highest ages will eventuate. Australia's demography is now entering an era in which the very elderly will form a sizeable section of the population for the first time.

36. Our estimates and forecasts also indicate that the official ABS estimates of the very elderly are not as accurate as they could be, and that their projections are also problematic. As Figure 8 shows, ABS centenarian ERPs exhibit volatile and implausible trends. Their centenarian projections in Series A, B and C exceed the upper bound of our 95% prediction interval because of forecast death rates which are too low, themselves the result of inflated ERPs at the highest ages. We encourage the ABS to adopt the Extinct Cohort and Survivor Ratio methods for estimating the very elderly population as described in this chapter. The UK's Office for National Statistics has applied these methods for estimating very elderly populations for several years now (ONS 2015). Furthermore, uncertainty about the future of the very elderly population is not reliably indicated by high-low ranges from the ABS Series A, B and C projection variants. It would be far better if the ABS produced just one forecast and then created prediction intervals around it from a probabilistic model.

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