Towards Fairer Retirement Outcomes: Socio-Economic Mortality Differentials in Australia

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Abstract

The Australian superannuation system faces the challenge of delivering equitable and sustainable income in retirement, yet the development of effective longevity products remains limited. A key barrier is the lack of detailed understanding of mortality differentials across socio-economic groups, which complicates the pricing and design of retirement income products. While it is known that mortality varies by factors such as income and education, comprehensive evidence for Australia has been scarce, particularly for the post-retirement population. This paper addresses this gap by analysing individual-level linked data from the Australian Bureau of Statistics' Personal Level Integrated Data Asset (PLIDA), covering the entire Australian population aged 60–100 over 2016–2017. We examine mortality differentials across socio-economic indicators including area-level socio-economic advantage and disadvantage, income, marital status, and home ownership using flexible Hermite-spline Poisson regression models. Our results reveal substantial disparities in mortality and life expectancy across socio-economic groups, with differences narrowing at older ages. For example, at age 60, the gap in period life expectancy between the most and least advantaged males is 11.5 years, and 9.1 years for females. Longevity differences translate into substantial variation in annuity income. The large and persistent differences by socio-economic characteristics suggest that uniform approaches to longevity product pricing may unintentionally disadvantage certain groups. These findings highlight the importance of accounting for heterogeneity in longevity when designing retirement income products and inform policies aimed at fairer outcomes in the retirement phase.

1 Introduction

The Australian superannuation system's retirement phase is in urgent need of further enhancement in order to meet its objective of providing a supplementary or alternative income to the Age Pension. The Australian government's initiative to develop a Retirement Income Covenant (Australian Government The Treasury 2018) in the Superannuation industry aligns with this goal, aiming to offer Comprehensive Income Products for Retirement (CIPR) and help its citizens achieve a sustainable standard of living in retirement through a delicate balance of income adequacy, flexibility, and risk management.

Currently, only a minor fraction of Australians invest in longevity products, limiting our understanding of the mortality rates among those in pooled annuity schemes. This data scarcity presents challenges for providers in accurately pricing longevity risk. Typically, insurers rely on their own client mortality data to inform assumptions for pricing, and when internal data is lacking industry-wide studies are consulted. However, the nascent stage of the Australian market means local industry data is almost always insufficient, prompting a reliance instead on international findings or assumptions based on general population statistics (Institute of Actuaries of Australia 2018).

This project aims to understand sub-group retirement mortality of Australians based on the general population experience. Although there has been growing interest and indeed research into studying the sub-group mortality experience both in Australia and around the world, this article is the first study to comprehensively explore retirement age mortality experience over a variety of subgroups, based on an individual-level linked mortality data set of the entire Australian population (2016-2017).

It is important to acknowledge that the Australian Life Table (ALT) is an authoritative source for population mortality, offering over a century's historical mortality experience (Australian Government Actuary 2019). Despite its comprehensiveness however, the ALT does not differentiate mortality data beyond basic demographic factors such as age and gender. Moreover, there is a recognised 'selection effect' among those purchasing longevity products, as (for example) they tend to be healthier individuals who anticipate a benefit from the pool. As such, this group will typically have mortality rates that are below the broader population average, resulting in even more expensive annuities and retirement products offering poorer value for money for the general population.

Mortality inequalities are a key consideration for public policy decision-making, and it is important we improve our understanding of socio-economic mortality differentials so that the superannuation and retirement industry can develop more suitable retirement products and fair pricing schemes for the general population. According to Korda et al. (2020), socio-economic differentials are not only unjust, but also impose a significant financial burden on society. For example, they found that in 2011-2012, the mortality rates of Australian men aged 25-84 years who had not completed year 12 were more than twice that of those who received a tertiary education. Welsh et al. (2021) found that while Australia has one of the highest life expectancies in the world, 'within-country' inequalities were substantial. In particular, those with the lowest education level had a life expectancy equivalent to the national average from 15-20 years ago. More recently, the Australian Government Actuary (2021) investigated the mortality experience and established sub-group life tables of the Australian resident population by relative socio-economic advantage and disadvantages using Socio-Economic Indexes for Areas (SEIFA). Their results revealed mortality was lower with increasing deciles of SEIFA (corresponding to higher socio-economic conditions) across both males and females, but there was a convergence of mortality at older ages across all deciles of SEIFA.

In this project, we investigate the mortality experience across a variety of subgroups, defined based on age, gender, area-level socio-economic advantage and disadvantage, income, marital status, and home ownership, across the entire Australian population over one year (from September 2016 to August 2017). In summary, our results show that:

- **Socio-demographic mortality differentials**: We find significant mortality differentials associated with IRSAD decile, marital status, home ownership, and personal income. These disparities tend to diminish with increasing age and become negligible by approximately age 100 for IRSAD decile, marital status, and income.
- **Life expectancy gaps**: There is substantial variation in life expectancy across the Australian population. Notably, the gap between the most socio-economically disadvantaged and advantaged males reaches 11.5 years; for females, the corresponding gap is 9.1 years.
- **Implications for retirement income**: Longevity differences translate into substantial variation in annuity income. For example, for a $100,000 investment at age 65 and a 3 percent interest rate, the annual income from a pure lifetime annuity (without indexation or a death benefit) ranges from $6,896 (females) and $8,521 (males) for individuals with the shortest life expectancy to just $5,387 (females) and $5,785 (males) for those with the longest. A female in the lowest socio-economic group could receive an annuity that is around 28% higher if these differences are taken into account. We note that the size of these differentials can vary depending on annuity design features, such as the inclusion of a death benefit, indexation, or guarantee periods. The large and persistent differences by socio-economic characteristics suggest that uniform approaches to longevity product pricing may unintentionally disadvantage certain groups.

These findings highlight the need to incorporate socio-economic heterogeneity into the design and pricing of retirement income products. In particular, they highlight the risk of adverse selection and potential inequities if uniform pricing is applied without accounting for these mortality differentials. A better understanding of post-retirement mortality patterns can support more equitable product offerings, inform appropriate policy settings under the Retirement Income Covenant, and ultimately contribute to fairer and more sustainable outcomes in the superannuation system.

2 Data

The data used in this report are provided by the Person Level Integrated Data Asset (PLIDA), and sourced from Australian Bureau of Statistics, DataLab. Linked by a unique ID entry from the Australian Bureau of Statistics (ABS), it includes information from the Australian Taxation Office, the Department of Education and Training, the Department of Health, the Department of Human Services, and the Department of Social Services, and comprises the following datasets:

- 2016 Census data – This includes information collected about the Australian census population as at Census night on August 9, 2016;
- 2009-2016 Social Security Related Information (SSRI) data – This includes various types of social security benefits data with start date and end date paid to individuals, fortnightly payment amounts at the beginning of each quarter, marital status of the corresponding individuals with start date and end date, their highest education level, and so on;
- Demographics data for individuals aged over 50 between 1 January 2007 and 31 December 2017 – This includes information such as gender, year of birth, month of birth, year of death, month of death, and so on.

2.1 Data period selection

The population used for the study is based on the 2016 Census data, which provides us with the potential to estimate mortality rates from 1 January 2016 to 31 December 2017. By analysing the possible under-reporting of deaths in the data using the monthly number of deaths reported by ABS, and comparing the mortality rates based on our data sample with the ALT, we decided to use the data in the twelve-month period from 1 September 2016 to 31 August 2017 for further analysis. Furthermore, given the 2016 Census took place on 9 August 2016, then this period was also selected as it:

- Maximises the availability of covariate data;
- Minimises issues with under-reporting of deaths; and,
- Being only 12 months, avoids possible issues with seasonality of deaths.

Since our main interest is mortality at retirement ages, we restrict our analysis to the age range of 60 to 100. With this data period selection, our sample comprised 57,158 female deaths and 58,592 male deaths, corresponding to, respectively, 2,467,416 and 2,178,730 years of (central) exposure. Table 1 presents a summary of the breakdown of exposure and the number of deaths across different age bands. We note there was a very small proportion of individuals in our sample with gender reported as "other", which we excluded for the remainder of the analysis.

Table 1: Exposure and deaths for ages 60 to 100 over the period 2016-09-01 to 2017-08-31

Age Range	Exposure (Females)	Deaths (Females)	Exposure (Males)	Deaths (Males)
60–64	619,013.74	2,511	581,448.80	3,793
65–69	559,997.65	3,573	531,303.41	5,576
70–74	441,430.68	4,886	415,403.93	7,383
75–79	326,246.02	6,405	291,101.48	8,990
80–84	239,177.81	8,936	191,696.13	10,628
85–89	170,777.70	12,588	115,231.84	11,860
90–94	86,458.85	12,244	43,791.22	7,870
95–100	24,313.21	6,015	8,753.31	2,492
Total	**2,467,415.65**	**57,158**	**2,178,730.12**	**58,592**

Figure 1 compares the crude central death rates (log scale) by gender based on our data, with the corresponding death rates from the ALT2015-2017 life table superimposed. Overall, we observe the death rates in our sample are consistent with the ALT rates.

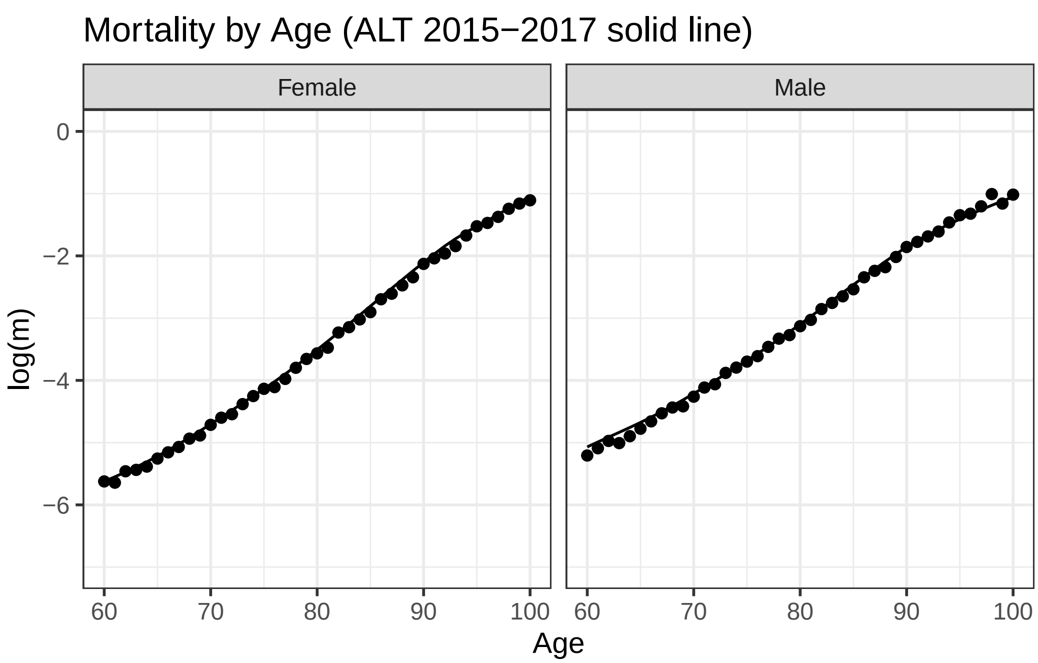

Figure 1: Comparison of crude central death rates in our data and ALT rates 2015-2017.

2.2 Predictor information

In this report, we source four covariates from the aforementioned data sources, namely Socio-Economic Indexes for Areas (SEIFA), home ownership, marital status, and income. We do not consider other factors such as education and occupation, as the data for those factors were deemed to be excessively noisy and contained significant proportions of missing data for the retirement-age population. Note the SEIFA variable already contains information regarding education and employment, which can at least provide indirect insights into the mortality differentials based on those factors. This paper has not yet incorporated health data; however, the inclusion of health-related variables is planned for future research.

2.2.1 Socio-Economic Indexes for Areas (SEIFA)

SEIFA is obtained from 2016 Census data based on the code `SA1_IRSAD_2016`. The Australian Bureau of Statistics (2021) builds four indexes to rank Australian areas according to relative socio-economic advantage and disadvantage using census data: Index of Relative Socio-Economic Disadvantage (IRSD), Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD), Index of Economic Resources (IER), and Index of Education and Occupation (IEO). In this report, we use IRSAD calculated at Statistical Area Level 1 (SA1) as the socio-economic index for areas. This is a general measure of relative advantage (high values) and disadvantage (low values) built from factors such as education, income, and employment. Its usage here is also consistent with the SEIFA variable used by Australian Government Actuary (2021).

The `SA1_IRSAD_2016` variable provides decile levels ranked from D1 (most disadvantaged) to D10 (most advantaged). Table 2 summarises the distributions of our sample across these IRSAD deciles. Note the proportion of data with missing IRSAD information is relatively small.

Table 2: Summary of total exposure and observed deaths by IRSAD decile and gender

IRSAD	Exposure (Female)	Deaths (Female)	Exposure (Male)	Deaths (Male)
D1 (Most Disadvantaged)	279,527.68	9,425	231,091.02	9,252
D 2	289,276.88	8,714	243,926.05	8,649
D 3	268,097.02	6,625	233,324.71	7,029
D 4	254,243.45	5,978	225,640.23	6,123
D 5	240,396.91	5,226	216,604.61	5,575
D 6	236,069.27	4,782	213,077.42	4,934
D 7	228,215.81	4,572	206,031.32	4,749
D 8	222,288.61	4,140	201,895.87	4,358

IRSAD	Exposure (Female)	Deaths (Female)	Exposure (Male)	Deaths (Male)
D 9	226,105.23	3,815	204,364.84	4,051
D10 (Most Advantaged)	221,063.69	3,483	202,021.64	3,593

2.2.2 Home ownership

Home ownership is obtained from two sources. First, it is based on the 2016 Census data using the code `TENLLD`, which corresponds to Tenure and Landlord Type. As with Australian Government Actuary (2021), it is assumed the 2016 census data on this predictor, when used, is representative of the retiree's state at or around retirement. `TENLLD` has the following coding structure:

- 1 – Owned outright
- 2 – Owned with a mortgage
- 3 – Rented: Real estate agent
- 4 – Rented: State or territory housing authority
- 5 – Rented: Community housing provider
- 6 – Rented: Person not in the same household
- 7 – Rented: Other landlord type
- 8 – Rented: Landlord type not stated
- 9 – Other tenure type
- & – Tenure type not stated
- @ – Tenure type not applicable

For ages below 68, individuals with code type 1 and 2 were classed as homeowners, those in groups 3-9 were classed as non-homeowners, while those in type @ were treated separately given how their category is defined according to the ABS Census website. Those in type & were treated as missing data.

Next, for all individuals below 68 that were treated as missing data, then we attempted to source their home ownership information from SSRI. Specifically, if an individual was in one of the following codes in SSRI data:

- DEE – Deemed interest in home
- GFH – Government-funded aged care homeowner
- HOM -– Homeowner
- JNT – Joint ownership with partner
- LHO – Homeowner living elsewhere
- LIF – Bequeathed life interest
- NHH – Aged care or nursing home homeowner

- OTH – Other forms of ownership
- PAR – Owns jointly with someone other than partner
- POH – Purchasing own home
- SRH – special resident (homeowner),

and this code was applicable before age 60 and ended after age 60, then they were classed as a homeowner. Otherwise, they were classified as a non-homeowner. If an individual had multiple entries satisfying this criteria, then the last (most recent) entry is taken.

Finally, for individuals aged 68 and above, all data were treated as missing. This is because the proportion of individuals in the missing data group increases with age, and includes individuals in non-private dwellings such as hospitals, retirement homes, and other institutional settings. Further investigation revealed the proportion of individuals residing in hospitals or retirement homes rises significantly from approximately age 70, with many living in retirement homes. As a result, home ownership status in these older age groups is less likely to reflect actual ownership in the conventional sense. Given these considerations, we therefore regard home ownership status as more representative at younger ages and therefore use age 68 as the cut-off for further modelling. Table 3 summarises the distributions of our sample by home ownership status.

Table 3: Summary of total exposure and observed deaths by home ownership and gender

Home ownership	Exposure (Female)	Deaths (Female)	Exposure (Male)	Deaths (Male)
No	195,183.50	1,427	187,928.20	2,636
Yes	746,111.00	2,468	691,417.60	4,019
missing	1,523,990.00	52,418	1,298,632.00	51,704

2.2.3 Marital Status

Marital status is obtained from 2016 Census data based on the code `MSTP`, which records information on Registered Marital status. It is assumed the 2016 Census data for this covariate is representative of the retiree's state at or around retirement. `MSTP` has the following coding structure:

- 1 – Never married
- 2 – Widowed
- 3 – Divorced
- 4 – Separated
- 5 – Married
- @ – Not applicable (person under 15 years)

Individuals with code type 1 to 4 and @ were classed as single, otherwise individuals with code 5 were classed as married.

Table 4 summarises the distributions of our sample by marital status. The proportion of missing marital status information is minuscule. It would also be interesting to analyse whether a person lives with a partner, as this can affect mortality outcomes, should relevant data become available.

Table 4: Summary of total exposure and observed deaths by marital status and gender

Marital Status	Exposure (Female)	Deaths (Female)	Exposure (Male)	Deaths (Male)
married	1,294,784.92	15,017	1,515,972.16	33,263
single	1,170,499.62	41,743	662,005.55	25,096

2.2.4 Income

Income is sourced from the 2016 Census using the variable `INCP`. The Census provides data on both self-reported total personal weekly income (`INCP`) and total weekly family income (`FINF`). For this study, we chose to use total personal income, as it proved to be a more informative predictor than family income during the modelling stage. The coding structure for `INCP` is as follows:

- 01 – Negative income
- 02 – Nil income
- 03 – $1 - $149
- 04 – $150 - $299
- 05 – $300 - $399
- 06 – $400 - $499
- 07 – $500 - $649
- 08 – $650 - $799
- 09 – $800 - $999
- 10 – $1,000 - $1,249
- 11 – $1,250 - $1,499
- 12 – $1,500 - $1,749
- 13 – $1,750 - $1,999
- 14 – $2,000 - $2,999
- 15 – $3,000 or more
- && – Not stated
- @@ – Not applicable

Based on our exploratory data analysis, we decide to group income into four broader categories, namely below $499, $500-$999, above $1000, and missing. Table 5 summarises the distributions based on these groupings of weekly personal income.

Table 5: Summary of total exposure and observed deaths by income group and gender

Income Group	Exposure (Female)	Deaths (Female)	Exposure (Male)	Deaths (Male)
1000+	302,991.70	2,424	526,259.11	4,853
500-999	558,557.48	8,483	530,158.44	10,408
<499	1,442,445.04	32,707	1,014,816.89	33,292
missing	161,290.33	13,146	106,743.27	9,806

Different from marital status and SEIFA, the missing data proportion for income is substantial, with 6.5% and 5.2% of the female and male exposure containing missing income information, respectively, noting that the codes `&&` and `@@` are counted as missing weekly personal income data. Due to this non-negligible percentage, in the modelling analysis below we treat observations with missing income as a separate category in the income covariate. More broadly, we note that of the individuals (and subsequently the exposures and deaths) whose income was listed as 'Not Stated', around 60% of those most likely corresponded to individuals who did not submit a census form at all, while the remaining 40% did not answer that particular question related to income (personal communication, ABS Census Data Division). Moreover, for those 60%, the vast majority of their information on attributes such as their gender and age were also imputed by the ABS itself via hot-deck imputation methods. With this in mind, and given we treat entries with missing income as a separate category, then in the analysis below we also caution against (over-)interpreting this particular level as it does not correspond to a subgroup of particular relevance to this study.

3 Descriptive analysis

As an initial exploration of the association between mortality and the different covariates, we examined mortality rate plots by age and gender for each of the four predictors discussed above.

3.1 Mortality rate plots by age, gender and covariate

Figure 2, Figure 3, Figure 4 and Figure 5 depict, respectively, mortality rates by IRSAD decile, home ownership status, marital status, and weekly personal income band. In all plots throughout the paper, we also included for reference the mortality rates given by ALT 2015-2017 as black dashed lines. Note in Figure 4 and Figure 2, we removed the 'missing' value groups since as the associated exposure is negligible.

Based on an examination of these plots, we observe the following features:

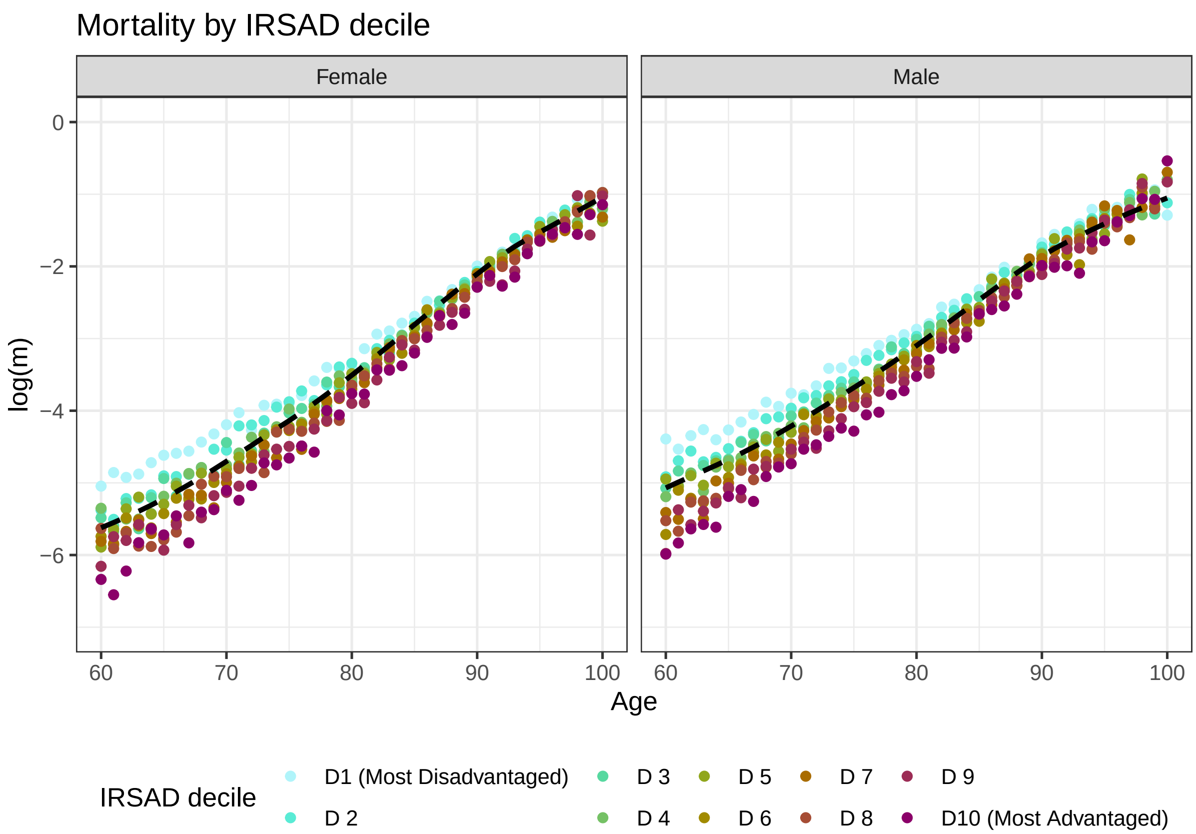

Figure 2: Crude mortality rates by age and gender according to SEIFA (IRSAD) decile.

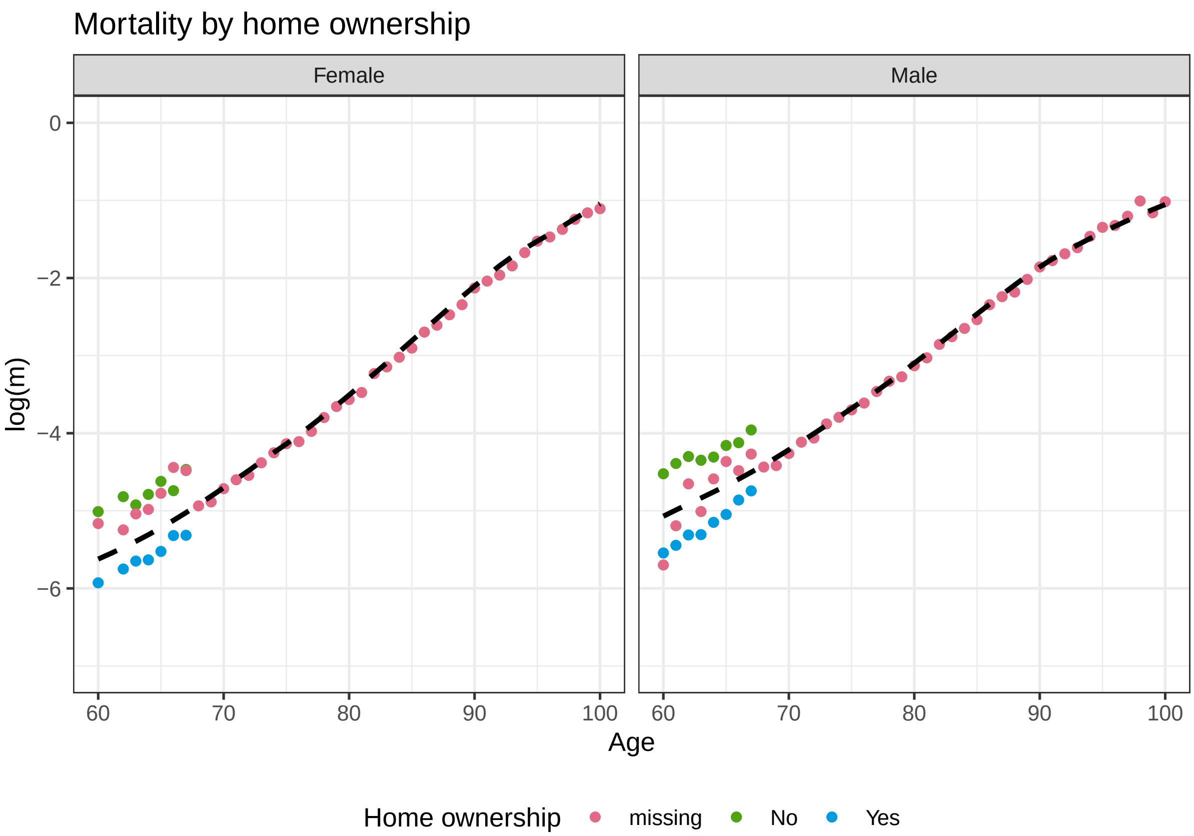

Figure 3: Crude mortality rates by age and gender according to home ownership status.

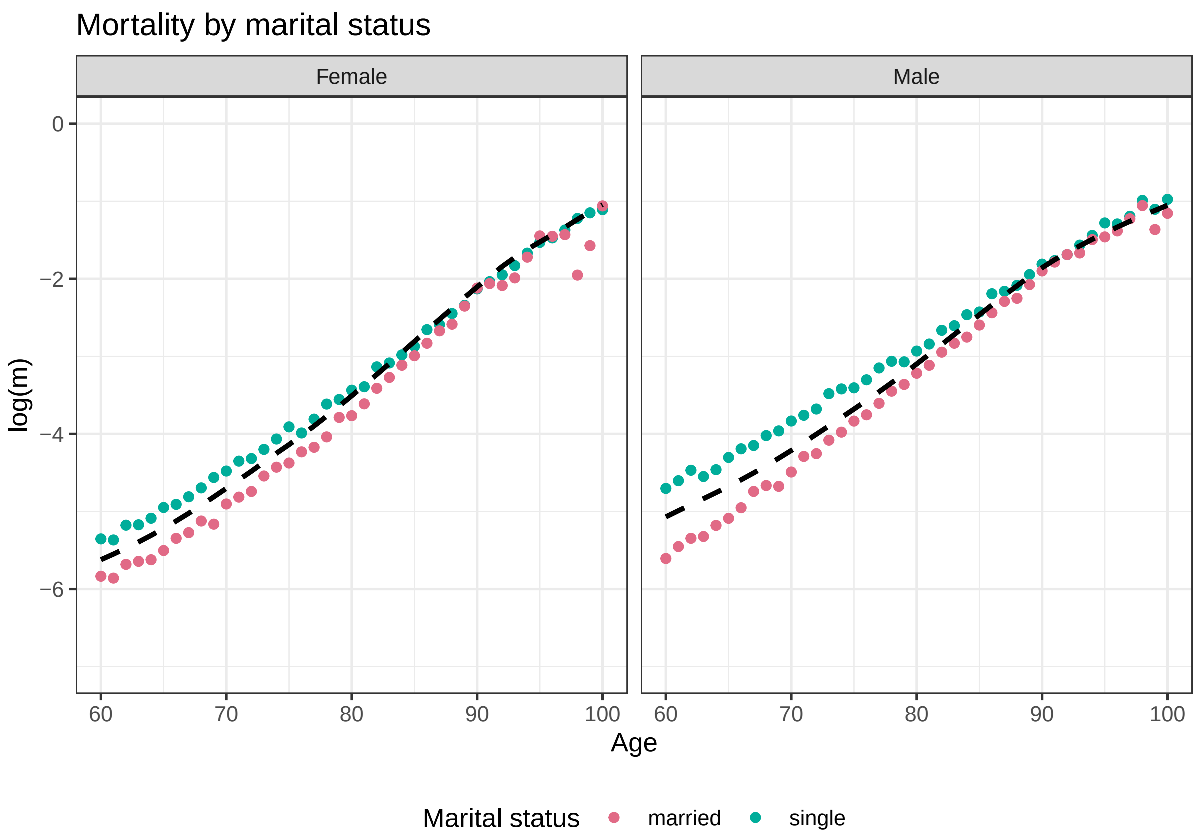

Figure 4: Crude mortality rates by age and gender according to marital status.

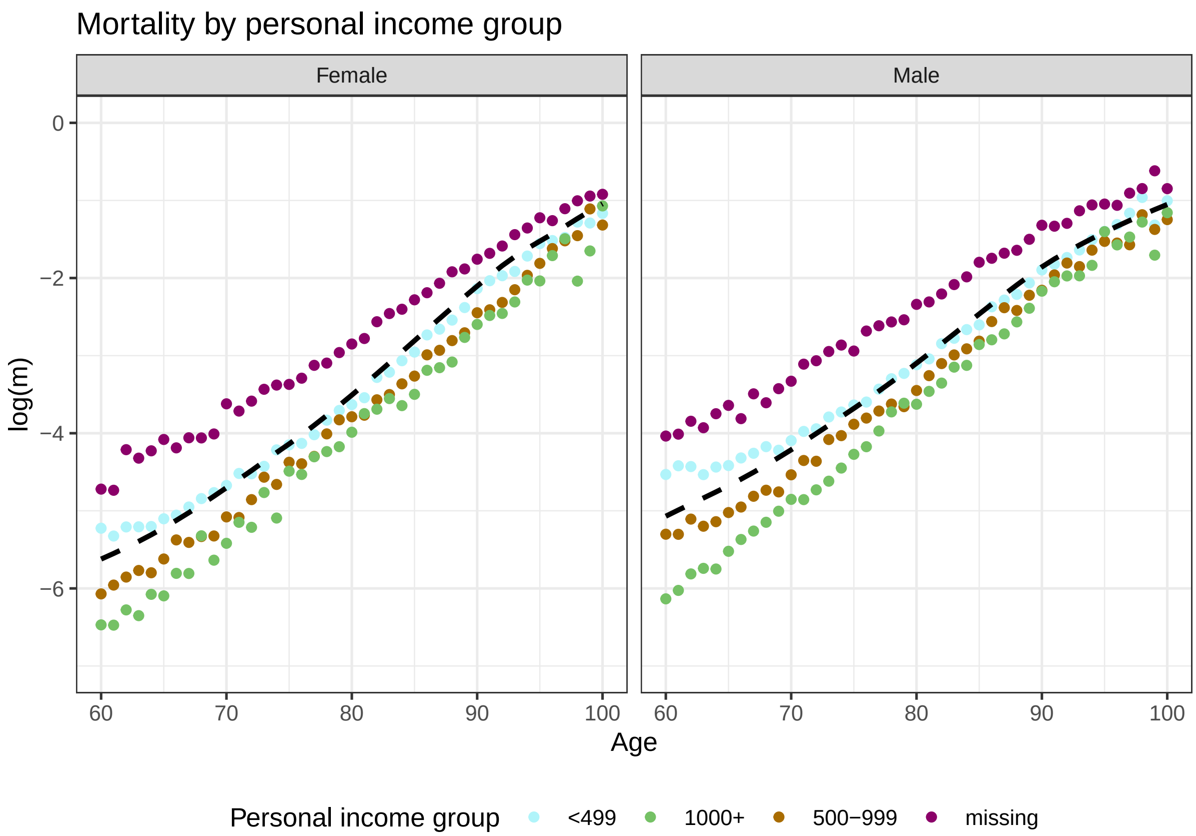

Figure 5: Crude mortality rates by age and gender according to personal weekly income.

- In Figure 2 we see that, as expected, the more advantaged decile levels are associated with lower mortality rates. The overall ALT 2015-2017 mortality rates lie in between the IRSAD deciles. Moreover, the mortality gap between different IRSAD decile groups shrinks as age increases, consistent with findings in Australian Government Actuary (2021);
- In Figure 3, we observe a clear and consistent mortality gap before age 68, where home ownership status is available and reliably measured, with homeowners experiencing lower mortality than non-homeowners across both genders. This difference remains relatively stable with age and is especially pronounced for males. These patterns suggest that home ownership is strongly associated with better mortality outcomes in the early years of retirement;
- In Figure 4, we see that unmarried individuals have higher mortality compared to their married counterparts across both genders. However, the mortality differentials are bigger for males than females. Consistent with the other covariates, the ALT 2015-2017 mortality rates lie between the two levels of marital status. The difference in mortality between the two marital groups shrinks as age increases;
- Finally, in Figure 5, we observe that individuals in higher income groups tend to have lower mortality rates. For this covariate, the ALT 2015–2017 mortality rates – particularly after age 70 – closely align with those of the lowest income bracket (<$499), which is unsurprising given that this group accounts for approximately 66% of the female exposure and 47% of the male exposure. As with IRSAD decile and marital status, the mortality differentials between income groups diminish with age. However, the proportion of missing income data is non-negligible, and this group exhibits substantially higher mortality rates than the other income bands. As noted earlier, we caution against over-interpreting results for this subgroup.

3.2 Summary of descriptive analysis

From the previous descriptive analysis, we draw the following three primary insights for our subsequent modelling exercise:

- *Diminishing differences in mortality with increasing age*: Figure 2, Figure 4, and Figure 5 all indicate that mortality differentials by IRSAD decile, marital status, and income are pronounced at younger ages but steadily decline as age increases, becoming almost negligible by around age 100. Our modelling approach should therefore be capable of capturing this age-related convergence in mortality;
- *Grouping of covariate levels:* The relationship between IRSAD decile and mortality is clear. However, for personal income, this relationship is somewhat nonlinear among adjacent income groups above $1000. With this in mind, and also to simplify interpretation later on, we choose to group personal weekly income brackets into three income groups "< $499", "$500-$999", "$1,000+", plus a missing income group for modelling purposes. We leave a more detailed exploration of this choice, and particularly whether to use finer

income brackets (noting this may not be permissible from a product pricing perspective), as an avenue of future research.

- *Missing data:* The proportion of missing values for IRSAD decile and marital status is minimal. By contrast, for personal income around 6% of the exposures have missing information (Table 5). With this in mind, then for the purposes of modelling below we decided to remove entries which have missing data in one or more of the IRSAD deciles and marital status, while we treat missing personal income as separate level in the covariate. We noticed that removing missing values leads to a reduction for both men and women of approximately 3% in the exposure and 4% in the number of deaths. We consider this to be acceptable, especially in light of the interpretable and reasonable results that we obtain below from the modelling process. For home ownership, we similarly retain individuals with missing information and treat them as a separate category, due to the increasing proportion of missingness at older ages and its potential link to residence in non-private dwellings such as aged care facilities.

4 Modelling framework

In this section, we introduce the framework used to model post-retirement mortality while accounting for the impacts of age, gender, IRSAD (SEIFA), home ownership, marital status, and weekly personal income. We adopt the Hermite-spline approach proposed by Richards (2020), which is a relatively flexible yet simple approach to account for the impact of covariates and their interactions with age. In comparison to alternative modelling approaches, the Hermite-spline approach has the advantage of capturing, parsimoniously, the decline in mortality differentials with rising age discussed in Section 3.2. Moreover, it can straightforwardly be formulated within a generalised linear modelling framework (Nelder and Wedderburn 1972), thereby facilitating the fitting of the models using standard statistical software in `R`.

4.1 Hermite Splines with only age

We start by introducing the Hermite spline model accounting only by age. Following Equation (4) in Richards (2020), in the Hermite family of models we assume that at age x, the force of mortality is given by

$$\log \mu_x = \alpha h_{00}(t) + m_0 h_{10}(t) + \omega h_{01}(t) + m_1 h_{11}(t)$$

where:

- $t = (x - x_0)/(x_1 - x_0)$ with x_0 and x_1 age limits set by the modeller, i.e.,the lower and upper limit of the age range for Hermite modelled rates. In our study, we assume $x_0 = 50$ and $x_1 = 110$;

- α, m_0, ω and m_1 are parameters to be estimated, and;
- $h_{00}(t)$, $h_{01}(t)$, $h_{10}(t)$, $h_{11}(t)$ are Hermite basis functions each with its own interpretation as we shall see shortly;

The Hermite basis functions, which are displayed in Figure 6, are given by:

- $h_{00}(t) = (1 + 2t)(1 - t)^2$;
- $h_{10}(t) = t(1 - t)^2$;
- $h_{01}(t) = t^2(3 - 2t)$; and
- $h_{11}(t) = t^2(t - 1)^2$.

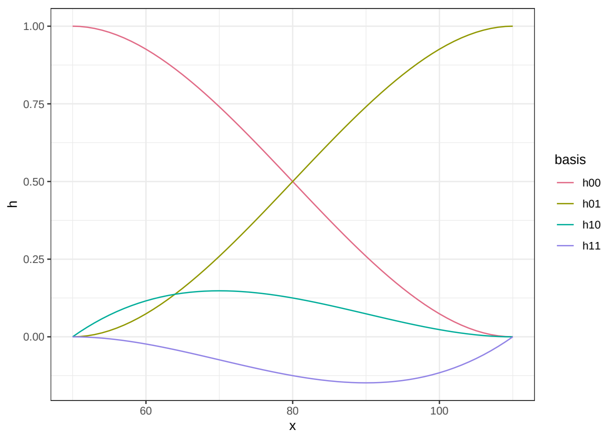

Figure 6: Hermite Spline basis functions for $x_0 = 50$, $x_1 = 110$.

Each of the Hermite basis functions has a natural interpretation in the context of mortality rates:

- $h_{00}(t)$ starts at 1 for x_0 and decreases to zero at x_1, capturing mortality effects which start at younger ages and vanish as age increases. Hence, the parameter α can be interpreted as an estimate of the (log) mortality rate at age x_0.
- In contrast, $h_{01}(t)$ begins at 0 for x_0 and increases to 1 at x_1, representing mortality effects that are minimal at younger ages but increase with age. Thus, the parameter ω can be interpreted as an estimate of the (log) mortality rate at age x_1.
- Both $h_{10}(t)$ and $h_{11}(t)$ start and end at zero for x_0 and x_1, respectively. The function $h_{10}(t)$ peaks around the first quartile of the age range, while $h_{11}(t)$ reaches its trough near the third quartile.

Depending on which combination of basis functions we include in the model, and the magnitudes of their corresponding estimated coefficients, we obtain different Hermite-spline models with varying degrees of flexibility in the resulting mortality curves. In the analysis below specifically, we consider the following four cases of the Hermite-spline model:

- Hermite I:
$$\log \mu_x = \alpha h_{00}(t) + \omega h_{01}(t)$$
- Hermite II:
$$\log \mu_x = \alpha h_{00}(t) + m_0 h_{10}(t) + \omega h_{01}(t)$$
- Hermite III:
$$\log \mu_x = \alpha h_{00}(t) + \omega h_{01}(t) + m_1 h_{11}(t)$$
- Hermite IV:
$$\log \mu_x = \alpha h_{00}(t) + m_0 h_{10}(t) + \omega h_{01}(t) + m_1 h_{11}(t)$$

4.2 Hermite spline with covariates

The Hermite-spline class of models offers a parsimonious way of capturing the effect of covariates on mortality. This is done by interacting the covariates with each of the different Hermite basis functions. For example, if we interact covariates with the $h_{00}(t)$ basis function, then we obtain a model that:

- captures the commonly observed decline of mortality differentials with rising age;
- avoids the crossover of mortality rates at older ages;
- only requires one additional parameter per covariate;

We can achieve further flexibility in the effect of a covariate on mortality by including interactions of this covariate with the other Hermite basis functions $h_{10}(t)$, $h_{01}(t)$ and $h_{11}(t)$.

4.3 Model estimation

Let $\mu_{x,s,h.m,i}$ denote the force of mortality at age x for an individual in IRSAD decile s, home ownership group h, marital status m, and personal income bracket i. Also, let $D_{x,s,h.m,i}$ denote the corresponding number of deaths, and $E_{x,s,h.m,i}$ the matching central exposed to risk. To estimate the models, we assumed $D_{x,s,h.m,i} \sim Poisson(E_{x,s,h.m,i}\mu_{x,s,h.m,i})$ and fitted the model by maximising the resulting log-likelihood function of a Poisson log-link regression model. Since the Hermite-spline models are linear in the covariates, they can be readily fitted in `R` via the `glm` function. We note that we fit separate model for females and males.

5 Results

Below, we present results of applying the various Hermite-spline Poisson regression models formulated above to estimate the impact of IRSAD, home ownership, marital status, and personal income on age-specific mortality. We consider separate analyses for females and males.

Table 6: Number of parameters and AIC for different models.

Model	No. of Parmeters	AIC Females	AIC Males
Age only			
Gompertz - Age only	2	57,852	60,586
Hermite I - Age only	2	57,775	60,494
Hermite II - Age only	3	57,639	60,489
Hermite III - Age only	3	57,623	60,483
Hermite IV - Age only	4	57,622	60,483
With covariates			
Gompertz - covariates	17	51,190	51,753
Hermite I - covariates	17	50,960	51,066
Hermite II - covariates	18	50,678	51,020
Hermite III - covariates	18	50,681	51,013
Hermite IV - covariates	19	50,658	51,013

5.1 Model selection

Table 6 presents the Akaike Information Criterion (AIC) values for several candidate models. AIC is a widely used model selection criterion that balances goodness of fit with model parsimony. However, we acknowledge that future research could explore alternative information criteria and variable selection approaches.

We consider the following groups of models:

- *Age-only models:* We fitted Hermite I to IV age-only models introduced in Section 4.1. For comparison purposes, as a baseline, we also included the Gompertz model which takes the form $\log \mu_x = a + bx$;
- *Hermite models with h_{00} interactions:* We fitted the four Hermite (I to IV) models, each incorporating interactions between covariates and the $h_{00}(t)$ Hermite basis function. As discussed in Section 4.2, this specification allows the models to capture diminishing differences in mortality with increasing age, while avoiding undesirable crossovers in mortality rates at older ages. For comparison, we also included the Gompertz model with main effects for each covariate – that is, interactions between the intercept parameter a and each of the four predictors.

Table 6 reports the number of parameters and AIC values for the different models fitted. We see clearly that models with covariates offer a substantially better fit than age-only models. For both males and females, the models with the lowest AIC is the Hermite IV models with covariates interacting with h_{00} (for males, Hermite III and IV performed similarly). As such, we select this model for our subsequent analysis.

5.1.1 Summary of selected model

The mathematical formulation of the selected "Hermite IV - with h00 interactions" model is as follows:

$$\log \mu_{x,s,h,m,i} = \alpha h_{00}(t) + m_0 h_{10}(t) + \omega h_{01}(t) + m_1 h_{11}(t)$$
$$+ (\sum_{s\in\mathcal{S}} \alpha_{IRSAD,s} u_{s,h,m,i} + \sum_{h\in\mathcal{H}} \alpha_{homeowner,h} v_{s,h,m,i} + \alpha_{married} w_{s,h,m,i} + \sum_{i\in\mathcal{I}} \alpha_{income,i} z_{s,h,m,i}) h_{00}(t)$$

where,

- $u_{s,h,m,i}$ denotes an indicator variable for SEIFA which equals 1 if the element belongs to IRSAD decile s and 0 otherwise, and $\mathcal{S} = \{D1, D2, \dots, D9\}$ represents the set of IRSAD deciles;
- $v_{s,h,m,i}$ denotes an indicator variable for home ownership which equals 1 if the element corresponds to a homeowner and 0 otherwise, and $\mathcal{H} = \{Yes, missing\}$;
- $w_{s,h,m,i}$ denotes an indicator variable for marital status which equals 1 if the element corresponds to a married individuals and 0 otherwise;
- $z_{s,h,m,i}$ denotes an indicator variable for personal weekly income bracket which equals 1 if the element belongs to income bracket i and 0 otherwise, and $\mathcal{I} = \{500-999, 1000+, missing\}$ represents the set of income brackets used; see Section 3.2 for the motivation behind these brackets.
- α, $\alpha_{IRSAD,D1}, \dots, \alpha_{IRSAD,D9}$, $\alpha_{homeowner,Yes}$, $\alpha_{homeowner,missing}$, $\alpha_{married}$, $\alpha_{income,500-999}$, $\alpha_{income,1000+}$, $\alpha_{income,missing}$, m_0, ω, and m_1 denote the corresponding (19) coefficients in the proposed model to be estimated.

Table 7 and Table 8 present the corresponding parameter estimates for males and females, respectively. In this model formulation, the reference case is an individual residing in IRSAD decile D10, who is not a homeowner, is unmarried, and has a personal weekly income of $499 or less. All coefficients are statistically significant at the 5% level, except for the h_{00} coefficient associated with IRSAD decile D9 for females, and the h_{10} coefficient for males. While each coefficient – particularly the interaction terms – could be interpreted in detail, our focus below is on visualising the overall estimated mortality curves and differentials, and interpreting these as a whole.

5.2 Assessing the quality of fit

We perform some basic visual diagnostics to asses the quality of the fit of our "Hermite IV - with h00 interactions" model. Specifically, we compare the death rates estimated from the model with the observed death rates for different covariates.

Table 7: Summary of model parameters for the selected model for Males.

Coefficient	Estimate	Std. Error	z value	P-value
Age				
h00	-4.7169	0.1246	-37.8549	0.0000
h01	-0.2955	0.1137	-2.5980	0.0094
h10	-1.1326	0.8641	-1.3107	0.1900
h11	2.2321	0.7519	2.9685	0.0030
IRSAD				
h00:IRSADD1 (Most Disadvantaged)	0.7532	0.0383	19.6542	0.0000
h00:IRSADD 2	0.6135	0.0387	15.8537	0.0000
h00:IRSADD 3	0.4886	0.0396	12.3292	0.0000
h00:IRSADD 4	0.3836	0.0405	9.4789	0.0000
h00:IRSADD 5	0.3983	0.0409	9.7400	0.0000
h00:IRSADD 6	0.2420	0.0420	5.7645	0.0000
h00:IRSADD 7	0.2316	0.0425	5.4449	0.0000
h00:IRSADD 8	0.1821	0.0433	4.2094	0.0000
h00:IRSADD 9	0.1036	0.0441	2.3491	0.0188
Home ownership				
h00:homeownershipYes	-0.5052	0.0299	-16.8790	0.0000
h00:homeownershipmissing	-0.3366	0.0384	-8.7697	0.0000
Marital status				
h00:marital_statusmarried	-0.5315	0.0162	-32.8475	0.0000
Income				
h00:personal_income_group500-999	-0.5318	0.0206	-25.8403	0.0000
h00:personal_income_group1000+	-0.9612	0.0271	-35.4802	0.0000
h00:personal_income_groupmissing	1.1629	0.0234	49.6216	0.0000

Table 8: Summary of model parameters for the selected model for Females.

Coefficient	Estimate	Std. Error	z value	P-value
Age				
h00	-4.9438	0.1406	-35.1514	0.0000
h01	-0.2377	0.0932	-2.5514	0.0107
h10	-4.7883	0.9557	-5.0101	0.0000
h11	3.1237	0.6671	4.6825	0.0000
IRSAD				
h00:IRSADD1 (Most Disadvantaged)	0.8659	0.0440	19.6976	0.0000
h00:IRSADD 2	0.6751	0.0446	15.1441	0.0000
h00:IRSADD 3	0.4937	0.0461	10.7116	0.0000
h00:IRSADD 4	0.4756	0.0468	10.1660	0.0000
h00:IRSADD 5	0.4171	0.0478	8.7323	0.0000
h00:IRSADD 6	0.3145	0.0487	6.4589	0.0000
h00:IRSADD 7	0.2535	0.0496	5.1153	0.0000
h00:IRSADD 8	0.2067	0.0505	4.0980	0.0000
h00:IRSADD 9	0.0740	0.0515	1.4361	0.1510
Home ownership				
h00:homeownershipYes	-0.5091	0.0374	-13.6308	0.0000
h00:homeownershipmissing	-0.2309	0.0484	-4.7702	0.0000
Marital status				
h00:marital_statusmarried	-0.4456	0.0192	-23.1947	0.0000
Income				
h00:personal_income_group500-999	-0.5929	0.0256	-23.1541	0.0000
h00:personal_income_group1000+	-0.8775	0.0412	-21.3096	0.0000
h00:personal_income_groupmissing	1.3655	0.0246	55.4170	0.0000

5.2.1 Age

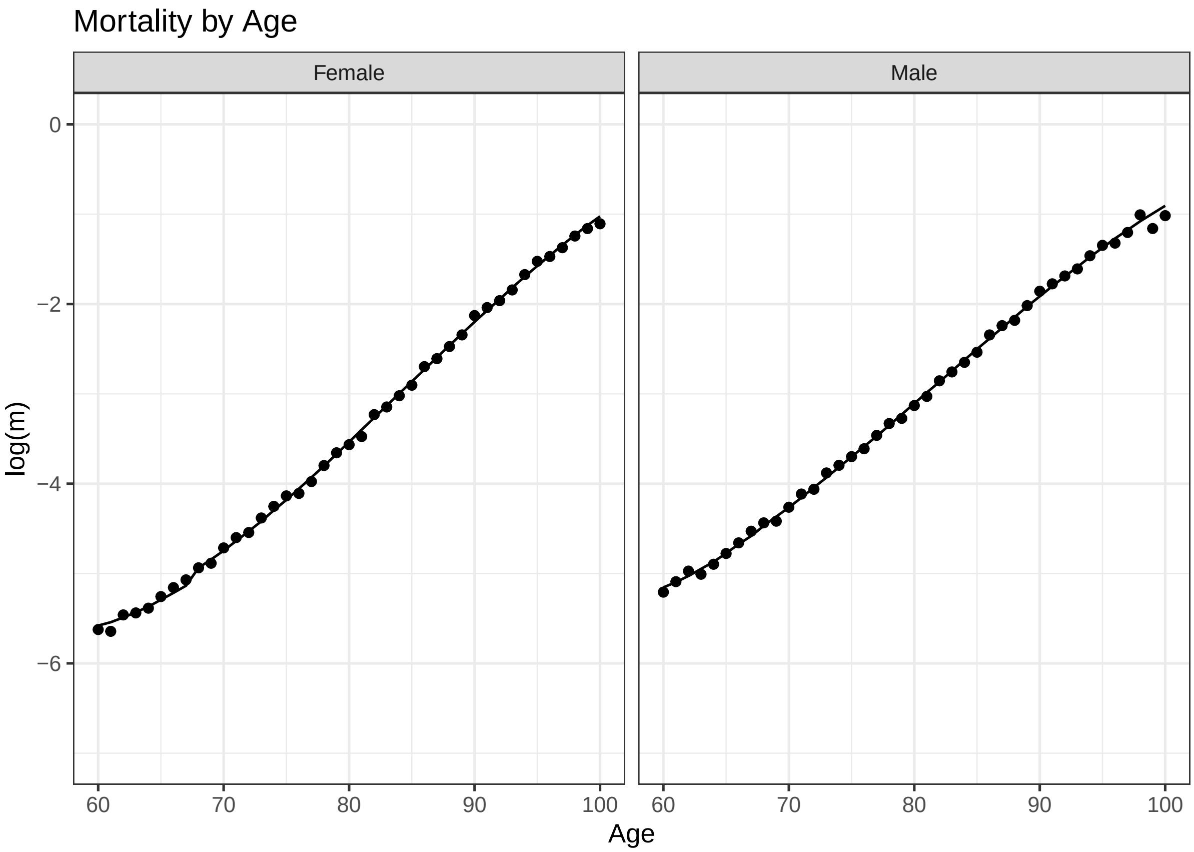

Figure 7: Fitted vs crude rates by age.

Figure 7 presents the fitted and crude mortality rates by age and gender for the full sample. Overall, the model captures the age trend well across both sexes. A slight kink is visible around age 68, both here and in individual plots for other covariates, due to our treatment of home ownership: data beyond age 68 is treated as missing and grouped into a single "missing" category. However, this artefact disappears when modeling mortality at a more granular level, accounting for all covariates simultaneously.

5.2.2 IRSAD

Figure 8 presents the fitted and the crude rates by IRSAD decile. To avoid clutter, we only include the crude rates for the most disadvantaged and most advantaged deciles. This figure again indicates that the estimated model captures the impact of the IRSAD reasonably well. In particular,

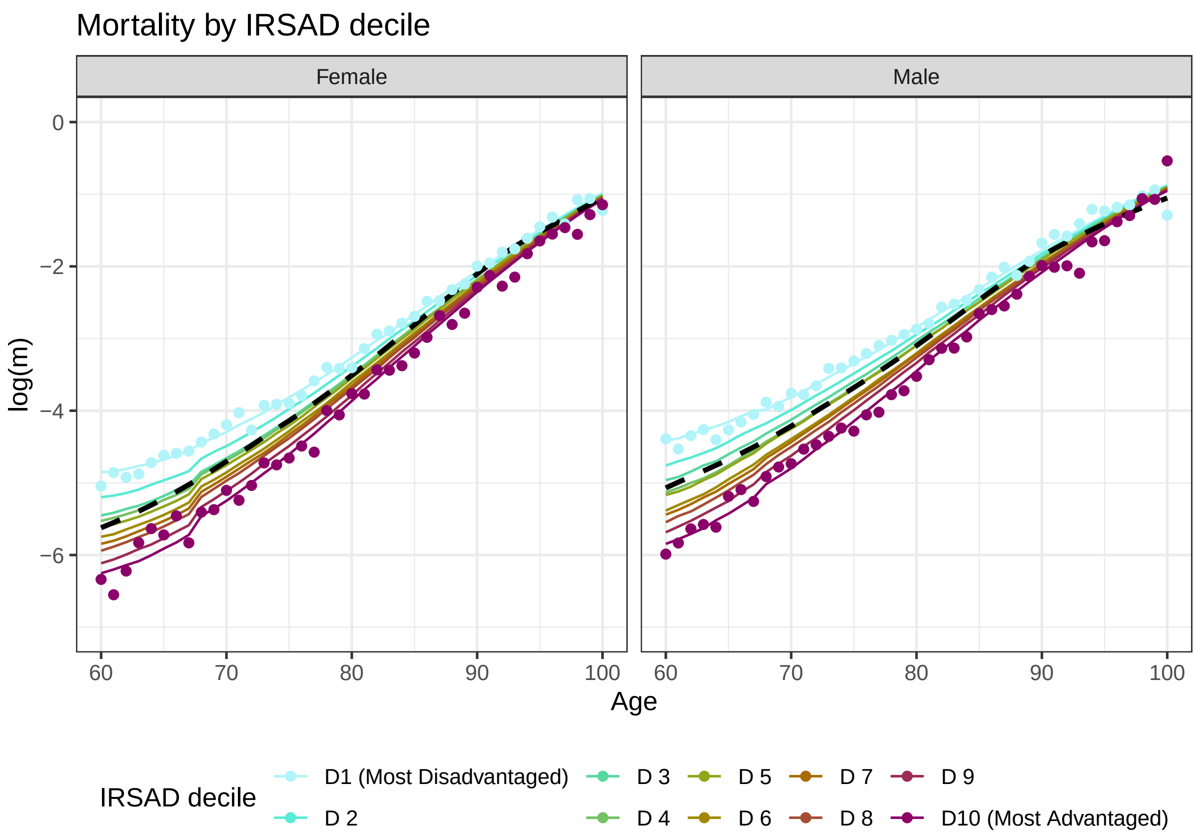

Figure 8: Fitted vs. crude mortality rates by age and gender according to IRSAD decile.

- the model captures well the narrowing of age differentials with increasing age while avoiding undesirable cross-overs;
- the model respects the expected ordering of mortality by IRSAD, with those living in more disadvantaged areas having higher mortality than those living in more advantaged areas;
- except for D1 and D2, the difference in mortality between adjacent deciles is generally small.

5.2.3 Home ownership

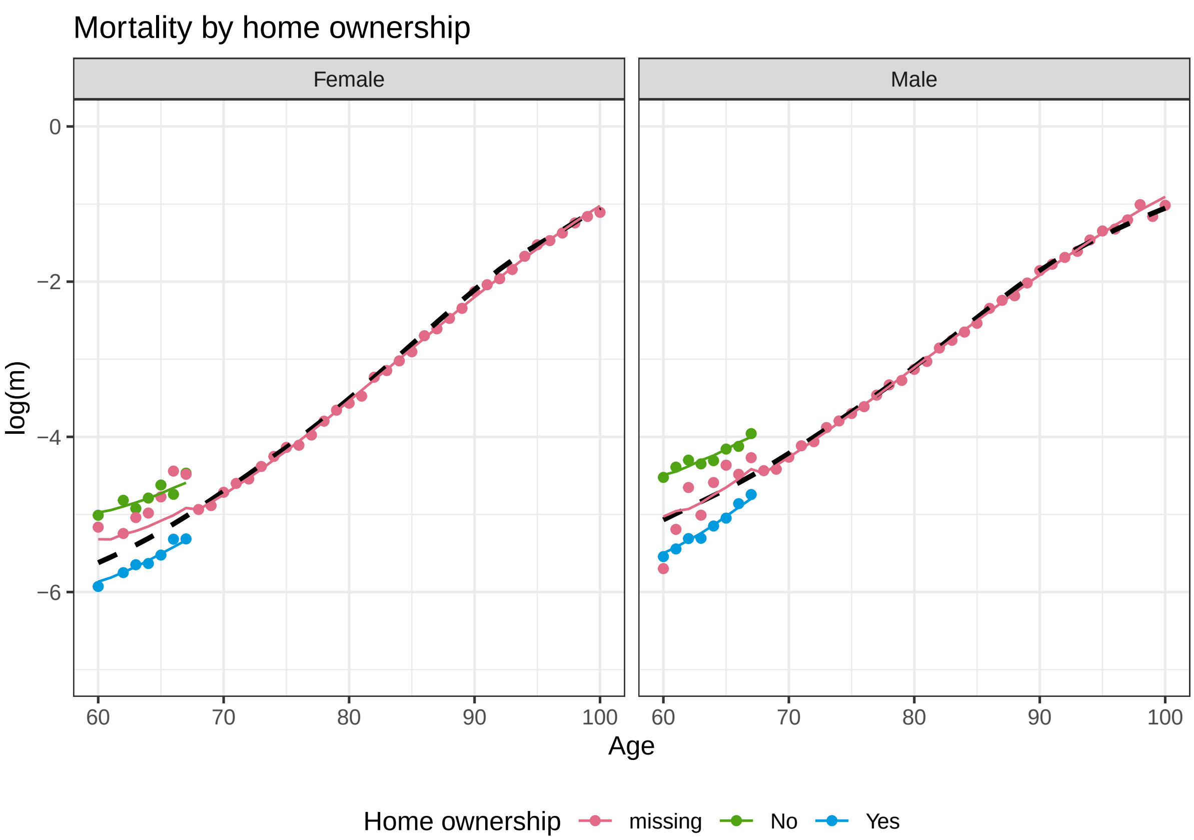

Figure 9: Fitted vs. crude mortality rates by age and gender according to home ownership status.

Figure 9 presents the fitted and crude rates for homeowners versus non-homeowners, again showing the model captures the association between home ownership and mortality satisfactorily.

5.2.4 Marital Status

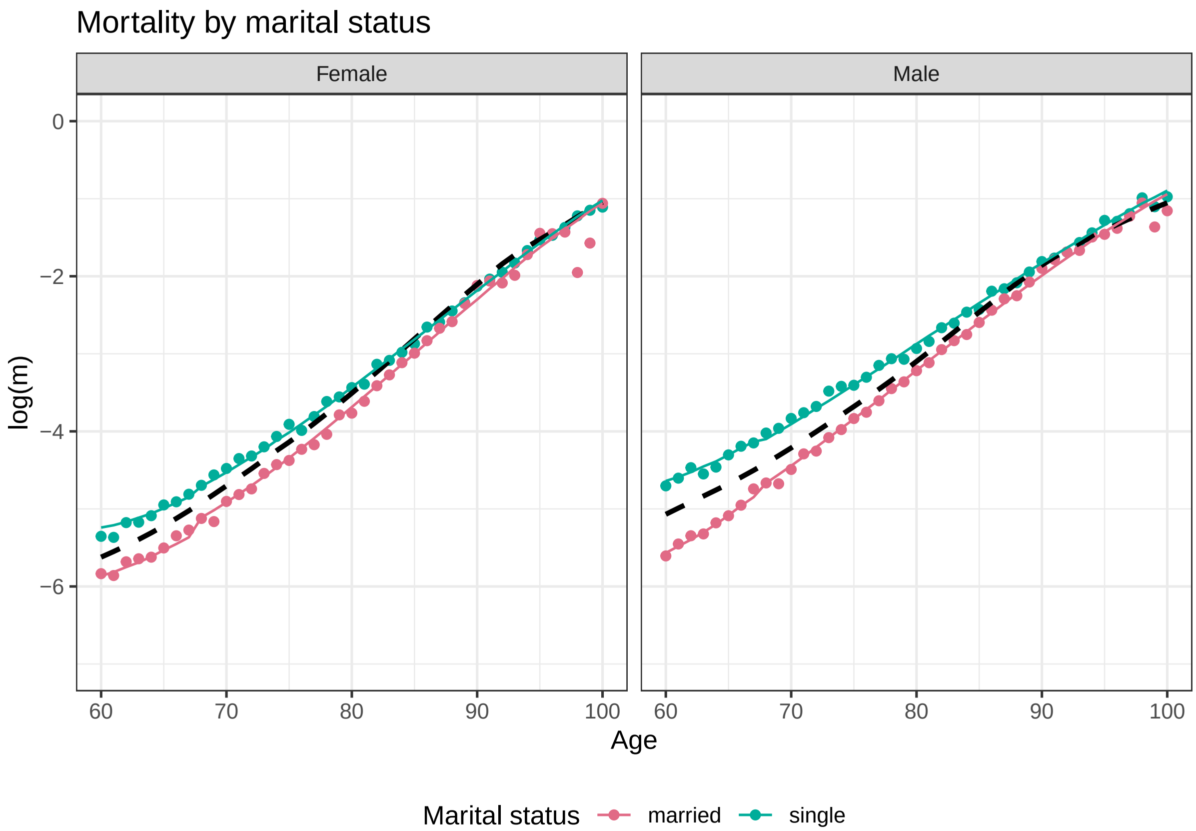

Figure 10: Fitted vs. crude mortality rates by age and gender according to marital status.

Figure 10 presents the fitted and crude rates for single and married individuals across both genders. Results show the model captured well the effect of marital status on mortality rates, with the exception of one or two outlying values for married individuals at the oldest ages. Noticeable, the difference in fitted rates between single and married individuals diminishes with increasing age, and does not crossover.

5.2.5 Personal income group

Figure 11 displays the fitted and crude rates for the different weekly personal income groups. This plot suggests that the model captured reasonably well the effects of these broad personal income brackets. In particular, there is a clear mortality differential between the income groups in the expected direction, and these differentials decrease as age increases. The group with missing income entries have the highest mortality by far across all ages and both genders, although we again caution against (over-)interpreting the results for this subgroup.

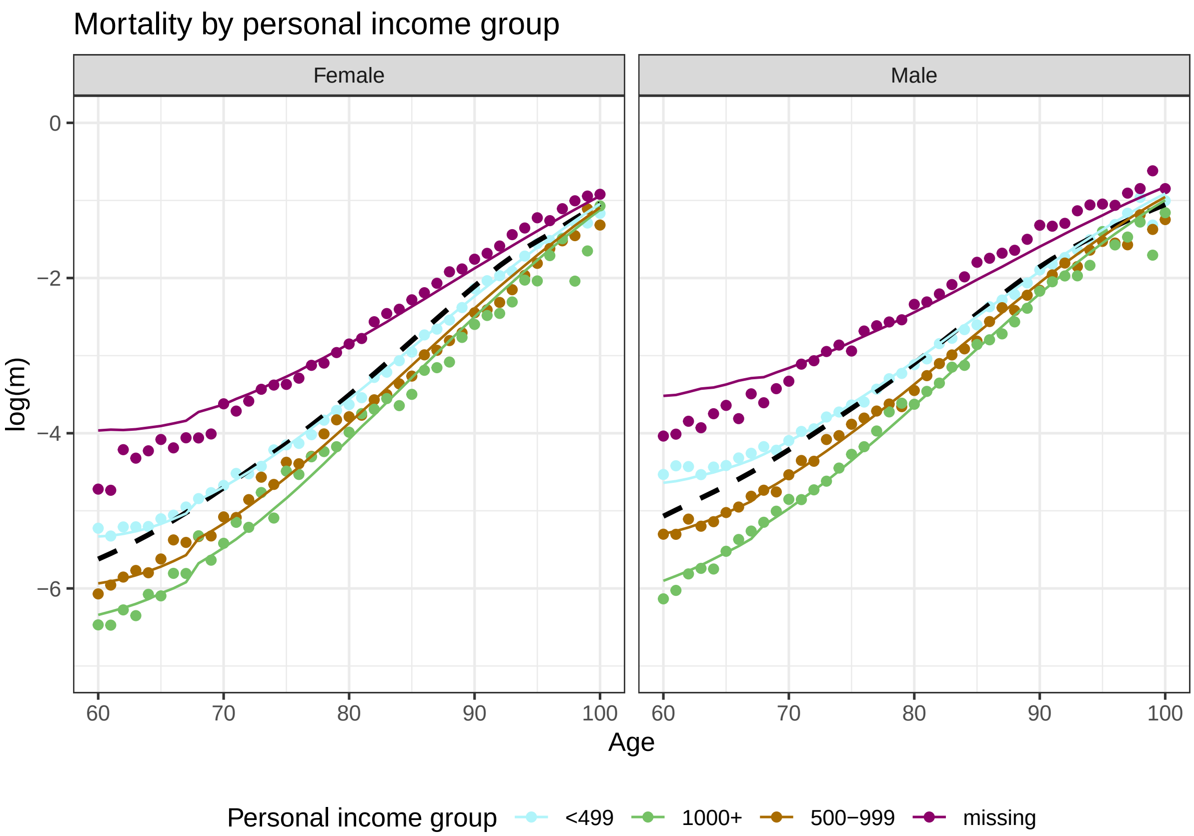

Figure 11: Fitted vs. crude mortality rates by age and gender according to income.

6 Applications of the modelling results

In this section, we illustrate three applications of the fitted model. First, we use the model to derive mortality rates for individuals with specific socio-economic profiles. Second, we examine the extent of variation in period life expectancy among older Australians. Third, we assess the financial implications of these mortality differences by calculating annuity rates and corresponding retirement income for each socio-economic profile.

6.1 Mortality rates for socio-economic profiles

Given specific values of IRSAD, home ownership, marital status and income, we can use the fitted model to construct mortality rates and period life tables for particular socio-economic profiles. As an illustration, we consider four profiles:

- *Profile 1 (low):* Single individual who is a non-homeowner, with an income of less than $499, and living in a D1 IRSAD area;
- *Profile 2a (intermediate I):* Single individual who is a non-homeowner, with an income in $500-$999 bracket, and living in a D5 IRSAD area;
- *Profile 2b (intermediate II):* Married individual who is a homeowner, with an income in $500-$999 bracket, and living in a D5 IRSAD area;
- *Profile 3 (high):* Married individual, who is a homeowner, with an income of more than $1000 and living in a D10 IRSAD area.

Figure 12 presents the predicted mortality rates for these four profiles, alongside the ALT 2015–2017 rates. For additional comparison, we include reference annuitant mortality rates, constructed following the methodology discussed in Institute of Actuaries of Australia (2018). Specifically, we derive the annuitant mortality rates by multiplying the ALT 2015–2017 rates by the ratio of annuitant to general population mortality reported in UK data, as outlined in Institute of Actuaries of Australia (2018). It is important to note that the mortality ratio between annuitants and the general population may differ between Australia and the UK, particularly if the propensity to purchase annuities varies across the two countries. This represents a qualification to the applicability of the UK reference rates. In particular, note that in the UK, annuitisation was mandatory prior to 2015—the period during which the reference data were collected. As a result, one would expect the annuitant-to-population mortality ratio in Australia to be lower than in the UK, since annuitisation in Australia has historically been voluntary and potentially more selective.

We observe that Profile 1 – the most disadvantaged – exhibits substantially higher mortality rates than the reference ALT rates for the Australian population. Profile 2a aligns closely with the ALT rates, while Profiles 2b and 3 – representing more advantaged individuals – have noticeably lower mortality. The annuitant mortality rates are lower than the ALT, closely matching Profile 2b for males, and converging towards Profile 2a and the ALT at older ages for females.

Finally, we note that the mortality curves beyond age 100 are extrapolated using the fitted Hermite-spline model, which yields higher rates than the corresponding ALT 2015–2017 estimates. As discussed in Section Section 4, the parameter ω can be interpreted as the log force of mortality at the upper endpoint, $x_1 = 110$, i.e., $\log(\mu_{110})$. In our fitted models, the estimated values of $\log(\mu_{110})$ are -0.2955 for males and -0.2377 for females, corresponding to mortality rates of approximately 0.525 and 0.545, respectively. These values lie within the range typically observed at such advanced ages (Barbi et al. 2018). If desired, one could instead enforce alignment with the ALT at the upper endpoint by fixing ω to the corresponding ALT value.

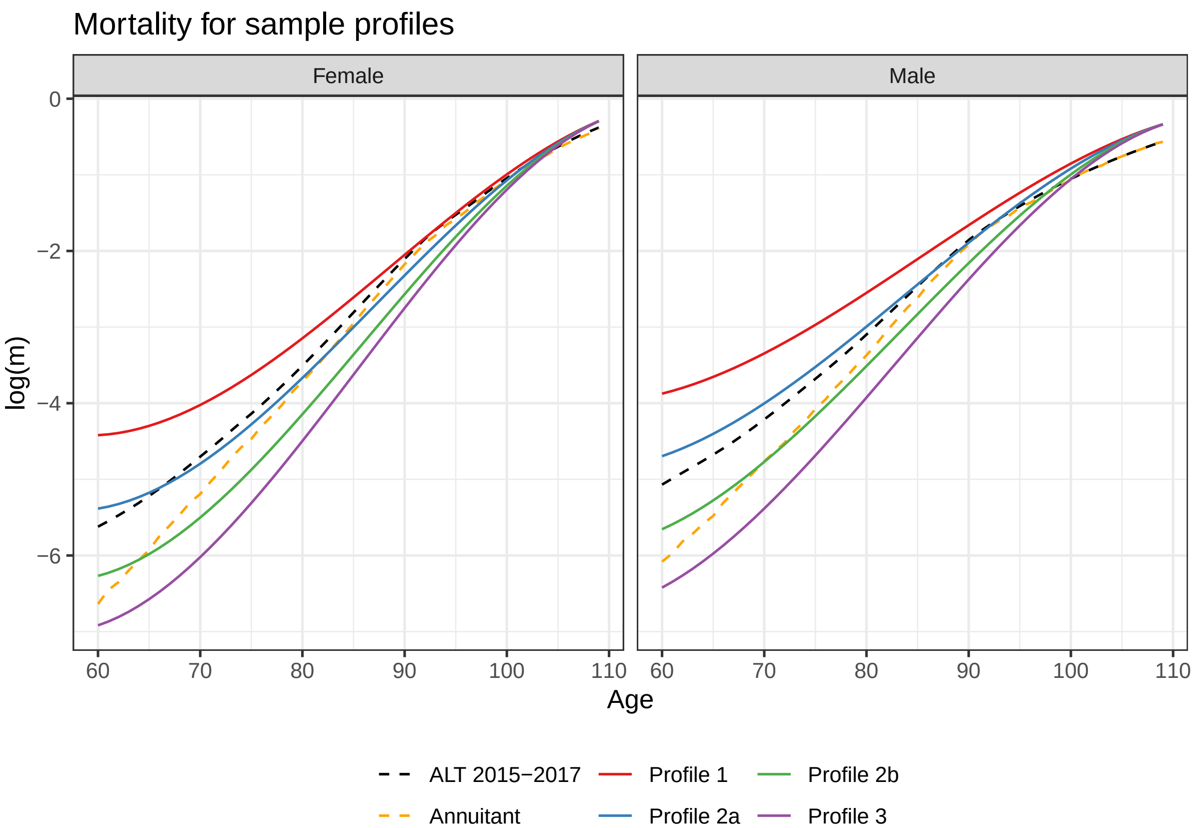

Figure 12: Predicted mortality rates for sample profiles.

6.2 Life Expectancy

In order to gauge the magnitude of longevity differences in the Australian population at retirement age, we compute period life expectancy at age 60 for the different socio-economic profiles. In detail, given estimated values of $\mu_{x,s,h,m,i}$ from the model, we compute period life expectancy at age 60 for each IRSAD decile s, home ownership group h, marital status m and personal income bracket i, as follows:

Table 9: Female period life expectancy at age 60.

Home ownership	Income	Marital status	IRSAD									
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
No	<499	Single	23.86	24.80	25.64	25.72	25.98	26.43	26.68	26.88	27.41	27.70
		Married	25.97	26.78	27.51	27.58	27.81	28.19	28.41	28.58	29.04	29.29
Yes		Single	26.24	27.04	27.76	27.83	28.05	28.42	28.64	28.81	29.26	29.50
		Married	28.04	28.73	29.34	29.40	29.59	29.92	30.10	30.24	30.63	30.84
missing		Single	24.99	25.86	26.64	26.72	26.96	27.37	27.61	27.79	28.29	28.55
		Married	26.95	27.71	28.38	28.45	28.65	29.01	29.22	29.37	29.80	30.03
No	500-999	Single	26.60	27.38	28.07	28.14	28.36	28.72	28.93	29.09	29.53	29.77
		Married	28.34	29.02	29.61	29.67	29.86	30.17	30.35	30.49	30.87	31.07
Yes		Single	28.57	29.23	29.82	29.87	30.05	30.36	30.54	30.67	31.04	31.24
		Married	30.04	30.61	31.11	31.16	31.32	31.59	31.74	31.86	32.18	32.35
missing		Single	27.54	28.26	28.90	28.96	29.16	29.50	29.70	29.84	30.25	30.47
		Married	29.15	29.77	30.33	30.38	30.55	30.84	31.01	31.14	31.49	31.68
No	1000+	Single	27.74	28.45	29.08	29.15	29.34	29.67	29.86	30.01	30.41	30.62
		Married	29.33	29.94	30.48	30.54	30.70	30.99	31.16	31.28	31.63	31.81
Yes		Single	29.54	30.13	30.67	30.72	30.88	31.16	31.33	31.45	31.79	31.97
		Married	30.87	31.39	31.85	31.90	32.04	32.28	32.42	32.53	32.82	32.98
missing		Single	28.60	29.25	29.84	29.89	30.07	30.38	30.56	30.69	31.06	31.26
		Married	30.06	30.63	31.13	31.18	31.34	31.60	31.76	31.87	32.19	32.37
No	missing	Single	15.68	16.95	18.13	18.24	18.61	19.26	19.63	19.92	20.71	21.15
		Married	18.59	19.78	20.86	20.97	21.31	21.89	22.23	22.49	23.20	23.58
Yes		Single	18.99	20.16	21.23	21.34	21.67	22.25	22.58	22.83	23.53	23.91
		Married	21.65	22.71	23.66	23.75	24.05	24.55	24.85	25.07	25.68	26.01
missing		Single	17.21	18.44	19.58	19.69	20.04	20.66	21.01	21.28	22.04	22.44
		Married	20.02	21.15	22.18	22.28	22.60	23.15	23.47	23.71	24.37	24.73

$$e_{60,s,h.m,i} = \frac{1}{2} + \sum_{j=1}^{50} p_{60,s,h.m,i}(j),$$

where the cumulative survival probabilities are given by

$$p_{60,s,h.m,i}(j) = \exp\left(-\sum_{k=0}^{j-1} \mu_{60+k,s,h.m,i}\right).$$

Table 9 and Table 10 present the resulting period life expectancy at age 60 for females and males, respectively. As a reference point, the life expectancy at age 60 based on the ALT 2015–2017 life table is 26.9 years for females and 24 years for males. Using the annuitant mortality rates illustrated in Figure 12, the corresponding life expectancies are 29.1 years for females and 26.8 years for males. Based on these results, we observe the following:

- There is significant heterogeneity in life expectancy among Australians. For example, single male non-homeowners living in an IRSAD D1 area and earning less than $499 a week have a period life expectancy at age 60 of only 18.7 years. At the other end of the spectrum, the period life expectancy for married male homeowners living in an IRSAD D10 area and earning more than $2,000 is 30.2 years. This corresponds to a substantial 11.5-year difference between the most disadvantaged and advantaged males.

Table 10: Male period life expectancy at age 60.

			IRSAD									
Home ownership	Income	Marital status	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
No	<499	Single	18.67	19.47	20.16	20.73	20.66	21.49	21.54	21.80	22.20	22.71
		Married	21.59	22.31	22.92	23.43	23.36	24.08	24.13	24.36	24.70	25.15
Yes		Single	21.45	22.17	22.79	23.30	23.23	23.96	24.01	24.24	24.59	25.04
		Married	24.06	24.68	25.22	25.66	25.60	26.23	26.27	26.46	26.76	27.15
missing		Single	20.56	21.30	21.95	22.48	22.41	23.17	23.22	23.46	23.83	24.30
		Married	23.27	23.92	24.49	24.95	24.89	25.55	25.59	25.79	26.11	26.51
No	500-999	Single	21.59	22.31	22.92	23.43	23.36	24.09	24.13	24.36	24.70	25.15
		Married	24.18	24.80	25.33	25.77	25.71	26.33	26.37	26.56	26.86	27.25
Yes		Single	24.06	24.68	25.22	25.66	25.60	26.23	26.27	26.46	26.76	27.15
		Married	26.31	26.84	27.31	27.68	27.63	28.16	28.20	28.36	28.62	28.95
missing		Single	23.27	23.93	24.49	24.95	24.89	25.55	25.59	25.79	26.11	26.52
		Married	25.63	26.20	26.68	27.07	27.02	27.58	27.62	27.79	28.06	28.41
No	1000+	Single	23.71	24.35	24.90	25.34	25.28	25.93	25.97	26.17	26.47	26.87
		Married	26.01	26.56	27.03	27.41	27.36	27.91	27.94	28.11	28.37	28.71
Yes		Single	25.90	26.46	26.93	27.32	27.26	27.82	27.85	28.02	28.29	28.62
		Married	27.89	28.36	28.76	29.09	29.04	29.52	29.55	29.69	29.91	30.20
missing		Single	25.21	25.79	26.28	26.69	26.63	27.22	27.26	27.43	27.71	28.07
		Married	27.29	27.79	28.21	28.56	28.51	29.01	29.04	29.19	29.43	29.73
No	missing	Single	11.56	12.42	13.19	13.85	13.76	14.73	14.79	15.10	15.59	16.22
		Married	14.86	15.72	16.48	17.12	17.03	17.96	18.02	18.32	18.77	19.36
Yes		Single	14.69	15.56	16.32	16.96	16.87	17.81	17.87	18.16	18.62	19.21
		Married	17.93	18.74	19.46	20.05	19.96	20.82	20.87	21.14	21.55	22.08
missing		Single	13.64	14.51	15.29	15.93	15.84	16.80	16.86	17.16	17.63	18.24
		Married	16.92	17.76	18.49	19.10	19.01	19.90	19.95	20.23	20.66	21.21

- For females, albeit smaller, the difference in life expectancy between the two ends of the socio-economic spectrum is 9.1 years (2.4 years smaller than males), with period life expectancy being 33 years for married female homeowners living in an IRSAD D10 area and earning more than \$2,000, and 23.9 years for single female non-homeowners living in an IRSAD D1 area and earning less than \$499 a week.

6.3 Annuity Rates

As a third example to assess the financial impact of socio-economic differences in mortality, we calculate the annual annuity income for various socio-economic profiles, based on a \$100,000 investment by an individual aged 65 in 2016. To account for future mortality improvements, we apply the improvement factors from the Australian Life Tables (ALT) 2015–2017, using the 125-year projection scenario (Australian Government Actuary 2019).

The annuity factor is the value of an annuity that pays one dollar at the end of each year. The annuity factor $a_{x,s,h,m,i}$ for an individual aged x in 2016, living in IRSAD decile s, home ownership group h, marital status m, and personal income bracket i, is calculated as follows:

$$a_{x,s,h,m,i} = \sum_{j=1}^{110-x} \frac{{}_jp_{x,s,h,m,i}}{(1+r)^j},$$

where r is the interest rate and ${}_jp_{x,s,h,m,i}$ is the cohort survival probability from age x to age $x+j$, defined as:

$${}_jp_{x,s,h,m,i} = \prod_{k=0}^{j-1} \left(1 - q_{x+k,s,h,m,i}(2016) \cdot \left(1 + \frac{I_x}{100}\right)^k \right),$$

where I_x denote the annual mortality improvement factor at age x. We also have $q_{x+k,s,h,m,i}(2016) = 1 - \exp(-\mu_{x+k,s,h,m,i})$, where $\mu_{x+k,s,h,m,i}$ is obtained from the fitted Hermite-spline mortality model.

Tables Table 11 and Table 12 report the annual annuity income for a \$100,000 investment for a person aged 65 in 2016, calculated as $\$100{,}000 \,/\, a_{65,s,h,m,i}$ and assuming an interest rate of $r = 3\%$. For comparison, the corresponding annuity income based on the ALT 2015–2017 life tables (under the 125-year scenario) is \$6,321 for females and \$6,973 for males. Using annuitant mortality rates, the income reduces to \$5,956 for females and \$6,381 for males.

The impact of longevity differences is substantial. For individuals with the shortest life expectancy (Profile 1), the annual annuity income would be \$6,896 for females and \$8,521 for males. In contrast, for those with the longest life expectancy (Profile 3), the income reduces to \$5,387 for females and \$5,785 for males. A female in the lowest socio-economic group could receive an annuity that is around 28% higher if these differences are taken into account.

Table 11: Annual annuity income for females from a $100,000 investment at age 65.

Home ownership	Income	Marital status	IRSAD									
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
No	<499	Single	6896	6696	6528	6512	6462	6379	6332	6297	6203	6154
		Married	6465	6314	6186	6174	6135	6071	6035	6008	5935	5896
Yes		Single	6413	6268	6144	6132	6095	6034	5999	5972	5902	5865
		Married	6097	5985	5889	5880	5851	5802	5775	5754	5698	5669
missing		Single	6658	6485	6339	6326	6282	6210	6169	6138	6056	6013
		Married	6285	6153	6040	6030	5996	5940	5908	5884	5820	5786
No	500-999	Single	6347	6209	6091	6080	6045	5986	5952	5927	5860	5824
		Married	6047	5939	5847	5839	5811	5765	5738	5718	5665	5637
Yes		Single	6010	5906	5817	5809	5782	5737	5711	5692	5640	5613
		Married	5783	5702	5631	5624	5603	5567	5546	5531	5489	5467
missing		Single	6182	6061	5957	5947	5917	5865	5835	5813	5753	5722
		Married	5918	5824	5742	5734	5710	5669	5645	5627	5580	5554
No	1000+	Single	6146	6029	5929	5919	5889	5838	5810	5788	5730	5700
		Married	5891	5799	5719	5712	5688	5648	5625	5608	5561	5537
Yes		Single	5859	5770	5693	5686	5663	5624	5602	5585	5540	5516
		Married	5664	5593	5531	5526	5507	5475	5457	5444	5407	5387
missing		Single	6006	5903	5814	5806	5779	5734	5709	5690	5638	5611
		Married	5780	5699	5628	5622	5600	5564	5544	5529	5487	5465
No	missing	Single	9466	8928	8488	8448	8320	8110	7993	7906	7676	7557
		Married	8327	7948	7634	7605	7513	7361	7276	7213	7045	6957
Yes		Single	8195	7833	7533	7505	7418	7272	7191	7130	6969	6886
		Married	7422	7160	6940	6919	6854	6747	6686	6641	6520	6457
missing		Single	8826	8379	8010	7976	7869	7692	7593	7520	7324	7223
		Married	7875	7555	7289	7264	7186	7056	6984	6930	6785	6710

Table 12: Annual annuity income for males from a $100,000 investment at age 65.

Home ownership	Income	Marital status	IRSAD									
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
No	<499	Single	8521	8237	8007	7828	7852	7606	7591	7518	7409	7273
		Married	7576	7380	7219	7093	7110	6937	6926	6875	6796	6699
Yes		Single	7615	7415	7252	7124	7141	6965	6954	6902	6822	6723
		Married	6943	6801	6684	6592	6604	6476	6468	6430	6372	6299
missing		Single	7883	7659	7476	7333	7353	7156	7144	7086	6998	6888
		Married	7132	6974	6844	6742	6756	6615	6606	6564	6500	6420
No	500-999	Single	7576	7379	7219	7093	7110	6936	6925	6874	6796	6699
		Married	6915	6775	6660	6569	6582	6456	6448	6410	6353	6281
Yes		Single	6943	6801	6684	6592	6604	6476	6468	6430	6372	6299
		Married	6460	6356	6270	6202	6212	6116	6110	6082	6039	5984
missing		Single	7132	6974	6844	6742	6756	6615	6606	6564	6500	6420
		Married	6597	6483	6388	6313	6324	6219	6213	6182	6134	6074
No	1000+	Single	7025	6876	6754	6657	6670	6537	6528	6489	6428	6352
		Married	6520	6412	6322	6251	6261	6162	6155	6126	6080	6024
Yes		Single	6542	6432	6340	6268	6278	6178	6171	6141	6095	6038
		Married	6165	6083	6015	5961	5968	5892	5887	5864	5829	5785
missing		Single	6687	6566	6465	6386	6397	6286	6279	6247	6196	6133
		Married	6273	6183	6108	6049	6057	5974	5969	5944	5906	5858
No	missing	Single	12574	11857	11286	10851	10909	10321	10284	10115	9859	9545
		Married	10250	9791	9422	9138	9176	8789	8765	8653	8482	8272
Yes		Single	10342	9874	9497	9207	9246	8851	8827	8712	8538	8324
		Married	8804	8492	8240	8044	8071	7803	7786	7707	7588	7440
missing		Single	10984	10446	10015	9684	9728	9279	9251	9121	8924	8681
		Married	9225	8872	8586	8366	8395	8093	8074	7986	7852	7686

The significant variation in annuity income observed across socio-economic profiles highlights critical equity concerns in the design of retirement income products. Our findings show that individuals with the shortest life expectancy—often those who are single, non-homeowners, residing in disadvantaged areas, and earning less than $499 per week—receive substantially higher annuity income per dollar invested, purely due to their lower projected longevity. In contrast, the most advantaged individuals receive much lower income for the same investment, reflecting their longer expected duration of payments. We acknowledge that these annuity income differentials could vary under alternative product designs, such as annuities with death benefits, indexation, or guarantee periods. The results presented here are based on a pure lifetime annuity without additional features.

If annuities are priced uniformly—without accounting for these mortality differentials, it can result in a cross-subsidy from disadvantaged groups to wealthier, healthier retirees. Such pricing may appear neutral, but in practice it may exacerbate inequality and undermine confidence in retirement income products. It could also lead to adverse selection and further undermine the viability of the longevity risk pool. Policymakers and product providers alike may need to reconsider how mortality heterogeneity is addressed to ensure the sustainability and fairness of Australia's retirement income system.

7 Conclusion

In this report, we have investigated mortality modelling for retirement-age Australians using a linked PLIDA data set. We explored mortality and life expectancy differentials based on age, gender, socio-economic advantage and disadvantage (SEIFA IRSAD decile), personal weekly income, marital status, and home ownership. Using a Hermite-spline Poisson regression model, we reach a number of major findings as follows:

- **Socio-demographic mortality differentials**: We find significant mortality differentials associated with IRSAD decile, marital status, home ownership, and personal income. These disparities tend to diminish with increasing age and become negligible by approximately age 100 for IRSAD decile, marital status, and income.
- **Life expectancy gaps**: There is substantial variation in life expectancy across the Australian population. Notably, the gap between the most socio-economically disadvantaged and advantaged males reaches 11.5 years; for females, the corresponding gap is 9.1 years.
- **Implications for retirement income**: Longevity differences translate into substantial variation in annuity income. For example, for a $100,000 investment at age 65 and a 3 percent interest rate, the annual income from a pure lifetime annuity (without indexation or a death benefit) ranges from $6,896 (females) and $8,521 (males) for individuals with the shortest life expectancy to just $5,387 (females) and $5,785 (males) for those with the longest. A female in the lowest socio-economic group could receive an annuity that is around 28% higher if these differences are taken into account. We note that the size of

these differentials can vary depending on annuity design features, such as the inclusion of a death benefit, indexation, or guarantee periods. The large and persistent differences by socio-economic characteristics suggest that uniform approaches to longevity product pricing may unintentionally disadvantage certain groups.

There are some notable limitations of this report. First, we focussed on a static period 2016-2017 to explore retirement mortality, which does not reflect the current mortality experience, although our explorations provide valuable insights into understanding mortality differentials as a whole. We are currently working towards applying the same models and methods for the 2021 Census data to provide a more up-to-date reflection of the Australian mortality landscape. Also, the advanced age mortality rates (above 100) are based on model extrapolation, given the data (and hence the model) is constrained to only contain mortality experience between ages 60 and 100. This can potentially lead to unlikely results for the mortality at the oldest ages. For example, in Figure 12, we see that mortality decreases for males above age 100, which is due to the model assumption that mortality rates converge at age 110 (Huang, Maller, and Ning 2020).

In future research, we could develop mortality models with better data to capture mortality patterns at the oldest ages, while for the purposes of this report we exhort readers to focus primarily on the mortality results between age 60 and 100. Along similar lines, there is a non-negligible amount of missing entries for weekly personal income, and this subgroup also experienced substantially higher mortality rates across both genders and all ages. Throughout this report, we have cautioned against interpreting this subgroup given personal communication with personnel from the ABS Census Data Division suggested that a large proportion of these correspond to individuals who did not complete a census form at all, meaning it is debatable whether they represent any useful subpopulation of interest. Finally, analysis at a finer granularity (not shown), we found some evidence that the benefits of being in the highest personal income bracket were less than those in the immediate bracket below. It is unclear what the reasoning behind this is, and further investigation is required here.

In addition, we plan to incorporate health data from the Medicare Benefits Schedule (MBS) and Pharmaceutical Benefits Scheme (PBS) to enrich our statstical analysis. Unfortunately, prominent health indicators such as current smoking status is not available in our datasets, and could not be accounted for in the current modelling, though they remain an important determinant of mortality worth considering in future research.

These results have clear implications for retirement income policy and product design in Australia. The large and persistent differences in mortality by socio-economic characteristics suggest that uniform approaches to longevity product pricing may unintentionally disadvantage certain groups. Incorporating heterogeneity in mortality into pricing frameworks could improve equity, reduce barriers to product uptake, and support the goals of the Retirement Income Covenant. As the superannuation system continues to evolve, evidence-based approaches that reflect real differences in longevity risk will be essential for designing fair and sustainable retirement income solutions.

8 Acknowledgements

We thank the Australian Government Actuary for their invaluable support in completing this project.

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