Multi-state modelling of functional disability and health status using a series of Australian cross-sectional data

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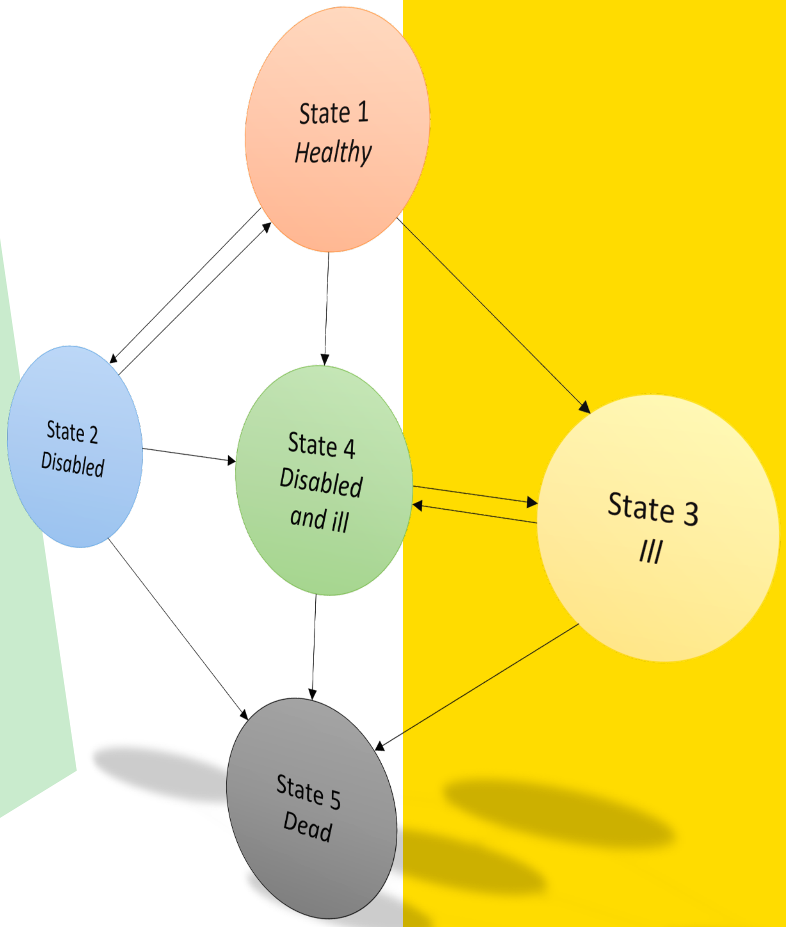

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Motivation

- Population ageing arouses the needs of optimal preparation for public aged care and development of long-term care (LTC) insurance in Australia.
- Dynamics of transitions between states based on functional disability and health status should be understood.
- To represent the transition dynamics, multi-state models have been widely used (e.g., Olivieri and Pitacco, 2001; Fong et al., 2015; Shao et al., 2017; Sherris and Wei, 2021).
- However, modelling for Australians has been difficult due to unavailability of longitudinal data. Several attempts include Leung (2004) and Hariyanto et al. (2014).

Objectives

- To fit a multi-state model of both functional disability and chronic illness status for Australians aged 60 or over with a minimal possible set of assumptions using observed prevalence of disability and illness in multiple years.
- To project the prevalence of functional disability and chronic illness, and estimate the (healthy) life expectancy of retirees with time spent in each state, with comparisons to previous studies.

While motivated (particularly) by Leung (2004) and Sherris and Wei (2021),
we are the first in fitting the model using more than two sets of the prevalence data,
and also the first in including separate illness state for the model for Australians.

Data

Survey of Disability, Ageing and Carers, Australia (SDAC) 1998, 2003, 2009, 2013, 2015 and 2018

→ Prevalence of disability and illness by age group and sex
→ Linearly filled to have the prevalence by age, sex and

Estimated Residen
Population By
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sex

Disability: Always needing help from at least two areas of five daily living activities, showering/ bathing, dressing, eating, toileting, and bladder/ bowel control.
Illness: Having conditions including heart problems, diabetes, lung disease and stroke.

Deaths, Year of registration, Age at death, Age-specific death rates, Sex, States, Territories and Australia, 2022

→ Mortality rates by age and sex in each single year, 2009-2018

Australian Bureau of Statistics

Method

Multi-state Markov Model

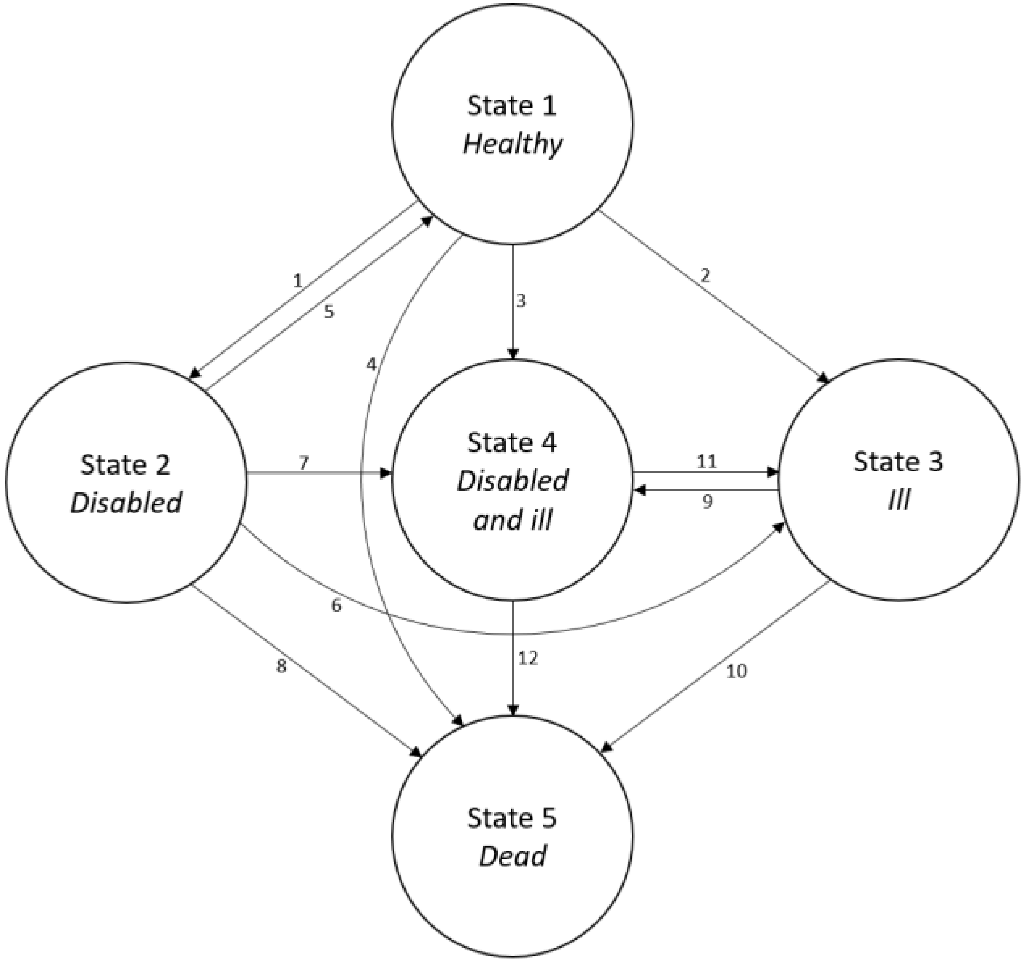

Figure 1: Five state model

- (Following Sherris and Wei [2021],)
  We use Cox Proportional Hazard equations to specify transition intensity as follows.

$ln\{\lambda_{k,s}\} = \beta_s + \gamma_s^{age} x_k + \gamma_s^{female} F_k$ (without trend)

$ln\{\lambda_{k,s}(t)\} = \beta_s + \gamma_s^{age} x_k(t) + \gamma_s^{female} F_k + \phi_s^{trend} t$ (with trend)

where s is transition type, $x_k(t)$ is age of individual k at time t, F_k is whether k is female, and β, γ and ϕ are regression coefficients.

- 1-year transition probability matrix (5x5) is estimated using the transition intensities.

Method

Computation using the model

State	AGE	Y1998	Y1999	Y2000	Y2001	
Healthy	60	47268	48278	48942	49633	...
Disabled	60	1541	1356	1149	929	...
Ill	60	29431	31651	33733	35933	...
Disabled and ill	60	1745	1633	1509	1373	...
Healthy	61	46396	46103	46594	46525	...
Disabled	61	1389	1204	1030	831	...
Ill	61	29087	31215	33989	36521	...
Disabled and ill	61	1160	1127	1120	1093	...
Healthy	62	44148	44620	43777	43875	...
Disabled	62	1207	1076	906	744	...
Ill	62	28006	31256	33750	37204	...
Disabled and ill	62	644	724	782	866	...
Healthy	63	40188	41401	41672	40898	...
Disabled	63	994	913	799	656	...
Ill	63	27223	30726	33800	36258	...
Disabled and ill	63	769	869	955	1027	...
		...	...	...	...	...

Actual data

State	AGE	Y1998	Y1999	Y2000	Y2001	
Healthy	60	47268	48278	48942	49633	...
Disabled	60	1541	1356	1149	929	...
Ill	60	29431	31651	33733	35933	...
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Healthy	63	40188				...
Disabled	63	994				...
Ill	63	27223				...
Disabled and ill	63	769				...
		...	...	...	...	...

Modelled data

Method

Optimisation

- Regression coefficients are estimated so that the model best describes the population by state, sex, age and year identified from data.
- That is done by minimising the measure, *Deviation* defined as follows.

$$Deviation = \sum_{All} \frac{\left(prevalence_{x(t),F,t}^{modelled} - prevalence_{x(t),F,t}^{actual}\right)^2}{prevalence_{x(t),F,t}^{actual}}$$

where $prevalence^{actual}$ is the population distributions for those aged 60 to 99 by age, sex and state in years from 2009 to 2018 identified in the data, and $prevalence^{modelled}$ is those according to the model for the same period.

- Function, *solnl*, under R package, *NlcOptim* package

Method

Assumptions/ constraints

- Linear filling for missing prevalence data
- Migration rate constant for each state
- Cox proportional hazard specification

- Mortality rate is greater for disabled or ill than healthy.
- Maximum mortality rates for healthy and disabled people aged 60 are 0.01 and 0.05, respectively.
- Minimum mortality rates for healthy, disabled, ill, and disabled and ill people in different states are 0.003, 0.003, 0.004 and 0.005, respectively.
- Mortality rates increase with age.
- Transition probability (other than those to death) are less than the probability of non-transition for any transition type.
- Improvements in medical technology.

Method

Evaluation

- Sensitivity test (test for significance of estimation)
- Comparison with previous studies
- Application of the method to available longitudinal data set to test the validity of the method

Result

Estimation of regression coefficients

Table 3: Estimated coefficients for the model without trend

Transition type	β_s	γ_s^{age}	γ_s^{female}
1	-6.2381	0.9110	-0.4649
2	-3.1764	0.5351	-0.0771
3	-6.0605	0.4248	-0.5227
4	-5.0369	0.6747	-0.2916
5	-4.3611	-0.0396	-0.0260
6	-3.6844	-0.1951	-0.1129
7	-3.4052	0.3782	-0.0561
8	-3.9408	0.7133	-0.3417
9	-5.8546	1.6030	-0.4483
10	-4.6364	1.0784	-0.1311
11	-4.2714	-0.1605	0.0430
12	-2.4500	0.7805	-0.8005

Value of the deviation: 0.00204799

Table 4: Estimated coefficients for the model with trend

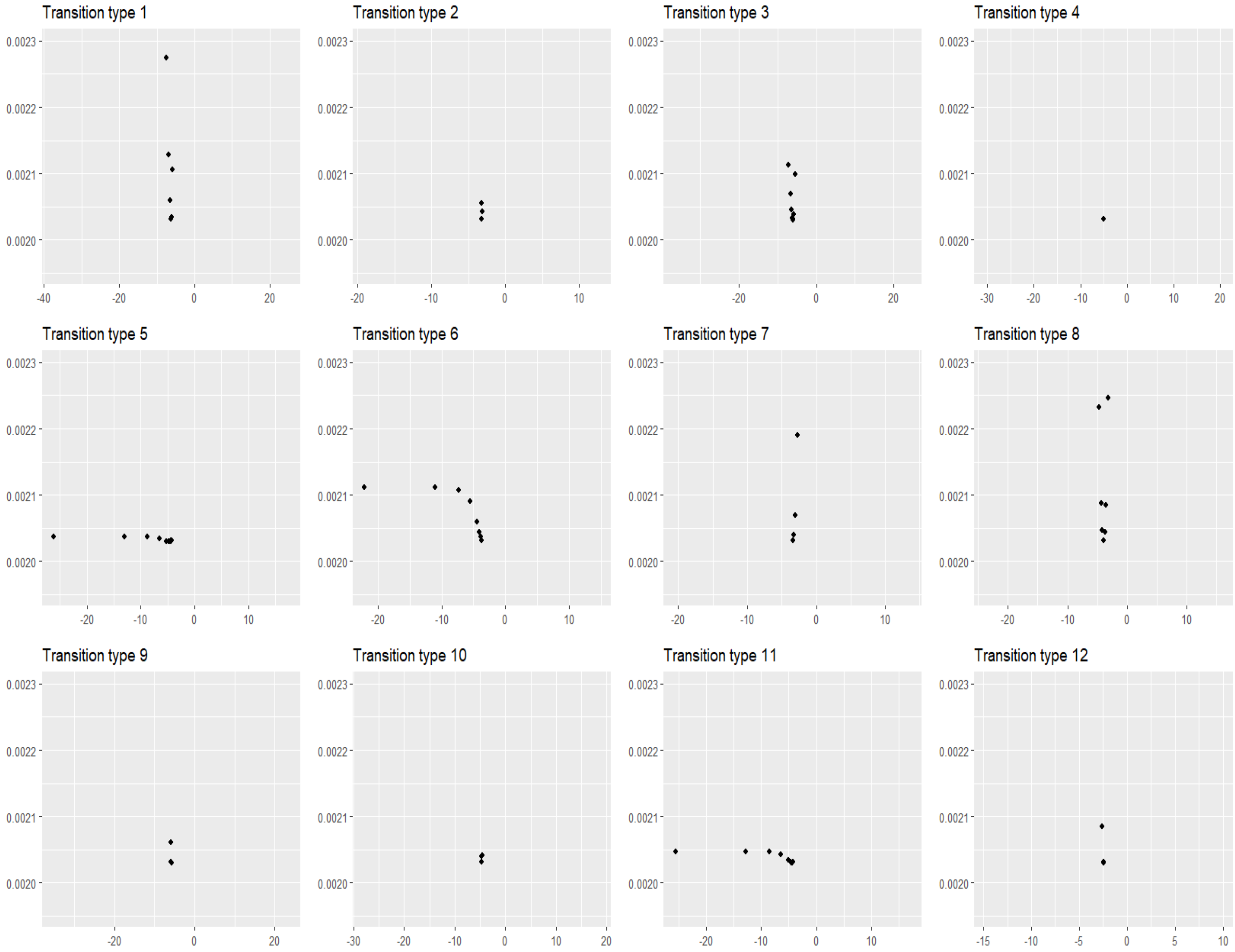
Transition type	β_s	γ_s^{age}	γ_s^{female}	ϕ_s^{trend}
1	-6.2381	0.9121	-0.4639	-7.26E-04
2	-3.1748	0.5364	-0.0767	-1.89E-05
3	-6.0604	0.4250	-0.5228	5.62E-06
4	-5.0369	0.6751	-0.2918	6.10E-07
5	-4.3611	-0.0400	-0.0263	-5.52E-07
6	-3.6844	-0.1954	-0.1131	1.10E-06
7	-3.4051	0.3777	-0.0571	7.32E-09
8	-3.9408	0.7134	-0.3426	-3.36E-07
9	-5.8532	1.6035	-0.4479	1.82E-18
10	-4.6365	1.0784	-0.1316	-9.00E-19
11	-4.2714	-0.1607	0.0430	5.41E-19
12	-2.4508	0.7807	-0.8002	2.20E-18

Value of the deviation: 0.002030692

Result

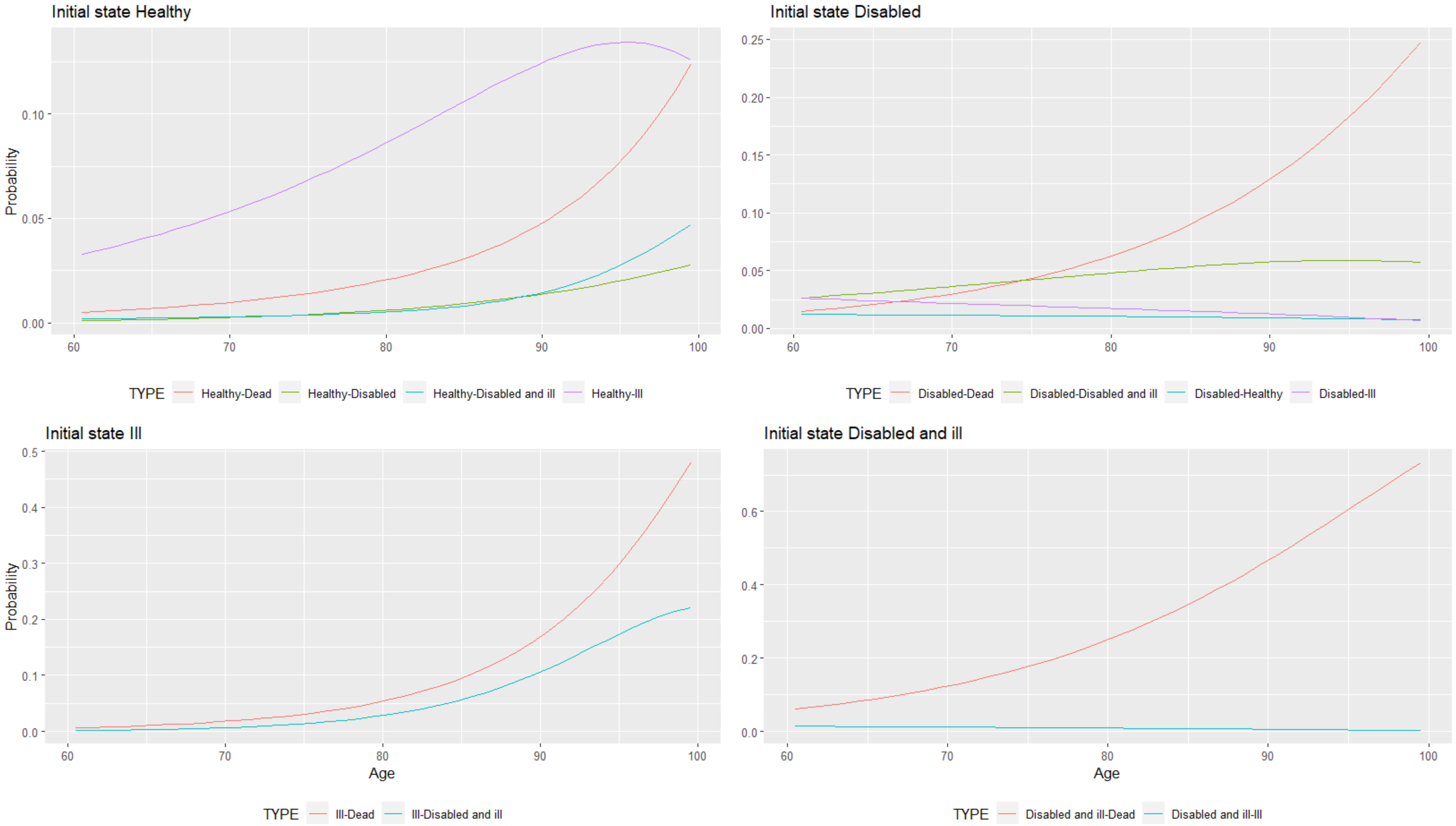
Sensitivity test

(Baseline parameter for the trend model)



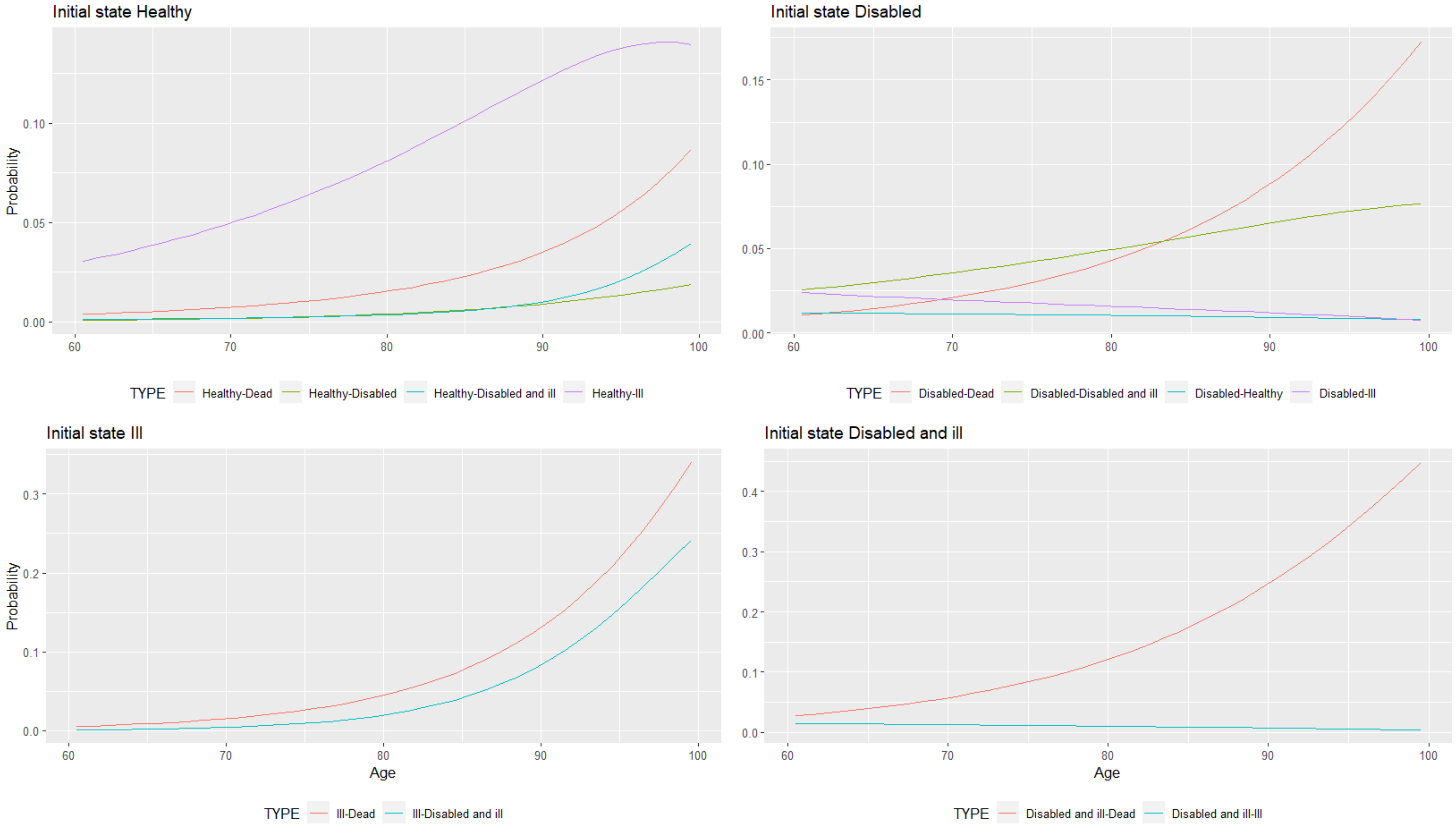
Result

Transition probability by age (Males)



Result

Transition probability by age (Females)



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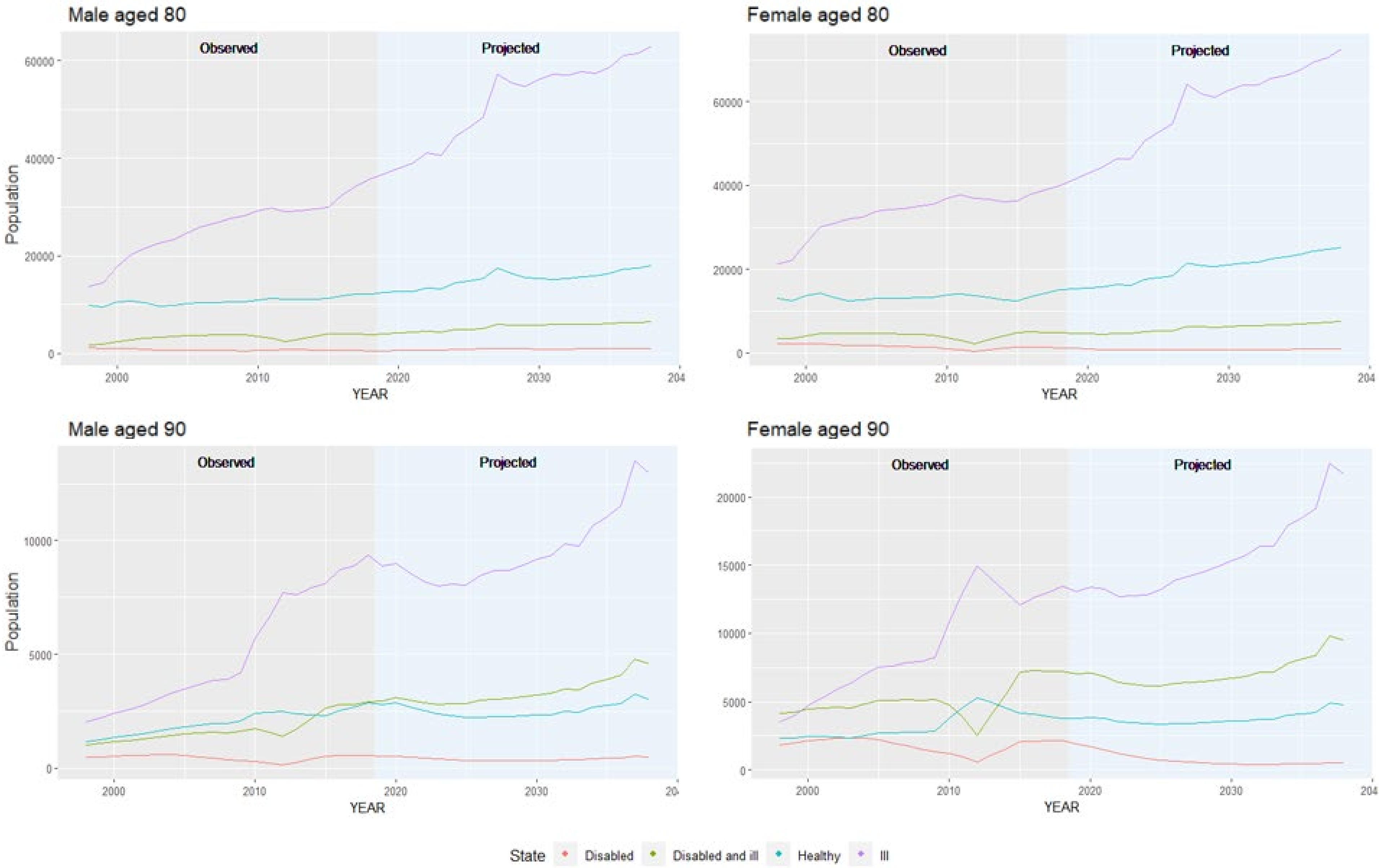
Result

Population by state (males and females aged 80 and 90, trend model)



Result

Life expectancy of males and females aged 65 in 2018

Table 7: Averaged remaining life and time spent in each state in years

	Total	Time spent in each state			
		Healthy	*Disabled*	*Ill*	*Disabled and ill*
Model without trend					
Male	20.04 (7.49)	10.72 (7.73)	0.36 (2.02)	7.02 (6.95)	0.94 (1.93)
Female	22.47 (7.96)	11.69 (8.23)	0.29 (1.84)	8.08 (7.49)	1.41 (2.92)
Model with trend					
Male	19.96 (7.53)	10.62 (7.65)	0.29 (1.68)	7.11 (6.98)	0.94 (1.93)
Female	22.43 (7.93)	11.77 (8.26)	0.23 (1.57)	8.03 (7.43)	1.4 (2.87)

Note: Standard deviations are in parentheses.

Contribution and Limitation

- Provides a framework for the development of public aged care policy or private LTC insurance for Australians.
- First in fitting the model using more than two sets of the SDAC data
- First in including separate illness state for the disability model for Australians.
- Compared to Leung (2005) and Hariyanto et al. (2014) where estimation was based on arbitrary rules, we tried to do the fitting with the greatest possible amount of data and minimised set of assumptions.
- Cannot be accurately evaluated in absence of actual transition information.
- However, measures based on transition intensities (e.g., projection of population by state, life expectancy etc.) can be usable.

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