MAIN ARTICLE

Projecting the Number of Elderly with Cognitive Impairment in China Using a Multi-State Dynamic Population Model

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Abstract

China is aging rapidly, and the number of Chinese elderly with dementia is expected to rise. This paper projects, up to year 2060, the number of Chinese elderly within four distinct cognitive states. A multi-state population model was developed using system dynamics and parametrized with age–gender-specific transition rates (between intact, mild, moderate and severe cognitive impairment and death) estimated from two waves (2012 and 2014) of a community-based cohort of elderly in China aged ≥65 years (N = 1824). Probabilistic sensitivity analysis and the bootstrap method was used to obtain the 95% confidence interval of the transition rates. The number of elderly with any degree of cognitive impairment increases; with severe cognitive impairment increasing the most, at 698%. Among elderly with cognitive impairment, the proportion of very old elderly (age ≥ 80) is expected to rise from 53% to 78% by 2060. This will affect the demand for social and health services China.

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Additional Supporting Information may be found online in the supporting information tab for this article.

Introduction

Dementia is a syndrome that results in the progressive deterioration of cognitive function, most commonly caused by Alzheimer's disease (AD). At advanced stages, it can lead to disability and dependence (Alzheimer's Disease International and Alzheimer's Australia, 2014). Globally, it was estimated that 47.5 million people had dementia in the year 2015 (World Health Organization, 2015). Coupled with an increasing dementia prevalence with age, this is a huge cause of concern in China, where the world's largest population is aging rapidly. In 2015, there were 131 million Chinese elderly aged ≥65 years, accounting for 22 percent of the elderly population in the

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world (United Nations, 2015). As the population continues to age, the number of Chinese elderly with dementia is expected to rise at an unprecedented rate.

With an inexorable progression, the risk of mortality and disability increases (Ishizaki *et al.,* 2006; Wang *et al.,* 2010). A recent study found that while both mild and moderate to severe cognitive impairment (CI) is associated with an increased risk for mortality, the latter has a greater limiting effect on life expectancy (Sachs *et al.,* 2011). Common risk factors for dementia include age, sex, environmental factors and lifestyle (Chen *et al.,* 2009) but can vary with ethnicity (Kalaria and World Federation of Neurology Dementia Research G, 2008; Venketasubramanian *et al.,* 2011; Catindig *et al.,* 2012). Another risk factor is mild CI, the intermediate state between normal cognitive aging and dementia (Petersen *et al.,* 1999). Currently, there is no substantially effective pharmacological treatment for dementia (Raina *et al.,* 2008), though behavioral interventions can moderate progression (Rapp *et al.,* 2002; Buschert *et al.,* 2011; Tsolaki *et al.,* 2011; Hwang *et al.,* 2012). Understanding the progression of CI can guide the development of programs to assist patients and families, and will facilitate targeting new treatments that may delay the onset of dementia.

Total cost of dementia in China was approximated to be US $45 billion (medical cost: US $9 billion; non-medical cost: US $4.5 billion; informal care cost: US $31 billion) in 2015 (Alzheimer's Disease International and Alzheimer's Australia, 2014), and individuals with a higher degree of CI accrue greater costs (Coughlin and Liu, 1989; Leicht *et al.,* 2011). Besides increased healthcare utilization among elderly with CI (Weiler *et al.,* 1991; Zhu *et al.,* 2013), their care needs vary with degree of impairment. Callahan *et al.* (1995) found that elderly primary care patients with moderate to severe CI were more likely than those with mild and no impairment to visit the emergency department and have higher hospitalization rates, but had fewer outpatient visits than those mildly or not impaired. Day-to-day functioning also differs by cognitive states. Mildly impaired elderly may require assistance only with complex tasks such as managing finances, whereas those moderately impaired may require assistance performing household tasks, and those severely impaired are likely to require assistance with daily activities such as dressing oneself (Mungas, 1991). Care hours required by individuals with dementia increase with severity (Riley *et al.,* 2012) and can have negative outcomes on caregivers. Excess caregiver burden is associated with depression (Papastavrou *et al.,* 2007; Malhotra *et al.,* 2012), poor physical health (Beach and Schulz, 1999) and reduced labor force participation (Wilson *et al.,* 2007; Arksey and Glendinning, 2008) among caregivers. This has huge implications on caregiving in China, where a large majority of elderly with dementia are cared for at home by their family (Dai *et al.*, 2013). Thus, analyzing the growth in number of cognitively impaired elderly by cognitive status can help policy planners pre-empt changes in demand, facilitating the planning of health and social care.

Epidemiological studies on CI in China on a national level is limited. Most studies that focus on enumerating the prevalence of mild CI or dementia are

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small scale and not generalizable to the population (Ding *et al.,* 2014; Su *et al.,* 2014), resulting in a large variability in the reported prevalence. A review and meta-analysis by Nie *et al*. (2011) found that the prevalence of mild CI in Chinese elderly ranged from 2.4 to 35.9 percent. Other studies investigating the risk factors of CI in Chinese elderly have also been inconclusive. Chen *et al*. (2011) reported a higher risk of dementia in females, whereas Li *et al*. (2007) reported no gender difference in risk. Very few studies document the progression of CI in Chinese elderly over time (Huang *et al.,* 2005; Xie *et al.,* 2012). Projections on the number of elderly with CI in future are also lacking. Most are simply obtained by applying current prevalence rates to the projected Chinese population (Wu *et al.,* 2013; Alzheimer's Disease International and Alzheimer's Australia, 2014; Li *et al.,* 2015), or aggregated with other developing countries (Ferri *et al.,* 2005). Furthermore, some projections focus on elderly formally diagnosed with AD or dementia (Ferri *et al.,* 2005; Wu *et al.,* 2013; Alzheimer's Disease International and Alzheimer's Australia, 2014), without distinguishing degree of CI, which is strongly related to distinct behavioral features and care needs.

In light of these pressing issues and the dearth of published evidence, this paper aims to project the number of elderly within four distinct cognitive states—intact, mildly, moderately and severely impaired—by considering the transition rates from one state to another, in a Chinese population of elderly aged ≥65, up to the year 2060.

Methods

To project the number of elderly Chinese and their corresponding cognitive status up to the year 2060, a dynamic multi-state population model was developed. The model required standard demographic data and estimates of transition rates between five states: intact, mild CI, moderate CI, severe CI and death. Demographic data were obtained from the National Bureau of Statistics of China and transition rates were derived from a large community-based study of Chinese elderly adults in longevity areas of the Chinese Longitudinal Healthy Longevity Survey (CLHLS). Written informed consent was obtained from all participants or their proxies. The Ethics Committees of Peking University and National University of Singapore approved this study.

Dynamic multi-state population model

The dynamic multi-state population model is a system dynamics (SD) model with explicit health states (Figure 1). It was constructed on Vensim DSS (Ventana Systems, Harvard, MA, USA) (Lutz and Goujon, 2001; Samir and Lentzner, 2010; Lutz *et al.,* 2014; Ansah *et al.,* 2015). SD models have

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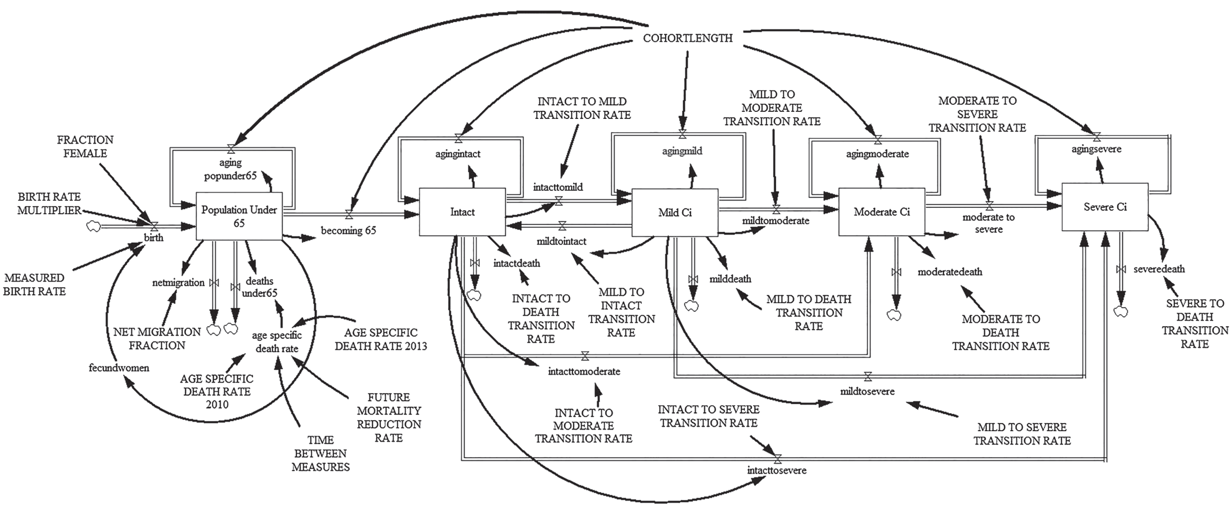

Fig. 1. Dynamic multi-state population model

been widely used to investigate the burden of chronic illnesses such as cardiovascular disease (Homer *et al.,* 2010), diabetes (Jones *et al.,* 2006) and in population health (Homer *et al.,* 2004; Milstein *et al.,* 2010). In the model, the Chinese population was divided into five groups: population < 65 years old, intact elderly, elderly with mild CI, elderly with moderate CI and elderly with severe CI. Within each group, the population was further subdivided into a two-dimensional vector (subscript): age (single age cohorts from newborn to age 0–64 for the <65 group, and single age cohorts from age 65–100 and older for the intact, mild CI, moderate CI and severe CI groups) and gender. The population < 65 increases via births and immigration and decreases via deaths, emigration and becoming elderly (i.e. aged ≥65). Births were calculated using the female reproductive age cohort (fecund women aged 15–49) and their corresponding fertility rates. Deaths were calculated based on the mortality rates for each age cohort obtained from life tables (National Bureau of Statistics of China, 2013). Emigration rate was estimated by calibration. At the end of each year, the surviving population in each age cohort ages and flows to the subsequent cohort, with the exception of the final age cohort (aged 100 and older). The aging process is conceptually straightforward, as illustrated by Figure 2. Babies born (births) are moved to a stock of newborns, and then immediately moved to the age 0–1 cohort. At the end of each year (cohort length), the surviving population in each cohort is moved to the next cohort, except for the last cohort (age 100 and older). The population age 100 and older remains in that cohort and decreases via death.

In the population model, the equations that shift the population at the end of each year from one cohort to another for the population < 65 years old are

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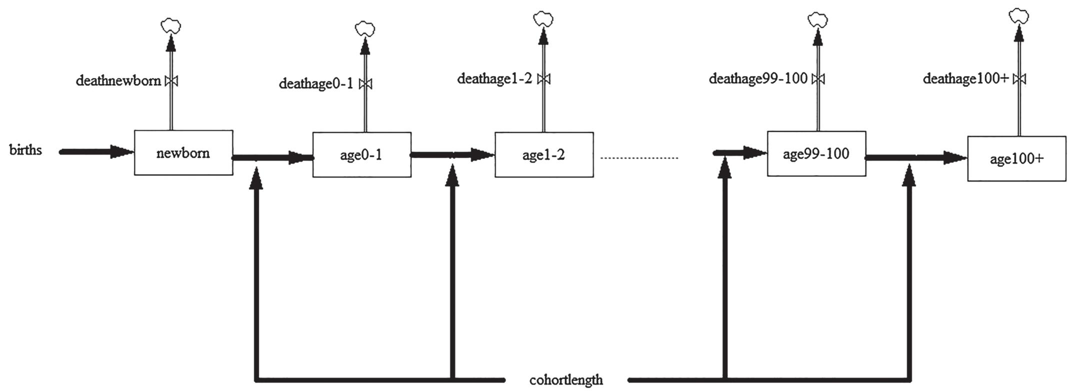

Fig. 2. Population aging process

illustrated in Eqs (1)–(4). Equations (1) and (2) show the aging process for the population under 65 years of age. The equations have two-dimensional vectors (*Sex* and *ageUnder65*) which are replicated for every vector combination to ensure consistent mapping. Age under 65 years herein comprise newborn, and *age0* to *age64*. Equation (1) applies to the aging process for *newBorn*, while that for *age0* to *age64* is represented by Eq. (2). At the end of each simulation time (which is a year)—represented herein as cohort length—the population in each cohort is divided by the cohort length and shifted to the subsequent age cohort. This process is represented by Eq. (3). However, to ensure that the population cohort *age64* does not age (since the last age cohort for population under 65 is *age64*), aging is herein assumed to be absent, thus represented by zero, as depicted by Eq. (4). To ensure that this age cohort (*age64*) does not accumulate beyond that age, we created an outflow "*becoming65*" to move those aged 64 at the end of the year to the health state "*intact*".

$$\begin{aligned} &\textit{population under } 65[\textit{Sex}, \textit{newBorn}](t) \\ &\quad = \textit{population under } 65[\textit{Sex}, \textit{newBorn}]\ (t - \mathrm{d}t) \\ &\quad + (\textit{birth}[\textit{Sex}] - \textit{aging popUnder}65[\textit{Sex}, \textit{newBorn}])^{*}\mathrm{d}t \end{aligned} \tag{1}$$

$$\begin{aligned} &\textit{population under } 65[\textit{Sex}, \textit{AllButYoungest}](t) \\ &\qquad = \textit{population under } 65[\textit{Sex}, \textit{AllButYoungest}]\ (t - \mathrm{d}t) \\ &\qquad\quad + (\textit{aging popUnder}65[\textit{Sex}, \textit{PreviousCohort}] \\ &\qquad\quad - \textit{aging popUnder}65[\textit{Sex}, \textit{AllButYoungest}] \\ &\qquad\quad - \textit{netMigration}[\textit{Sex}, \textit{AllButYoungest}] \\ &\qquad\quad - \textit{deaths Under}65[\textit{Sex}, \textit{AllButYoungest}] \\ &\qquad\quad - \textit{becoming } 65[\textit{Sex}, \textit{AllButYoungest}])^{*}\mathrm{d}t \end{aligned} \tag{2}$$

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$$agingpopUnder65[Sex, AgeUnder64] = \frac{population\ under\ 65[Sex, AgeUnder64]}{cohortLength[AgeUnder64]} \tag{3}$$

$$agingpopUnder65[Sex, Age64] = 0 \tag{4}$$

The transition across health states (i.e. intact, mild, moderate and severe CI) also has two dimensional vectors, i.e. sex and elderly. Like the previous equations, the transition from one age cohort to the other happens at the end of the simulation time (year). The transition from one health state to the other is determined by age (elderly) and gender-specific transition rate for each health state. This ensures that when an individual transitions from one health state to the other at the end of each year, that individual also moves to the proper age and gender group. Equations (5)–(16) show the equations used in the "intact" health state. Equations for the entire model can be found in the online supplementary material (supporting information).

$$\begin{aligned} Intact[Sex, Elderly](t) = Intact[Sex, Elderly](t - dt) & \\ + (agingIntact[Sex, pElderly] - agingIntact[Sex, Elderly] & \\ +(becoming\ 65[Sex, Age64]^{*} ageSubscript[Sex, Elderly]) & \\ +MildToIntact[Sex, Elderly] - IntactDeath[Sex, Elderly] & \\ -intactToMild[Sex, Elderly] & \\ -intactToModerate[Sex, Elderly] & \\ -intactToSevere[Sex, Elderly])^{*} \mathrm{d}t & \end{aligned} \tag{5}$$

$$agingIntact[Sex, Age\ 64] = 0 \tag{6}$$

$$agingIntact[Sex, yElderly] = \frac{intact[Sex, yElderly]}{cohortLength[yElderly]} \tag{7}$$

$$AgingIntact[Sex, Age\ 100\ and\ over] = 0 \tag{8}$$

$$becoming65[Sex, Age64] = \frac{population\ under\ 65[Sex, Age64]^{*} becoming65\ subscript[Sex, Age64]}{cohortLength[Age\ 64]} \tag{9}$$

$$ageSubscript[Sex, Age65] = 1 \tag{10}$$

$$ageSubscript[Sex, AgeOver65] = 0 \tag{11}$$

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$$MildToIntact[Sex, Elderly] = Mild\ CI[Sex, Elderly] * Mild\ To\ Intact\ Transition\ Rate[Sex, Elderly] * (1 + effect\ of\ intervention\ on\ transition\ rates) \quad (12)$$

$$IntactDeath[Sex, Elderly] = Intact[Sex, Elderly] * intact\ To\ Death\ Transition\ Rate[Sex, Elderly] \quad (13)$$

$$intactToMild[Sex, Elderly] = Intact[Sex, Elderly] * intact\ To\ Mild\ Transition\ Rate[Sex, Elderly] * (1 - effect\ of\ intervention\ on\ transition\ rates) \quad (14)$$

$$IntactToModerate[Sex, Elderly] = intact[Sex, Elderly] * intactToModerateTransitionRate[Sex, Elderly] * (1 - effect\ of\ intervention\ on\ transition\ rates) \quad (15)$$

$$IntactToSevere[Sex, Elderly] = intact[Sex, Elderly] * intactToSevereTransitionRate[Sex, Elderly] * (1 - effect\ of\ intervention\ on\ transition\ rates) \quad (16)$$

Assumptions

Fertility rate

2010–2014 total fertility rates of China from the National Bureau of Statistics of China were used in the model. Fertility rate in 2014 was assumed to remain constant throughout the projection period, because a change in fertility (newborns after 2014 will not be 65 years by 2060) will have no impact on the simulation by year 2060.

Mortality rate

Age-specific mortality rates from the 2010 China Population Census were applied to the model. Mortality rates for the population < 65 used age-specific mortality rate from the National Bureau of Statistics of China for 2010 and 2013 World Health Organization (WHO) age-specific mortality rate for China (we used WHO numbers because no official statistics were found). A future mortality decline of 7% per annum was assumed from 2013. The mortality

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rate for the population ≥ 65 was estimated from the CLHLS data, and the likely changes were accounted for using the bootstrap estimates.

Cognitive state transition rates

Cognitive state transition rates were estimated only for those ≥65 years, as this paper focuses on elderly cognition. In addition, the model allows for transition between the cognitive states, except for improvement in cognition from moderate and severe CI (Kryscio *et al.,* 2006; Tyas *et al.,* 2007). A 10 percent improvement across cognitive state transition rates (except transition to deaths) was assumed and simulated, as part of the sensitivity analysis, to simulate the likely impact of future behavioral and pharmacological interventions on cognitive impairment.

Data and estimation of transition rates

CLHLS is an ongoing longitudinal survey established in 1998. Baseline and follow-up surveys were conducted in half of the counties and cities in the selected 22 provinces in 1998, 2000, 2002, 2005, 2008–09, 2011–12 and 2014. Home interviews were conducted to collect data on demographics, socioeconomic, lifestyle and dietary behaviors, health status, disease, cognition function and physical performance. Participants' survival status was ascertained during the follow-up survey. Details of this survey can be found elsewhere (Gu, 2002). Cognitive transition rates were estimated using data from the 2012 and 2014 waves of the CLHLS. These two waves were specifically chosen as they were follow-up surveys of a closed cohort, as compared to other waves in which new participants were recruited into the survey. In addition, the 2011–2014 waves used in this study has the highest follow-up rate (62.1 percent) compared to other waves with response rates ranging from 47.78 to 56.39 percent. The final sample consisted of 1824 Chinese elderly (814 men and 1010 women) aged ≥65 who answered the Chinese Mini Mental State Examination (MMSE).

Fertility rates, mortality rates and demographic data used to populate the model were obtained from the National Bureau of Statistics of China (2013). Cognitive transition rates were estimated using data from the 2012 and 2014 waves of the CLHLS. Information on death, the absorbing health state, was included in the 2014 wave. Cognitive functions of the elderly were measured using the Chinese version of the MMSE (Folstein *et al.,* 1975; Katzman *et al.,* 1988), which is widely used to assess cognitive status. It consists of 30 items, with scores ranging from 0 to 30. Higher scores indicate better cognition. MMSE assesses participants' orientation, memory, attention, calculation, language, and written and visual construction. Cognitive function was classified as follows: intact (MMSE score ≥ 24), mild CI (18–23), moderate CI (10–17) and severe CI (≤9) (Tombaugh and McIntyre, 1992).

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Using the longitudinal data, the rates of transitioning from one cognitive state to another or death, with the exception of improvement in cognitive states from both moderate and severe CI, was estimated for the overall sample (Kryscio *et al.,* 2006; Tyas *et al.,* 2007). To estimate 1-year transition probabilities from two waves of survey conducted over a 2-year gap (2012 and 2014), we employ a method adapted from the SAS code of a study by Cai *et al.* (2010). This allows us to circumvent the lack of data in the year 2013 with minimal assumptions by assigning a cognitive state to the participants in year 2013. In doing so, the following rules were applied: (1) if the participant had the same cognitive state in both 2012 and 2014, then we assume he/she has been in that particular cognitive state in 2013 since there is no information on transition from the survey; or (2) if the participant was in different cognitive states in 2012 and 2014, then the transition is assumed to occur randomly between 2012 and 2014 (i.e. cognitive state in 2013 can be the same as that in 2012: transition occurred at the end of 2013 or the beginning of 2014; or cognitive state in 2013 can be the same as that in 2014: transition occurred at the end of 2012 or the beginning of 2014). Equation (17) below, with age and sex as covariates, was used to estimate the transition rate. The equation was solved with multinomial logistic regression models using the "multinom" function in R (v3.2.1):

$$\ln\left(\frac{p_{ij}}{p_{ii}}\right) = \beta_{0ij} + \beta_{1ij}\cdot age + \beta_{2ij}\cdot age^2 + \beta_{3ij}\cdot Sex \tag{17}$$

where p_{ij} is the transition rate from the current state i to state j ($i \neq j$), where i corresponds to intact, mild, moderate or severe cognitive impairment and j corresponds to the same states as well as death. Transition rates were disaggregated according to age (single age cohort from age 65 to 100 and older) and gender (female, male).

A simple test was implemented to validate the transition rates estimated. First, a microsimulation was developed in Vensim. This microsimulation was initialized with synthetic baseline data similar to CLHLS data. The microsimulation had only two states—intact and CI—over 2 years (baseline to wave 1; wave 1 to wave 2) including death from year 1 to 2, and the model was simulated to generate individual-level data for 6000 elderly, over 2 years (time 0, 1 and 2 years). Individual outcomes and aggregate outcomes of population fractions in either states were recorded. Using the above-mentioned regression method, in which year 1 state is imputed, transition rates were estimated. The resultant transition rates were then used to populate a simple aggregated SD model. Results from both the microsimulation and SD model were compared to ensure that the two approaches produce similar results (see supporting information supplementary material for the microsimulation and SD model comparison), indicating that the method is robust and reliable.

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Probabilistic sensitivity analysis

After computing point estimates for the transition rates from the multinomial logistic regression model above, the bootstrap method was used to estimate the likely distribution of transition rates to obtain the 95 percent confidence interval around these point estimates. First, we rescale sampling weights so that they sum to 100 percent, and then use the weights as probabilities to draw respondents (by identification, ID) with replacement using the "sample" function in R (v3.2.1). Each respondent (ID) may be drawn once, more than once or not at all in the sampling. This process was repeated 1000 times to obtain 1000 datasets, which are then used to estimate the transition rates. Next, transition rates were estimated using the 1000 samples with the multinomial logistic regression model. Based on the 1000 sets of estimated transition rates, the distribution of age- and sex-specific transition rates and 95 percent confidence intervals (empirical intervals) were obtained. Transition rates from the bootstrap analysis was used as input to the sensitivity analysis to obtain the likely variation in the projected number of elderly with cognitive impairment.

Results

Transition rates by age and gender

Point estimates of the age- and gender-specific cognitive impairment rates of transition from one cognitive state to another or death are presented in Figure 3. For both sexes, the rate of transitioning to a poorer cognitive state or death increases with age, while the rate of transitioning to an improved cognitive state (i.e. from mild to intact) decreases with age. Transition rates from intact to mild, moderate or severe CI are higher in females than in males. This is also similar for transition rates from mild CI to intact or death, and from severe CI to death. In contrast, transition rates from intact to death, mild CI to moderate or severe CI, and moderate CI to severe CI are higher for males than in females. Further, the transition rate from moderate CI to death for males decreases to a level lower than females at very old age (about 97 years old).

Steady state fractions

To ensure that the long-term results are meaningful, the system dynamics model was also set to equilibrium with a fixed population to estimate the steady-state fraction of the population in each CI state. This was done by removing the aging process from the model to reduce the complexity of the equations as inflows to a stock equal outflows at equilibrium. Transition rates estimated from empirical data were maintained, and equations (see

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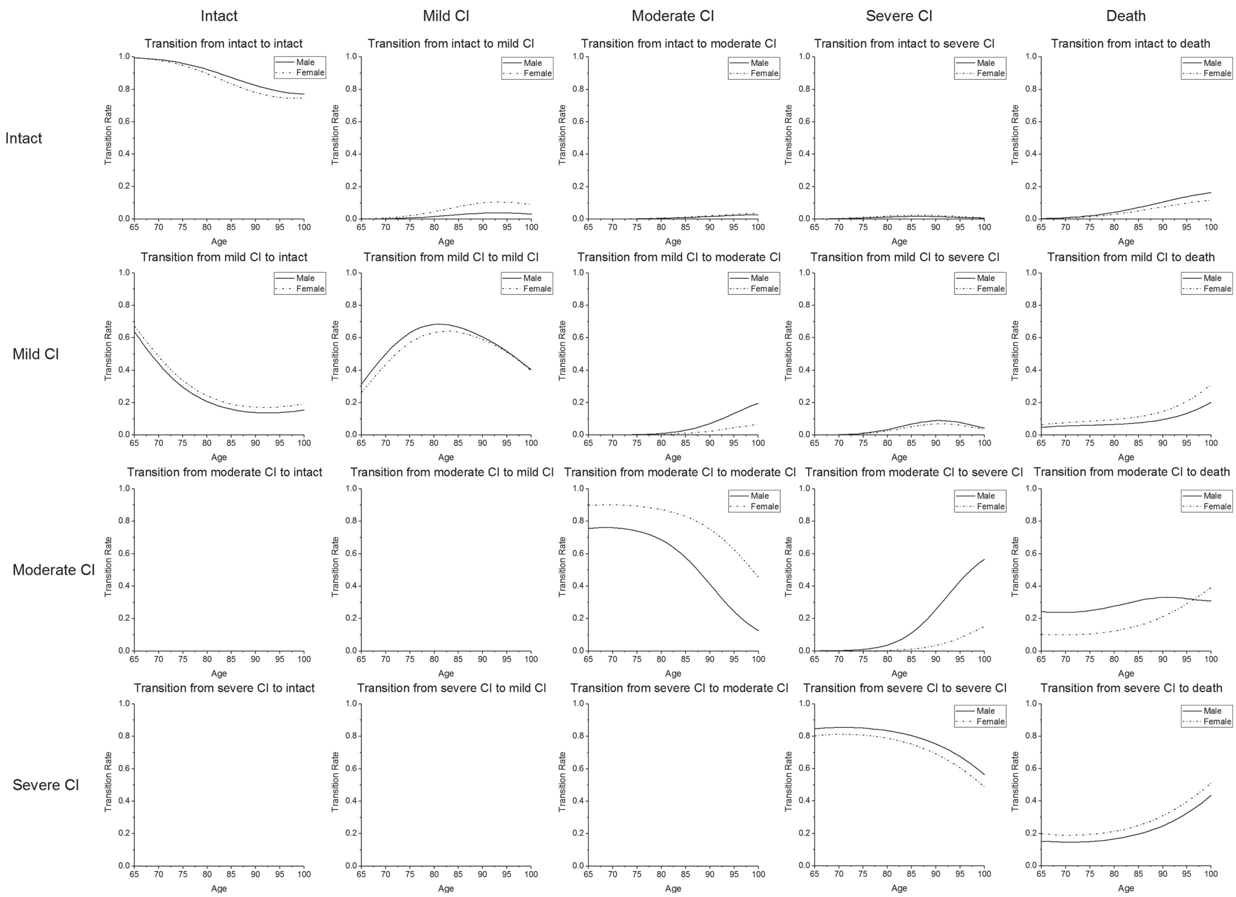

Fig. 3. Transition rates across cognitive states. The estimation allows for transition between the cognitive states, except for improvements in cognition from moderate and severe CI, represented by blank graphs

supporting information) were analytically derived for the stocks: intact, mild CI, moderate CI and severe CI. Results show that, at equilibrium, the fraction of elderly with mild, moderate and severe CI are 2.43, 1.161 and 3.139 percent, respectively. This suggests that, at equilibrium, 6.729 percent of the elderly in China will have CI.

Projecting number of elderly with cognitive impairment

The total number of elderly was projected to increase 214 percent from about 117.6 million in 2010 to approximately 369.1 million by 2060 (Table 1). Of the 369.1 million elderly in 2060, approximately 12% (sensitivity analysis at 95%

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Table 1. Projected population and elderly with CI in China up to 2060

Outcome	Base year		Projected				% change from 2010 to 2060
	2010	2020	2030	2040	2050	2060	
Total population	1,331,530,000 [1,331,530,000–1,331,530,000]	1,393,850,000 [1,387,210,000–1,399,280,000]	1,430,430,000 [1,421,900,000–1,446,650,000]	1,413,530,000 [1,401,310,000–1,439,250,000]	1,351,440,000 [1,336,390,000–1,388,650,000]	1,265,880,000 [1,249,140,000–1,315,260,000]	−5%
Total elderly	117,645,347 [117,645,347–117,645,347]	183,942,810 [179,303,000–191,373,000]	263,303,360 [254,777,000–279,520,000]	347,196,380 [334,981,000–372,915,000]	378,533,380 [363,481,000–415,741,000]	369,106,800 [352,370,000–418,484,000]	214%
Age 65–74	72,767,000 [72,767,000–72,767,000]	106,358,000 [104,078,000–108,222,000]	149,197,000 [145,939,000–151,868,000]	185,485,000 [181,071,000–189,142,000]	175,380,000 [171,112,000–178,944,000]	160,925,000 [156,905,000–164,293,000]	121%
Age 75–84	37,262,600 [37,262,600–37,262,600]	57,631,200 [55,122,500–60,853,300]	82,456,800 [78,026,000–88,453,000]	116,381,000 [110,163,000–124,881,000]	139,417,000 [131,607,000–150,221,000]	133,245,000 [125,682,000–143,785,000]	258%
Age 85–94	7,210,240 [7,210,240–7,210,240]	17,980,600 [16,124,400–21,277,200]	27,130,300 [23,732,500–33,223,500]	38,458,700 [33,726,300–47,309,500]	53,996,600 [47,408,100–66,352,000]	61,540,000 [53,727,200–76,498,100]	754%
Age 95+	405,507 [405,507–405,507]	1,973,010 [1,199,730–3,636,180]	4,519,260 [2,490,330–10,857,200]	6,871,680 [3,589,180–19,340,900]	9,739,780 [5,032,790–30,746,500]	13,396,800 [6,829,040–45,814,800]	3204%
Total elderly with mild CI	4,810,689 [4,810,689–4,810,689]	6,316,107 [4,567,040–9,357,220]	9,349,005 [6,808,690–14,628,100]	13,189,812 [9,617,840–20,968,700]	17,006,130 [12,375,400–27,606,100]	18,159,690 [12,930,500–31,387,400]	277%

(Continues)

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Table 1. (Continued)

Outcome	Base year 2010	2020	Projected 2030	2040	2050	2060	% change from 2010 to 2060
Age 65–74	1,555,800 [1,555,800–1,555,800]	703,644 [231,013–1,747,180]	972,927 [319,844–2,416,020]	1,311,980 [438,912–3,177,450]	1,262,640 [426,422–3,026,900]	1,184,920 [401,994–2,816,880]	−24%
Age 75–84	1,972,940 [1,972,940–1,972,940]	2,971,670 [1,880,520–4,433,210]	4,281,260 [2,705,240–6,324,530]	5,988,380 [3,789,950–8,821,650]	7,491,620 [4,691,310–11,126,700]	7,218,790 [4,525,620–10,732,000]	266%
Age 85–94	1,211,320 [1,211,320–1,211,320]	2,354,050 [1,488,680–3,953,510]	3,482,290 [2,191,490–5,964,250]	4,977,330 [3,127,590–8,561,480]	6,957,390 [4,369,400–11,996,100]	7,988,750 [4,966,340–14,046,000]	560%
Age 95+	70,629 [70,629–70,629]	286,743 [70,665–1,025,950]	612,528 [133,096–2,779,510]	912,122 [196,896–4,786,760]	1,294,480 [277,241–7,558,380]	1,767,230 [372,501–10,728,500]	2402%
Total elderly with moderate CI	1,725,231 [1,725,231–1,725,231]	2,171,264 [985,657–4,906,410]	3,253,796 [1,452,090–8,390,850]	4,626,892 [2,061,310–12,793,900]	6,089,054 [2,747,720–18,951,900]	6,747,029 [3,095,420–26,312,700]	291%
Age 65–74	29,634 [29,634–29,634]	199,828 [10,966–667,542]	277,586 [15,125–938,244]	378,766 [20,967–1,283,910]	367,360 [20,280–1,248,170]	346,119 [19,046–1,177,530]	1068%
Age 75–84	1,005,080 [1,005,080–1,005,080]	866,961 [210,254–2,125,580]	1,254,990 [301,575–3,288,400]	1,758,020 [421,687–4,620,980]	2,224,500 [539,622–5,909,820]	2,153,610 [526,684–5,776,880]	114%

(Continues)

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Table 1. (Continued)

	Base year	Projected					% change from 2010 to 2060
Outcome	2010	2020	2030	2040	2050	2060	
Age 85–94	634,501 [634,501–634,501]	933,591 [364,167–2,411,740]	1,351,780 [521,210–3,821,890]	1,937,970 [741,223–5,499,050]	2,711,510 [1,039,420–7,657,700]	3,170,160 [1,211,940–9,232,220]	400%
Age 95+	56,016 [56,016–56,016]	170,884 [25,666–932,501]	369,440 [49,351–3,301,850]	552,136 [72,246–6,869,170]	785,684 [101,651–11,818,000]	1,077,140 [136,894–18,360,800]	1823%
Total elderly with severe CI	2,357,816 [2,357,816–2,357,816]	6,278,683 [3,897,920–10,746,600]	9,631,086 [5,852,970–18,991,000]	13,618,040 [8,308,540–28,148,500]	17,468,850 [10,518,500–37,359,400]	18,818,680 [11,248,300–44,714,400]	698%
Age 65–74	59,269 [59,269–59,269]	944,934 [319,376–2,453,920]	1,311,130 [441,900–3,456,210]	1,786,670 [611,971–4,719,200]	1,728,320 [599,190–4,604,960]	1,628,470 [567,310–4,338,800]	2648%
Age 75–84	1,005,080 [1,005,080–1,005,080]	2,899,190 [1,575,210–5,333,220]	4,283,460 [2,274,820–8,263,890]	6,006,470 [3,185,940–11,615,200]	7,546,770 [3,957,940–14,605,100]	7,289,330 [3,810,080–14,176,900]	625%
Age 85–94	1,139,220 [1,139,220–1,139,220]	2,122,430 [967,338–4,119,180]	3,334,000 [1,494,410–7,380,750]	4,750,690 [2,130,930–10,653,000]	6,675,100 [2,976,940–14,967,900]	7,802,360 [3,431,500–17,978,600]	585%
Age 95+	154,247 [154,247–154,247]	312,129 [57,906–1,309,860]	702,496 [116,565–4,022,160]	1,074,210 [169,618–7,614,470]	1,518,660 [237,114–12,226,500]	2,098,520 [322,780–18,331,600]	1260%
Fraction of very old with CI	0.528 [0.528–0.528]	0.682 [0.579–0.775]	0.699 [0.604–0.802]	0.704 [0.611–0.811]	0.752 [0.669–0.850]	0.783 [0.703–0.880]	48%

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confidence range: 10–19%) were expected to have CI. Thus, the total number of elderly with CI is projected to rise from approximately 8.9 million in 2010 to 43.7 million (36.1–77.7 million) in 2060 (Figure 4).

The projected number of elderly with mild CI is expected to increase from 4.8 million in 2010 to 18.2 million (12.9–31.4 million) by 2060. Projected numbers for those with moderate and severe CI are expected to increase from 1.73 million and 2.36 million in 2010 respectively, to 6.75 million (3.1–26.3 million) and 18.8 million (11.2–44.7 million) by 2060, respectively.

Among the elderly with CI, the female proportion is projected to increase from 56 percent in 2010 to 62 percent (53–66%) by 2060. However, among those with mild CI, the female proportion is projected to increase from 55 percent in 2010 to 70 percent (60–78 percent) by 2060; while that for moderate CI rises from 57 percent in 2010 to 69 percent (58–74%) in 2060. Conversely, for those with severe CI, the female proportion is projected to decrease from 59 percent in 2010 to 51 percent (44–56 percent) by 2060.

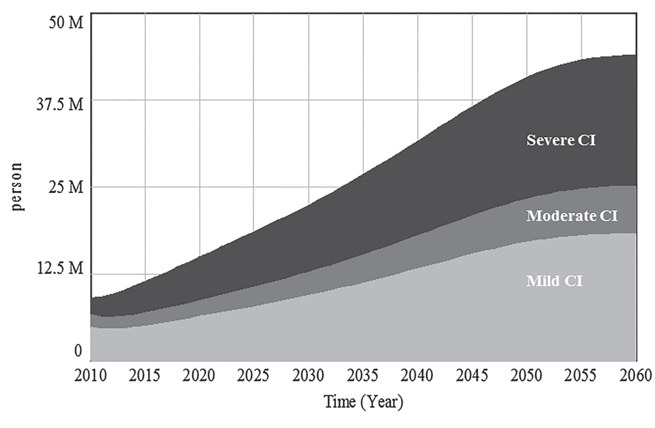
The proportion of young-old (age 65–79), among the elderly with CI, is projected to decrease significantly from 47 percent in 2010 to 22 percent (12–30 percent) by 2060, whereas that of the very old (age ≥ 80) is expected to rise from 53 percent in 2010 to 78 percent (70–88 percent) by 2060 (Table 1).

Lastly, further sensitivity analysis suggests that a 10 percent improvement across cognitive state transition rates (except transition to deaths) will decrease the prevalence of mild, moderate and severe CI by 8 percent (6–8 percent), 5 percent (4–6 percent) and 9 percent (8–10 percent), respectively, by 2060.

Discussion

The total population in China is projected to increase from 2010 to 2030 and then decrease thereafter, similar to the United Nations (UN) projections

Fig. 4. Projected number of elderly with cognitive impairment



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(United Nations, 2015). While the recent abolishment of the one-child policy in China may impact fertility rates, its effects cannot be ascertained at such an early stage; hence the model assumed a future fertility rate similar to the observed fertility.

Our results support current literature reporting rising numbers of Chinese elderly with CI. According to Alzheimer's Disease International (2014), the number of Chinese elderly with dementia is projected to increase by 77.7 percent from 2030 to 2050. This is similar to our results, where the sum of elderly with moderate and severe CI (equivalent to dementia) increased 82.8 percent over the same time period. Using the 2010 China Census, Li *et al*. (2015) estimated that 16.5 million Chinese elderly will suffer from dementia in 2030, which is higher than our projection of 12.9 million Chinese elderly with moderate and severe CI in 2030. More importantly, projections in these studies were obtained by applying prevalence rates to the projected Chinese population, neglecting dynamic movements across different cognitive states, potentially resulting in an overestimation of individuals with CI (Figure 5). Using the dynamic multi-state population method to project CI provides a flexible approach for modeling population changes over time, which facilitates implementation of interventions applicable to specific population groups of interest: mild, moderate and severe CI. Also, this method allows for the combination of all the main components of population change by age and gender with various transitions that the population groups may experience, while avoiding potential inconsistencies arising from inappropriately defined rates. Lastly, the level of details included in the dynamic multistate population method allows for capturing the potential cohort effect, which is unlikely to be captured in the simple prevalence-based approach. Most importantly, this method has the ability to estimate reliable uncertainty bounds that can be placed around point estimates.

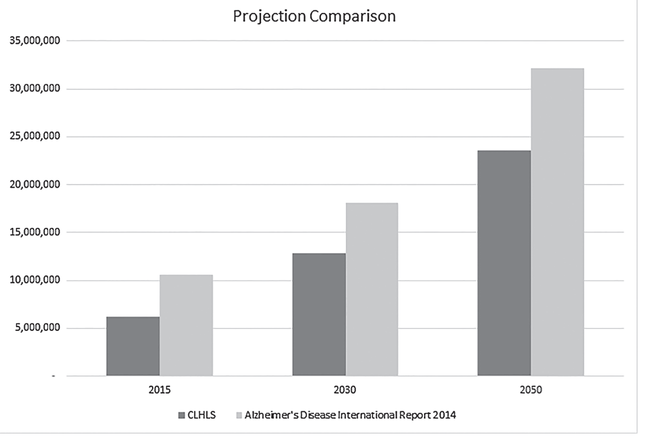

Fig. 5. Comparison of projection results with external source

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The forecast significant increase in the number of elderly with CI of all degrees will have health and social care implications. Given the progressive nature of CI, and the larger increase in the proportion of elderly with CI of higher severity, the need for caregiving and healthcare services will rise drastically. This will result in increased costs associated with informal care (unpaid family caregivers), social care (community and residential care) and medical care (healthcare utilization) (Song and Wang, 2010).

The emphasis on filial piety and family units as the center for eldercare in Asian cultures suggests that cognitively impaired elderly in China are more likely to be cared for at home (Liu and National University of Singapore, 1998). It is estimated that up to 96 percent of Chinese elderly with dementia are cared for by family members at home (Dai *et al.,* 2013). Similarly, in the CLHLS study, the majority of the elderly lived with at least one household member (78 percent in 2012 and 76 percent in 2014). As the number of elderly with CI increases, care burden (both formal and informal) is expected to increase. Further, as the proportion of elderly with severe CI is projected to increase the most, there will be a more than a proportionate increase in the care hours required. This will put a strain on caregivers, making them at risk of the negative health outcomes associated with caregiving, such as depressive and anxiety disorders and weakened immunity (Schulz and Martire, 2004). Hence support systems for informal caregivers can potentially benefit both caregivers and recipents, and should be implemented. Evidence suggests that provision of support services at home can decrease institutionalization of elderly with dementia (Gaugler *et al.,* 2005). Moreover, with an increasing trend of out-migration of the young, family support systems for rural elderly are dwindling (Zhang and Goza, 2006). As their cognitive functioning continues to decline, these elderly will no longer be able to live alone, increasing the demand for alternative long-term care (LTC) arrangements.

Yet, such arrangements are not well established in China. While it is widely acknowledged that there is a need for additional formal services such as adult day care, respite care and institutional care services, the formal LTC system remains in the preliminary stages of development (Dai *et al.,* 2013). Even in urban China, there is a significant unmet need for home care services (Wong and Leung, 2012). Most LTC facilities in China are also not equipped to care for elderly with CI, and the staff are often inadequately trained in handling CI needs (Song *et al.,* 2014). The imminent increase in cases of CI from our results point to the need for improved efforts for such development.

In addition, there is a perceived stigma attached to CI in China. The Chinese term for AD and dementia, *laonian chidai*, when translated, means “stupid, demented elderly”. This has resulted in a discrimination of elderly with CI, which are characteristic of AD and dementia (Dai *et al.,* 2013). Affected elderly may delay or not seek treatment because of this negative perception of the disease (Garand *et al.,* 2009). The resultant lack of support for this group of elderly, together with declining cognition and function, greatly increases

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the risk of them being socially isolated (Bennett *et al.,* 2006; Wang *et al.,* 2014). Social isolation has been found to be associated with negative mental and physical health outcomes, such as cardiovascular disease and dementia (Berkman *et al.,* 2000; O'Luanaigh *et al.,* 2012). To eliminate the social stigma, the Ministry of Health of China has reworded *laonian chidai* to *aerzihaimobing*, which is the literal translation of AD (Dai *et al.,* 2013). However, changes in perception will likely only change slowly.

Another important approach to eliminating CI discrimination is to increase awareness of the disease. Caregivers often mistake early stages of CI for the natural memory decline in aging (Dai *et al.,* 2013). As the risk of mortality increases with CI severity, understanding the disease will also help caregivers and family members identify it at earlier stage and help elderly seek appropriate treatment. More effort will be needed in training staff to provide the relevant support. Currently, specialist care for cognitively impaired elderly in China is lacking, with few memory clinics situated only in large urban areas. Medical staff are also not competent in identifying CI due to the lack of formal training (Dai *et al.,* 2013; Hsiao *et al.,* 2015). Therefore, public education and training of health professionals and caregivers are important in raising awareness of CI and its management.

Limitation

Due to the limited number of elderly with more than 2 years of education in the CLHLS, our projection results did not account for education effects. Moving forward with this study, we aim to include more elderly with higher educational attainment in our surveys in future.

Conclusion

Using a multi-state dynamic population model facilitated the integration of available empirical data on CI among elderly in the community; population dynamics provided credible projections that can facilitate service delivery and planning of care resources for elderly with CI and their caregivers. The segmentation of CI patients into mild, moderate and severe subgroups will help policymakers and planners to identify needs-specific health and social care services and interventions required to improve wellbeing and quality of life of elderly with CI and their caregivers to improve health outcomes. Moreover, the robust projections with uncertainty bounds placed around the projections will help policymakers to possibly plan within a reliable boundary and avoid the likelihood of over- or under-building of health and social care services for elderly with CI and their caregivers. In addition, the projections from this research could be used by policymakers as input to estimate the likely care burden of CI on families and on China.

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