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Abstract

We develop a rich life-cycle model to assess the demand for life annuities, critical illness insurance, and long-term care insurance by retirees in a portfolio-allocation setting. We calibrate our model to urban China, where retirees face limited public insurance and undeveloped private markets. We show that retirees with a low pension should allocate at least 30% of their financial wealth at retirement to a life annuity. Those with an average pension should allocate at least 30% to critical illness insurance. The allocation to long-term care insurance ranges from 5% to 33% across all economic profiles considered. Access to critical illness and long-term care insurance does not necessarily increase annuity demand. However, access to annuities decreases the demand for long-term care insurance. Our results suggest that countries with limited public insurance should first ensure the adequacy of retirement income and then focus on covering catastrophic medical expenses while providing basic long-term care services for all.

Keywords: Life-cycle saving; Annuity; Long-term care insurance; Critical illness insurance; Health insurance; Retirement; China

JEL Codes: D14; G52; I13; J14; J32

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1. Introduction

Improvements in life expectancy and lower fertility rates have led to rapid population aging in many low- and middle-income countries, including Brazil, China, and Mexico. The growing older populations in these countries require access to pension income, medical services, and long-term care (LTC). In the past, older adults relied mainly on family members for financial support and personal care. However, smaller families, increased internal and external migration and an increase in female labor force participation challenge this traditional model of family support (e.g., Chen and Fang, 2021; Fischer and Muller, 2020). At the same time, public insurance programs in many low- and middle-income countries often provide only basic pension benefits and limited cover for critical illness and LTC. As a result, individuals and their families may face high out-of-pocket medical costs for critical illnesses such as cancer, heart attack, or stroke, which often require expensive drugs and advanced medical treatments that must be imported from high-income countries (World Health Organization and World Bank, 2023), and little or no cover for care costs.

An important consequence of the lack of adequate insurance for uncertain out-of-pocket health-related costs is that retirees may self-insure and hold assets that would otherwise be drawn down to support their retirement (e.g., De Nardi et al., 2010, 2023; Peijnenburg et al., 2017). Previous studies on demand for insurance covering longevity- and health-related risks have largely focused on annuities and/or LTC insurance (e.g., Achou, 2021; Ameriks et al., 2020; Horneff et al., 2020; Reichling and Smetters, 2015). Insurance to cover critical illness costs has been ignored.

In this paper, we develop a new multiperiod life-cycle model to study the demand for longevity and health-related insurance for retirees in a low- to middle-income country context, with limited public insurance and an undeveloped private insurance market. We consider annuities that provide lifetime income, critical illness insurance that provides a lump sum benefit when the insured is diagnosed with a critical illness for the first time, and LTC insurance that provides regular income when the insured requires LTC.

We calibrate the model to reflect the institutional setting in urban China, which has a rapidly aging population, a basic system of public insurance and a slowly developing private insurance market.[1] In 2022, around 1.05 billion people were covered by the public pension system through separate schemes for urban employees, public sector employees, and rural and urban residents not elsewhere covered. The three schemes have disparate contribution and benefit levels. Public health insurance is close to universal but offers only basic benefits, resulting in a high chance of incurring high out-of-pocket costs for critical illnesses (Yip et al., 2023; Liu et al., 2017). Public LTC insurance is still in the development phase: by 2021, pilot programs had been introduced in only 49 cities. The private life and health insurance market in China does not adequately cater for longevity and care risks facing older persons. The focus is on short-term products for investment purposes. Retirees are largely excluded from illness and care-related insurance, where the policies are typically short-term and are subject to an age limit for purchase. Our model provides evidence of optimal insurance demand and welfare gains from access to three insurance products providing cover for longevity, critical illness and LTC risk, offering insights into the development of the private insurance market.

This paper makes three main contributions. First, this paper is the first to study life annuities, critical illness insurance, and LTC insurance simultaneously in a life-cycle framework. It brings together various strands of literature, focusing on the impact of uncertainty about future health-related costs, longevity, and LTC risks. Previous studies, mostly set in a high-income country context with more established public and private insurance arrangements, generally focus on a

[1] For a review of the public insurance systems in China for pensioners see Fang and Feng (2020), for healthcare, see Yip et al. (2023), and for long-term care, see Liu et al. (2023).

single insurance type, for example, annuities or LTC insurance (e.g., De Nardi et al., 2010; Pashchenko, 2013; Reichling and Smetters, 2015; Peijnenburg et al., 2017; Ameriks et al., 2020; Achou, 2021),[2] and few consider critical illness insurance (Schendel, 2014; Hambel, 2020).

We find that the demand for annuities, critical illness insurance and LTC insurance largely depends on retirees' economic background (specifically wealth at retirement and public pension adequacy). For those with a low public pension, annuities are the most important insurance product, while for retirees with an average public pension, critical illness insurance is the most important.[3] The demand for LTC insurance is relatively low but positive for all levels of wealth and pensions considered here and is higher for women. Our results also serve as a reference for studies on stated preferences for retirement insurance, including longevity and health-contingent insurance (e.g., Wu et al., 2022b; Wan et al., 2024).

Second, we are the first to show how demand for one type of insurance is affected by access to other types of insurance in a portfolio-allocation setting. In particular, we extend the literature on the so-called "annuity puzzle", focusing on the role of precautionary savings in response to health-related risks (e.g., Reichling and Smetters, 2015; Peijnenburg et al., 2017). Specifically, we show that access to critical illness and LTC insurance does not necessarily increase annuity demand. This is because retirees have reduced wealth available for annuity purchase after obtaining insurance cover for critical illness and LTC. We also show that when public insurance provides only basic health cover, retirees with an average pension will purchase critical illness insurance rather than an annuity. We further show that access to annuities and LTC insurance

[2] Wu et al. (2022a) consider annuities and LTC insurance together.

[3] In this study, we choose to model the insurance demand of retirees in urban China with low and average public pension incomes. Their pension replacement rates are low and this group are financially considerably more vulnerable than retirees with a high pension.

increases the demand for critical illness insurance for retirees with high wealth and that access to annuities decreases the demand for LTC insurance for retirees with a low pension.

Third, we find that state-dependent utility, that is, whether the marginal utility of consumption is higher or lower in a poor state of health than in a healthy state (e.g., Viscusi and Evans, 1990; Finkelstein et al., 2013), matters for the demand for annuities, critical illness insurance and LTC insurance. This study thus contributes to the literature on the state-dependent utility of consumption. Blundell et al. (2023) and Achou et al. (2023) find that state-dependent utility is an important determinant of consumption and LTC choices in North America, while Peijnenburg et al. (2017) show that such preferences do not affect annuity demand in the US context. We find that a higher marginal utility of consumption in the critically ill and LTC states increases the demand for critical illness and LTC insurance but decreases the demand for annuities. Our results highlight the importance of state-dependent utility in understanding the dynamics of consumption and savings in retirement.

Existing studies are mostly set in a high-income country context (e.g., Reichling and Smetters, 2015; Peijnenburg et al., 2017; Achou et al., 2023; Blundell et al., 2023; De Nardi et al., 2023). We consider a low- and middle-income country context where public health insurance provides only basic cover for critical illness and LTC, highlighting the importance of critical illness and LTC insurance on annuity demand. Compared with the case of no private insurance, we find that the welfare gains with optimal insurance are substantially higher for less wealthy retirees.

We provide valuable insights for policymakers and insurers in low- and middle-income countries. Our results suggest that they should first focus on supplementing retirement income for those with low pensions and then turn to covering large expenditures due to critical illness. There should also be a basic level of LTC services for all, with a higher level for women. We also highlight the importance for insurers of targeting potential consumers, and we identify theoretically optimal insurance demand in a portfolio to better support financial advisory services. Our results further suggest that bundled longevity and health-contingent insurance products can increase annuity demand, extending the literature on bundling LTC insurance and annuities (e.g., Webb, 2009; Brown and Warshawsky, 2013).

Our paper is organized as follows. In Section 2, we describe the life-cycle model of consumption and portfolio allocation for retirement. In Section 3, we present the benchmark results of insurance demand for retirees with differing levels of public pension and financial wealth. In Section 4, we show the impact of variation in key model parameters on insurance demand. Section 5 sets out our discussion and concluding remarks.

2. The model

In this section, we introduce a multiperiod life-cycle model for a single retiree in a low- and middle-income country context who faces risks related to longevity, critical illness, and LTC. We model men and women separately and assume that the retirees are covered by China's public pension for urban employees and public health insurance. Our model includes individuals who retire with different levels of initial financial wealth and public pension benefits. At retirement, the individual can use a portion of their wealth to purchase one or more of the following: a life annuity, critical illness insurance, and LTC insurance. Their remaining wealth is deposited into a savings account. During their lifetime, in each period/year, the retiree receives a public pension, is covered by public health insurance, faces stochastic health shocks due to critical illness or need for LTC services, receives insurance payouts (if purchased), and chooses their level of consumption. Upon their death, the individual leaves a bequest. Our model extends previous studies (De Nardi et al., 2010; Reichling and Smetters, 2015; Peijnenburg et al., 2017; Ameriks et al., 2020) by including critical illness and LTC states and the associated random catastrophic medical expenditure and costs due to informal care; this is imperative in a low- and middle-income country context. We also consider state-dependent utility because it is crucial in understanding consumption and savings in retirement (Blundell et al., 2023).

2.1. Heterogeneous individuals

Because health risks often differ by gender, we model the case for women and men separately. Additionally, we consider different levels of financial wealth and public pension income, recognizing their importance in financial planning (Inkmann et al., 2011) and due to the substantial wealth and income disparities among older Chinese (e.g., Hanewald et al., 2021). We consider men aged 60 and women aged 55, which is in line with the statutory retirement age for men and women in white-collar jobs in China.

Individuals retire with financial wealth W_0 and receive an annual public pension P_t at period t. We derive the optimal insurance demand for four types of retirees with different economic profiles: i) low pension, low wealth, ii) low pension, high wealth, iii) average pension, low wealth, and iv) average pension, high pension. We focus on retirees with low and average public pensions because they are more financially vulnerable than retirees in receipt of a high pension. Based on Zhu and Walker (2018) and the data on average provincial-level monthly pensions in 2020,[4] we set the low and the average pension incomes to 1,000 CNY and 3,000 CNY, respectively.[5] The wealth values are calibrated around the 30th and 80th percentile of the wealth distribution based on data from the 2018 wave of the nationally representative China Health and Retirement Longitudinal Survey

[4] The monthly pension at the provincial level is available at http://www.stats.gov.cn/sj/ndsj/2021/indexch.htm (in Chinese).

[5] The exchange rate was 1.00 USD = 6.97 CNY on March 8, 2023.

(CHARLS); these are 150,000 CNY and 1 million CNY for the 30th and 80th percentile, respectively.

We assume the same public health insurance for urban employees (Employee Basic Medical Insurance) for all four types of retirees since the benefits are almost identical for all scheme participants. The critical illness and LTC costs in our model are out-of-pocket (see Section 2.4 for more detail).

Our model captures several means-tested government subsidies in a stylized way through a minimum consumption floor S; this subsidy reflects a public safety net. We set the consumption floor according to the government subsidy "Dibao" – a subsidy for those without sufficient income for necessities. The average subsidy was 687 CNY per month, according to official 2020 provincial data (Ministry of Civil Affairs, 2020).

2.2. Health and health-related costs

In each period $t > 0$, the retiree can be in one of the four states $H_t \in \{1,2,3,4\}$, where $H_t = 1$ corresponds to being healthy, $H_t = 2$ corresponds to being critically ill (diagnosed with a critical illness), $H_t = 3$ corresponds to being LTC dependent, that is, the retiree has difficulty undertaking three or more of the six activities of daily living (bathing, dressing, eating, toileting, continence, transferring in and out of bed),[6] and $H_t = 4$ corresponds to death.

We model health as an exogenous Markov process and assume a maximum age of 105. In Appendix A, we describe the estimation of the models for the age-specific health-transition probabilities. We estimate separate models for men and women using official tables for mortality

[6] In China, failing to perform at least three activities of daily living is usually required to qualify for private LTC insurance payments.

and critical illness and estimates for LTC transitions based on CHARLS data. We show the sensitivity of the assumptions for health transitions in Appendix B.1.

The individual faces uncertain critical illness cost, $CostCI_t$, and random LTC cost, $CostLTC_t$. Both are paid out-of-pocket, given that China's public insurance provides only limited partial cover for critical illness, and there is no widely available cover for LTC. Because of limited data, we base the calibrations of these costs on empirical studies and industry reports. For simplicity and to accommodate the data limitations, we assume the cost distributions are the same for men and women. Please refer to Appendix C, in which we detail our calibration of the lognormal distribution for the health-related cost.

2.3. Insurance products

As described earlier, China's private insurance market offers few long-term insurance products for retirees. We consider long-term insurance covering longevity, health-related and care risks available for purchase at retirement. At the start of the period (on retirement), the retiree can purchase one or more of the following products: a life annuity, critical illness insurance, and LTC insurance. For simplicity, the retiree cannot sell or terminate the insurance contracts or purchase additional cover in the future. The life annuity pays a fixed amount of real income, $Annuity_t$ at each period *t*, until death. Critical illness insurance provides a real lump sum payment CII_t when the insured is diagnosed with a critical illness for the first time. LTC insurance provides a fixed real income $LTCI_t$ in each period when the insured needs LTC. Such cash benefit insurance is highly valued, regardless of the insured' characteristics because of the flexibility (e.g., de Bresser et al., 2022). We note that LTC in our model includes informal care – the primary form of care in most developing countries. Our calibration for LTC costs includes the financial cost of informal care, which is based on the number of hours of care-related services provided by relatives. The payout from the LTC insurance could be used to pay for nurses or reimburse family members for their time, which could affect their labor market behaviors (e.g., Coe et al., 2023). This means that our predicted demand for LTC insurance can be interpreted as a demand to pay for care-related costs and services, including informal care.

The payments from the insurance products can be used for consumption and health-related costs. For example, the annuity income can be saved to cover future health costs. The annuity and critical illness insurance are priced in an actuarially fair way according to age and gender using the relevant official tables in China.[7] Since there are no official tables for LTC insurance, we have based our estimates for this on the CHARLS data. The pricing details for LTC insurance are described in Appendix D.[8] In addition, we assume a 15% insurance loading for all retirement insurance products, similar to Mitchell et al. (1999). This loading represents the level of administrative costs in China's insurance market (Zhang et al., 2021).

In our benchmark model, 10,000 CNY could buy a monthly annuity income of about 35 CNY for men and 28 CNY for women. Similarly, it could purchase a lump sum payout for critical illness of about 19,496 CNY for men and 21,365 CNY for women or a regular payment of about 471 CNY and 329 CNY when being LTC dependent for men and women, respectively.[9] The price

[7] We use the official mortality table for pension business to price the annuities (CBIRC, 2016), the official table for critical illness incidence rates (CBIRC, 2013) and the mortality table for health insurance business (CBIRC, 2016) to price critical illness insurance. The new official tables for critical illness incidence were released in 2020. However, they were not publicly available when the research was conducted. Compared with the old version, the new tables show slightly lower critical illness incidences for the old. This will make the premium slightly lower and likely result in greater insurance demand for the old.

[8] Note that these insurance products are priced separately according to either official mortality and illness tables or estimated LTC transition probabilities. Therefore, they are not priced according to the same health transition matrix in the life-cycle model. This reflects that in reality there is a mismatch between the health probabilities used for pricing and those for agents to plan for the future (see, e.g., O'Dea and Sturrock (2023)). We show the results when there is no such mismatch in Section 4.3.

[9] In our life-cycle model, we do not model inflation. This means that, the insurance payments, the health-related costs, the public pension and subsidy are defined in real values (2020 prices) and will not grow in future.

differences are due to women having a longer life expectancy than men, a relatively comparable cumulative incidence of critical illness, and a longer duration of needing LTC. We investigate the impact of pricing assumptions in Section 4.2.

Retirement wealth not used to purchase any of the three insurance products and regular income or payments not used for consumption is deposited into a savings account that earns a risk-free rate. We do not consider risky assets because they are not common in the Chinese context, with less than 5% of urban individuals close to retirement participating in the stock market.[10]

Throughout, we assume a real interest rate of R = 2% per year, and set the real discount rate for insurance pricing at 1.5%, which is in line with insurance regulations in China.[11]

2.4. Preferences

We consider state-dependent preferences following empirical studies that have documented that the marginal utility of consumption depends on an individual's state of health (e.g., Finkelstein et al., 2013; Viscusi and Evans, 1990) and that this state-dependent utility is important for consumption behavior in retirement (Blundell et al., 2023). For our benchmark results, we assume the agent's utility from consumption is time-separable with subjective discount factor β, and use a state-dependent period utility function similar to that in Finkelstein et al. (2013), Koijen et al. (2016) and Peijnenburg et al. (2017):

$$u(c_t, H_t) = \frac{\eta_{H_t} c_t^{1-\gamma}}{1-\gamma}, \tag{1}$$

[10] Authors' calculation based on the CHARLS 2018 data.
[11] The average real interest rate in China from 2010 to 2019 was 2.04%. See https://data.worldbank.org/indicator/FR.INR.RINR?locations=CN. The China Banking and Insurance Regulatory Commission requires that the nominal interest rate for long-term insurance be no higher than 3.5%.

where c_t is the consumption in period t, γ is the inverse of elasticity of intertemporal substitution or the relative risk aversion coefficient (e.g., Yaari, 1965; Davidoff et al., 2005), and η_{Ht} is a parameter weighting the impact of the health state on the marginal utility of consumption. This function distinguishes the marginal utility of consumption in different health states, as suggested by Finkelstein et al. (2013), and extends the function used by Peijnenburg et al. (2017) to allow for state-dependent utility with more than one unhealthy state.[12]

Note that the state-dependent utility given in Equation (1) reduces to the standard case without state-dependent utility for η_{Ht} = 1 in every health state, and we study this case as a sensitivity test in Section 4.1.2.

We use $v(M)$ to value the bequest motives:

$$v(M) = \frac{bM^{1-\gamma}}{1-\gamma}, \tag{2}$$

where M is the bequest wealth, and b is the strength of the bequest motive. This bequest function has been used in simulations to identify optimal portfolio allocation (e.g., Friedman and Warshawsky, 1990) and in empirical studies with life-cycle models (e.g., Iskhakov and Keane, 2021). Its form is consistent with the state-dependent utility framework in Equation (1) when death is considered as a health state, as described in Section 2.2.

We generate our benchmark results by calibrating the subjective discount factor β = 0.999 and risk aversion ρ = 3 to represent a high level of patience and average risk aversion in the Chinese population, following İmrohoroğlu and Zhao (2018), who study LTC risks and savings in China.

[12] Another way to specify a state-dependent utility is to assume that consumption, rather than utility, is discounted in different health states (Laitner et al., 2018). We follow the former approach to incorporate state-dependent utility because i) in our model, the individual chooses consumption after paying health-related costs and, therefore, consumption need not be discounted to reflect non-medical consumption, and ii) we are interested in the impact on insurance choice of the marginal utility of consumption in the poor health states.

We set the strength of the bequest motive b = 50 to reflect a relatively strong motive, following Friedman and Warshawsky (1990). We test the sensitivity of the results to these preference parameters in Section 4.1.

Regarding the parameter for state-dependent utility, the empirical results are mixed for high-income countries (e.g., Finkelstein et al., 2013) and limited for China. Wang and Wang (2020) estimate a linear probability model and find that, for older Chinese, the value of non-medical consumption is around 20% higher when an individual has several chronic diseases and around 30% lower if they have limitations in three or more activities of daily living. Therefore, we set $\eta_{Ht,}$ to 1.2 if the individual is critically ill and 0.7 if they need LTC. We test the sensitivity of the results to variation in these assumptions in Section 4.1.

2.5. The retiree's objective and decision problem

We model the decision of a healthy retiree who, at retirement, decides to use a portion of their wealth to purchase one or more of a life annuity, critical illness insurance, and LTC insurance and chooses their consumption in each future year until death. The retiree's objective is to maximize their expected lifetime utility of consumption in retirement, which is given by the following recursive specification:

$$V_t(M_t, H_t) = \max_{c_t,\, \omega_{Annuity},\, \omega_{CII},\, \omega_{LTCI}} E_t\left(u(c_t, H_t) + \beta\left[\sum_{H_{t+1}=1}^{4} \pi_t(H_t, H_{t+1}) V_{t+1}(M_{t+1}, H_{t+1})\right]\right)$$

s.t.

$$A_t = M_t + P_t - CostCI_t - CostLTC_t + Annuity_t + CII_t + LTCI_t - c_t,$$

$$M_{t+1} = R \times A_t,$$

$$A_t > 0,$$

$c_t \geq S,$

$\omega_{Annuity}, \omega_{CII}, \omega_{LTCI} \geq 0,$

$$\omega_{Annuity} + \omega_{CII} + \omega_{LTCI} \leq 1, \qquad (3)$$

where $V_t(M_t, H_t)$ is the value function at period t given state variables wealth M_t and health H_t, and $V_t(M_t, 4) = v(M_t)$ is the bequest function described in the previous subsection; E_t is the expectation operator; $u(c_t, H_t)$ is the state-dependent utility of consumption defined in Equation (1), and $\pi_t(H_t, H_{t+1})$ is the transition probability from health state H_t to H_{t+1} in time t.

In each period, we assume the following constraints for retirement planning: borrowing is not allowed; the consumption floor is the government subsidy S; the retiree cannot sell or cancel the insurance contracts. Given the insurance allocation made in the initial period, from period t to $t + 1$, the retiree starts with available retirement wealth M_t, and receives the public pension P_t and annuity income $Annuity_t$. If the retiree is critically ill ($H_t = 2$), they incur the cost of critical illness, $CostCI_t$, and receive a lump sum payment, CII_t, if the period t is the first time they are diagnosed with a critical illness. If the retiree is LTC dependent ($H_t = 3$), they incur the LTC cost, $CostLTC_t$, and receive a regular income $LTCI_t$ if they are LTC dependent. The insurance payments $Annuity_t$, CII_t and $LTCI_t$ depend on the proportions $\omega_{Annuity}$, ω_{CII}, and ω_{LTCI} of initial retirement wealth M_0, allocated to purchase these products.

Next, the retiree chooses consumption c_t, based on her current cash on hand A_t. Their remaining wealth is deposited into a savings account, growing at a real risk-free rate, R, and becomes the available wealth M_{t+1}, in the next period. After they choose consumption in the last period, any wealth remaining in the next period becomes her bequest.

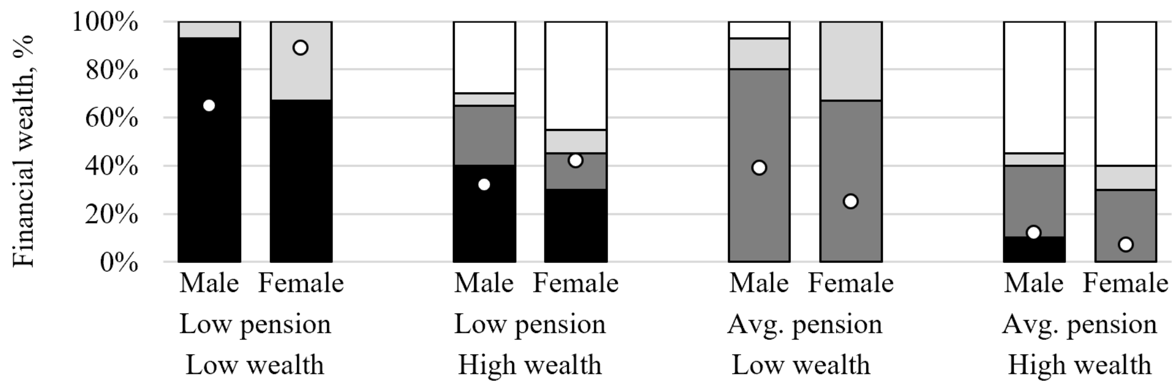
We convert the optimization problem with several choice variables expressed in Equation (3) into sub-problems conditioning on a grid of possible insurance allocations. We solve the sub-optimization problems for consumption numerically by backward induction using the endogenous gridpoint method in Carroll (2006). Appendix E sets out the solution procedure. We then use simulations to determine the optimal insurance choices of the retiree. For each retirement portfolio allocation, we calculate the average lifetime utility obtained with 10,000 Monte-Carlo path simulations based on the solved optimal consumption functions. The optimal retirement portfolio is that with the largest average utility.

Similar to Horneff et al. (2020), we calculate a retiree's welfare gains from optimal insurance as the percentage increase of financial wealth without insurance. We first simulate the average lifetime utilities without insurance for an equally spaced sequence of six levels of financial wealth ranging from 100% to 200% of the individual's financial wealth. We then use splines to connect these points to obtain a utility curve with respect to financial wealth. The value of financial wealth that is equal to the utility achieved with optimal insurance reflects the wealth needed to generate the same utility without insurance. We calculate the percentage increase of financial wealth and designate this as the welfare gain for a retiree with optimal insurance.

3. Main results

3.1. Optimal insurance demand

In this section, we provide the optimal insurance allocations and welfare gains predicted by the calibrated life-cycle model described in the previous section. We report optimal insurance for men and women for four combinations of financial wealth (low: 150,000 CNY, high: 1 million CNY) and monthly public pension amounts (low: 1,000 CNY, average: 3,000 CNY). Figure 1 shows the results for men and women. We analyze the impact of preferences, pricing, and government subsidies on optimal insurance in Section 4.



	Low pension, Low wealth: Male	Low pension, Low wealth: Female	Low pension, High wealth: Male	Low pension, High wealth: Female	Avg. pension, Low wealth: Male	Avg. pension, Low wealth: Female	Avg. pension, High wealth: Male	Avg. pension, High wealth: Female
□ Savings account	0%	0%	30%	45%	7%	0%	55%	60%
□ LTCI	7%	33%	5%	10%	13%	33%	5%	10%
■ CII	0%	0%	25%	15%	80%	67%	30%	30%
■ Annuity	93%	67%	40%	30%	0%	0%	10%	0%
○ Welfare gain	65%	89%	32%	42%	39%	25%	12%	7%

Fig 1. Optimal insurance for men and women with different pensions and financial wealth.

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men at age 60 and women at age 55 with different pension and financial wealth levels (low pension: 1,000 CNY per month; average pension: 3,000 CNY per month; low wealth: 150,000 CNY; high wealth: 1 million CNY). Welfare gain is marked by white circles.

We first consider men and women with a low monthly pension and low financial wealth. Figure 1 shows that for both men and women, the optimal insurance at retirement (time zero in the model) consists of an annuity and some LTC insurance but no critical illness coverage. Compared to the baseline with no private insurance, the welfare gain with this optimal insurance strategy is 65% of initial financial wealth[13] for men and 89% for women. These welfare gains are the largest among all four economic profiles we considered, highlighting the importance of optimal insurance choice for those with limited economic resources.

We then consider retirees with a low pension and high wealth. Figure 1 shows that the optimal insurance for men and women include all three insurance products and some savings. The welfare

[13] This means that for men with retirement savings of 150,000 CNY and a pension of 1,000 CNY pension, the expected lifetime utility from the optimal portfolio is equivalent to the expected lifetime utility they could obtain with retirement savings of 247,500 CNY (150,000 CNY * 165%) without any private insurance.

gain from optimal insurance is 32% for men and 42% for women. Compared with those with the same low pension, retirees with higher retirement savings can afford to buy a larger annuity (e.g., for men, 40% times an initial wealth of 1 million CNY vs. 93% times 150,000 CNY) and other insurance.

Next, we consider retirees with an average pension and low wealth. Figure 1 shows that, in this case, the optimal insurance for men and women includes mostly critical illness insurance, some LTC insurance, but no annuity. These results suggest that those with an average pension can focus on insuring out-of-pocket health-related costs, especially for critical illness, rather than purchasing annuities. The welfare gains are 39% for men and 25% for women.

Finally, we consider the most affluent group we study, men and women with an average pension and high wealth. The optimal allocation for this group includes critical illness insurance, some LTC insurance, some annuity (for men), and savings. Of all four economic profiles, these affluent retirees have the highest percentage of wealth allocated to savings, showing the impact of bequest motives and the potential for self-insurance. The welfare gain from optimal insurance, in this case, is 12% of initial financial wealth for men and 7% for women.

Overall, our model predicts a substantial demand for life annuities, critical illness and LTC insurance, but this varies substantially with respect to a retiree’s gender and financial circumstances. Annuity demand is high for those with a low public pension, and there is a high demand for critical illness insurance for those with an average pension. We find a positive demand for LTC insurance for all economic profiles considered here, while the demand for life annuities and critical illness insurance can be zero, depending on the pension level. LTC insurance demand is higher for women[14] and for those with low levels of financial wealth. This indicates that LTC insurance has a unique role in retirement financial planning. We also find that the welfare gain from optimal insurance is larger for retirees with low levels of wealth or pension income. This means that the impact of optimal retirement planning is relatively larger for less affluent individuals than for their wealthier counterparts.

3.2. How does the insurance demand influence each other?

Section 3.1 shows the optimal insurance demand when annuity, critical illness insurance and LTC insurance are all accessible. Our model also predicts insurance demand when only one type of insurance is accessible. Contrasting these two analyses enables us to study whether these insurance products complement or substitute each other, providing insights for insurance expansion, especially for countries with limited public insurance. In particular, it shows whether access to critical illness insurance and LTC insurance can release the precautionary savings for annuity purchase.

Table 1 reports the results for both men and women. First, we find that total insurance demand, that is, the total retirement wealth allocated to insurance, increases when more types of insurance are accessible. Second, for almost all economic profiles considered, annuity demand decreases when retirees can purchase critical illness and LTC insurance, while the demand for critical illness insurance increases when they can purchase an annuity and LTC insurance. For example, for women with a low pension and high wealth, the annuity demand decreases from an allocation of

[14] This is likely caused by the fact that the chance of needing LTC is much higher for women, while their chance of being critically ill is comparable to that of men, as reported in Section 2.3. These health-related risks are the primary risks compared with the longevity risk.

Men	**Low pension Low wealth**				**Low pension High wealth**			
Annuity	93%	100%			40%	35%		
CII	0%		0%		25%		5%	
LTCI	7%			33%	5%		0%	10%
Savings account	0%	0%	100%	67%	30%	65%	95%	90%
	All accessible	Only annuity	Only CII	Only LTCI	All accessible	Only annuity	Only CII	Only LTCI

	Avg. pension Low wealth				**Avg. pension High wealth**			
Annuity	0%	0%			10%	15%		
CII	80%		87%		30%		20%	
LTCI	13%			7%	5%			5%
Savings account	7%	100%	13%	93%	55%	85%	80%	95%
	All accessible	Only annuity	Only CII	Only LTCI	All accessible	Only annuity	Only CII	Only LTCI

Women	**Low pension Low wealth**				**Low pension High wealth**			
Annuity	67%	100%			30%	45%		
CII	0%		0%		15%		0%	
LTCI	33%			67%	10%			15%
Savings account	0%	0%	100%	33%	45%	55%	100%	85%
	All accessible	Only annuity	Only CII	Only LTCI	All accessible	Only annuity	Only CII	Only LTCI

	Avg. pension Low wealth				**Avg. pension High wealth**			
Annuity	0%	0%			0%	0%		
CII	67%		67%		30%		10%	
LTCI	33%			33%	10%			5%
Savings account	0%	100%	33%	67%	60%	100%	90%	95%
	All accessible	Only annuity	Only CII	Only LTCI	All accessible	Only annuity	Only CII	Only LTCI

Table 1. Optimal insurance for men and women when all three types of insurance are accessible or only one type of insurance is accessible.

Notes: The percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men at age 60 and women at age 55 with different pension and financial wealth levels (low pension: 1,000 CNY per month; average pension: 3,000 CNY per month; low wealth: 150,000 CNY; high wealth: 1 million CNY).

45% of retirement wealth to 30%, while the demand for critical illness insurance increases from zero to 15%. In addition, Figure 2 shows how the utility with one type of insurance changes when two other types of insurance are accessible. For example, when critical illness and LTC insurance are accessible and with their optimal amounts predicted in Section 3.1, the utility curve with respect to annuity demand becomes flatter, implying that sub optimal annuitization choices are less costly. Figure 2 also shows the impact of annuity and LTC insurance on demand for critical illness insurance is large. Its demand increases from 0 to 15%, but the curvature near the optimal allocation (15%) is relatively flat. Third, we find that the demand for LTC insurance among retirees with a low pension decreases when an annuity is accessible. For example, men with a low pension and low wealth would have demand for either LTC insurance of 33% of their retirement wealth or full annuitization, when only LTC insurance or annuities are accessible. However, when all types of insurance are available, the demand for LTC insurance drops to only 7% of retirement wealth, while annuity demand drops to 93%.

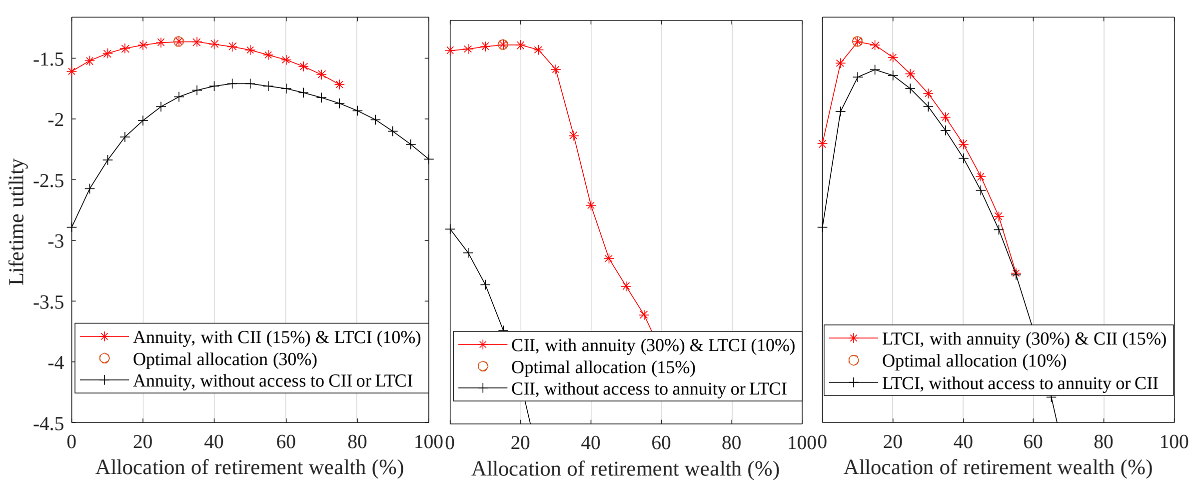


Fig 2. Lifetime utilities when only one or all types of insurance are accessible.

Notes: The figures plot the lifetime utilities achieved with demand, that is, percentage allocations of initial retirement wealth, for annuities, critical illness insurance (CII), and long-term care insurance (LTCI). Each subplot contrasts the utilities obtained with one type of insurance, when it is the only accessible insurance and when other types of insurance are already purchased at their optimal levels according to Section 3.1. Results are for women at age 55 with a low pension (1,000 CNY per month) and a high wealth (1 million CNY).

Similarly, for women with a low pension and high wealth, the demand for LTC insurance drops from 67% of retirement wealth to 33%, while annuity demand drops from 45% to 30%. These results also provide support for annuities and LTC insurance being potential substitutes.

Overall, the above analysis shows that total insurance demand increases when more types of insurance providing cover for retirement risks are accessible. Notably, annuity demand does not necessarily increase when health-related expenditures are partly covered. First, this is likely because retirees are constrained by their financial wealth as the remaining wealth available to purchase annuities decreases after purchasing critical illness insurance and LTC insurance.[15] Second, using the specific insurance to cover the risk it is designed for is more efficient than using a life annuity to cover all the risks, hence reducing annuity demand. Aside from that, we find evidence that access to annuities and LTC insurance can increase the demand for critical illness insurance, and that access to annuities could decrease demand for LTC insurance among retirees with a low pension.

4. Sensitivity tests

In this section, we assess alternative assumptions for preferences (risk aversion, time preference, bequest motives, state-dependent utility), product pricing, and a minimum consumption floor, and summarize their impact on the insurance demand. The sensitivity tests for risk aversion, time

[15] Note that here we are assuming the insurance are priced separately according to their official tables. However, the insurance products could also be priced in a joint way, that is, based on the same health transition matrix. In this way the insurance products are like a bundled product and with a different risk pool. We discuss the insurance demand for this case in Section 4.2.

preference, and the consumption floor are conducted for both men and women, while the remaining tests are conducted for men only.

4.1. Preferences

First, we summarize the results for risk aversion, time preference, and bequest motives, then we discuss the impact of state-dependent utility. Overall, the results confirm that the insurance demand varies substantially based on economic profiles, while changes in the preference assumptions have only a small to moderate effect on the benchmark results.

4.1.1. Risk aversion, time preference, and bequest motives

We vary the risk aversion parameter γ from 3 to 2 and 9, the subjective discount factor β from 0.999 to 0.985 and 0.96, and the strength of the bequest motive b from 50 to 0 (no bequest motive) and 100. These values are within the range of parameters used in other studies of retirement insurance (e.g., Friedman and Warshawsky, 1990; Peijnenburg et al., 2017; İmrohoroğlu and Zhao, 2018). In the following, we mainly report results for retirees with an average monthly pension and high financial wealth.[16] We report detailed results in Appendix B.2.

We find that greater risk aversion increases insurance demand for men and women with high levels of financial wealth, while for those with low financial wealth insurance demand increases only for annuities and critical illness insurance. When the risk aversion parameter increases from 2 to 9, for example, for male retirees with high financial wealth and an average monthly pension, annuity demand increases from 0% to 25%, demand for critical illness insurance increases from

[16] This is because it is easier to evaluate the impact of preferences on insurance choices as they are less financially constrained.

30% to 35%, and demand for LTC insurance increases from 5% to 10%. For men with low levels of financial wealth and a low monthly pension, the optimal allocation to annuities and critical illness insurance increases from 53% to 73% and 0% to 27%, respectively. However, the allocation to LTC insurance drops from 40% to 0%. The results for women are consistent with these.

A higher subjective discount factor only slightly increases the demand for insurance. For example, increasing the subjective discount factor from 0.96 to 0.999 for male retirees with an average pension and high wealth increases their optimal allocation to annuities from 0% to 10% of initial financial wealth, while the demand for critical illness insurance and LTC insurance remains at 30% and 5%, respectively. For women with an average pension and high wealth, the demand for critical illness insurance increases slightly from 25% to 30%, while the demand for the other two forms of insurance remains the same.

Increasing the bequest motive decreases annuity demand but has only a small effect on the demand for critical illness and LTC insurance. For example, for male retirees with an average pension and high wealth, annuity demand drops from 30% of initial financial wealth to zero, which is in line with the findings in Europe that higher bequest motives are linked to a lower probability of annuitization (Bello et al., 2024), while the demand for critical illness and LTC insurance decreases only slightly.

4.1.2. State-dependent utility

Next, we test the impact of state-dependent utility on optimal insurance. For our benchmark results reported in Section 3.1, we set the weight parameter for the marginal utility of consumption to $\eta_{Ht=2} = 1.2$ if the retiree is critically ill and to $\eta_{Ht=3} = 0.7$ if they need LTC. We explained in Section 2.2 that these numbers are selected based on the reduced form estimates from Wang and Wang (2020), who find the marginal utility of consumption is higher for those diagnosed with a critical illness and lower for those who are LTC dependent. In Appendix B.3, we test three assumptions for η_{Ht}: i) marginal utility is independent of health; ii) marginal utility is lower in the poor health states (critically ill, LTC dependent); and iii) marginal utility is higher in the poor health states. Overall, the results show that state-dependent utility has a mild to moderate impact on insurance demand. The largest difference occurs for annuity demand of retirees with high wealth, which drops from 55% to 25% of initial retirement wealth, when the marginal utility of consumption for those in poor health states increases from 0.8 to 1.2. The remaining results are broadly consistent with our main results reported in Section 3.1, with a maximum allocation difference of 20% of initial retirement wealth for retirees with low wealth. The impact of state-dependent utility is larger than identified in Peijnenburg et al. (2017) in the US context, who find that varying state-dependent utility changes optimal annuity demand by 5% of total wealth. The higher impact of state-dependent utility found in our case is likely because we explicitly model critical illness and LTC health states and their associated costs and insurance. Also, when the marginal utility of consumption increases from low to high in poor health states, annuity demand decreases while the total demand for critical illness and LTC insurance increases.

In summary, our findings indicate that a higher risk aversion increases demand for all three of annuities, critical illness and LTC insurance among retirees with high financial wealth. However for retirees with low financial wealth, we find an increase in the demand for annuities and critical illness insurance but a decrease in the demand for LTC insurance. Being more patient tends to slightly increase insurance demand, while a stronger bequest motive tends to reduce annuity demand with minimal effects on other forms of insurance. Higher marginal utility in the poor health states increases the demand for health-related insurance but decreases the annuity demand.

4.2. Product pricing and bundled insurance

To generate our benchmark results in Section 3, we assume that all insurance products are priced independently, following standard practices for insurance pricing in China. For example, the annuity is priced using the official mortality curve for pensions without explicitly considering the possibility of the beneficiary being critically ill or needing LTC. However, pricing retirement insurance products independently of each other could produce adverse selection, which could, in turn, result in a failing insurance market (e.g., Finkelstein and Poterba, 2004; Braun et al., 2019). Also, as noted in Section 2.3, such a pricing approach would result in a mismatch between the health transitions used for pricing and in the life-cycle model, reducing the interpretability of the results.

In the following, we consider an alternative approach where we price the three insurance products "jointly" to examine the impact of pricing on the insurance demand. We base the alternative product pricing on the health transition matrix introduced in Section 2.2, and consider alternative health transition assumptions introduced in Appendix B.1 as a robustness check. We calculate the prices of the three insurance products as the expected present value of the sum of the discounted future insurance payouts based on 2,000,000 simulated health projections, adding the same 15% loading to each insurance product as in Section 2.3. The results for men are depicted in Appendix B.4.

This pricing approach allows us to study the potential demand for bundled longevity and health-contingent insurance products consisting of life annuities, critical illness insurance, and LTC insurance as components. This is because by following this pricing approach, we have made the implicit assumption that the risk pooling is now larger such that insurers know that the same person will purchase three types of insurance at the same time.[17]

Overall, compared with our benchmark results, whether each insurance is priced independently or jointly has a limited effect on optimal insurance demand, except for retirees with an *average* pension and *high* wealth, where the allocation to annuities increases from 10% of initial financial wealth to 35%. Around three fourths of this increase is due to the reduced price of the annuity in bundled insurance, which is much lower than when it is priced independently, according to the official mortality curve for pension businesses. The pure bundling effect, that is, the impact of accessing to critical illness and LTC insurance, explains one fourth of the increase in annuity demand.[18] Further, the results are robust with respect to the three alternative assumptions about health transitions introduced in Appendix B.1. In all tests, the welfare gains are similar to the benchmark results.

4.3. Consumption floor

Studies based on life-cycle models show that means-tested benefits, such as a minimum consumption floor, can affect demand for retirement insurance (e.g., Pashchenko, 2013), particularly for low-income individuals. In the following, we test two alternative assumptions for the consumption floor, the minimum (491 CNY) and maximum (1,170 CNY) of the 2020 official monthly government subsidy (Ministry of Civil Affairs, 2020), and compare the results with the benchmark where we assumed the monthly average (687 CNY).

[17] We do not include any discount for such bundled products. With a discount the predicted demand should be higher.
[18] The results are calculated based on the comparisons when three types of insurance products are accessible and only the annuity is accessible, when price independently and jointly. Results are averaged across the alternative assumptions about health transition, and are available upon request.

The results confirm that the assumed consumption floor has a large impact on the insurance demand of retirees with a low pension and low wealth and little impact on other retirees with more resources. Appendix B.5 shows that, for retirees with a low pension and low wealth, when the subsidy amount increases from 491 to 1,170 CNY, the predicted demand for LTC insurance decreases while that for annuities increases. This impact is larger for women; their allocation to LTC insurance drops from 67% to 0% of initial financial wealth, and that for annuities increases from 33% to 100%, while for men, this shift of allocation is 13 percentage points.

These results contrast with the findings of Pashchenko (2013), who show that annuity demand decreases with the consumption floor. However, Pashchenko's model does not consider LTC insurance. Because both annuities and LTC insurance provide income in our model, they could, to some extent, be substitutes. Our model predicts that an increase in the consumption floor would have the opposite impact on the demand for LTC insurance and annuities. This result highlights the importance of considering the interaction between means-tested benefits and the provision of retirement insurance when planning for relevant social policies.

5. Discussion and concluding remarks

Retirees in low- and middle-income countries are often inadequately covered for longevity, critical illness, and LTC risks. We develop a novel multiperiod life-cycle model of retirement, with stochastic illness- and care-related costs and health-state-dependent preferences, to assess the demand for annuities, critical illness and LTC insurance. This is the first study to consider the demand for these three types of insurance simultaneously in a portfolio choice context. We calibrate the model to Chinese data and predict the insurance demand for retirees who receive the urban public pension. We provide new findings on the insurance demand to cover longevity, critical illness and LTC risks in a low- and middle-income country context, and we show how demand for one type of insurance is affected by access to other types of insurance.

First, we find a high annuity demand only for those with a low pension; those with an average pension have a substantially lower demand for annuities and a higher demand for critical illness insurance. This finding contrasts with studies set in the US that predict a high annuity demand with or without health costs (e.g., Davidoff et al., 2005; Pang et al., 2010). It also extends the literature on the annuity puzzle regarding the role of precautionary savings for health-related risks (e.g., De Nardi et al., 2010; Reichling and Smetters, 2015; Peijnenburg et al., 2017) by showing that in some circumstances individuals would purchase health-contingent insurance instead of an annuity. As well, we find that access to critical illness and LTC insurance does not necessarily increase annuity demand.

Second, we predict a relatively small but positive LTC insurance demand, which is higher for women, for all economic profiles. At first glance, the relatively low demand for LTC insurance appears to be inconsistent with China's effort to develop public LTC insurance programs. The reason for this result is that wealthy retirees can rely on self-insurance and regular income from public and private pensions to build a buffer. By contrast, for less wealthy retirees, their limited budget means that it is optimal to focus on retirement income security (annuity demand) or to cover catastrophic illness costs before considering LTC costs. We find that the demand for annuities decreases the demand for LTC insurance for retirees with a low pension.

We note that the demand for LTC insurance is relatively small but persistent across all four economic profiles we model and almost doubles for women. In contrast, the demand for critical illness insurance and annuities varies substantially across economic profiles and is zero for some profiles. These results reflect the unique role of LTC insurance and are consistent with China's aim to provide universal basic LTC insurance. This finding of the LTC insurance demand is consistent with Ameriks et al. (2020), whose model suggests that more than half of older Americans across all income and wealth quintiles should have a positive demand for LTC insurance and is supported by de Bresser et al. (2022), who discrete choice experiment finds that most respondents value basic levels of LTC support. Moreover, our model does not consider the needs of surviving spouses or the increasing portion of the aged in the population, which is expected to exacerbate the gap between the demand and supply of LTC services. This implies the predicted demand for LTC insurance is on the conservative side.

Third, we show that a higher marginal utility of consumption in the critical illness and LTC states, increases the demand for the relevant insurance but decreases the demand for annuities. This contributes to the literature concerning state-dependent utility in understating the dynamics of consumption and savings in retirement (e.g., Viscusi and Evans, 1990; Finkelstein et al., 2013; Blundell et al., 2023).

In our model, we derive the optimal insurance level for an economically rational individual. In a related survey-based study conducted in China, Wan et al. (2024) find that higher risk aversion is associated with a higher demand for critical illness and LTC insurance but a lower demand for annuities. Strategic transfers within the family (e.g., Liu and Mukherjee, 2020), cognitive impairment (e.g., Friedberg et al., 2023), and behavioral factors such as framing, loss aversion, and mental accounting could also affect insurance demand (e.g., Gottlieb and Mitchell, 2020; Benartzi et al., 2011).

Our findings offer valuable insights for policymakers and insurers in other low- and middle-income countries. First, our findings show that it is more welfare improving to increase retirement income security and then focus on coverage for catastrophic medical expenditures. This is a plausible approach because sufficient medical treatment is often needed to live long enough to experience longevity and LTC risks. Second, it is important to consider the interaction between means-tested benefits and retirement insurance when planning policies for pensions and LTC. Third, bundling health-contingent and longevity insurance products can increase annuity demand (by releasing precautionary savings otherwise held to cover critical illness and LTC costs), and hybrid insurance products could become an important component in insurance markets. Fourth, the welfare gain with optimal insurance is much larger for retirees who are financially more vulnerable, suggesting that financial education should be provided in conjunction with the expansion of insurance markets. Fifth, we find substantial demand for long-term retirement insurance products. This provides demand-side insights for insurers to develop long-term retirement products, which are generally not available for retirees in China.

The model proposed in this paper can be easily adjusted and applied to the institutional setup in other countries with less well-developed public insurance and private insurance markets.

Data availability

The datasets used in this study are all publicly available (registration needed for the CHARLS data) and can be accessed by links provided in the manuscript.

Declarations of interest

None.

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Demand for Longevity, Critical Illness and Long-Term Care Insurance

Supplementary materials – Online Appendices

Contents

Appendix A. Health transition model

Following Yogo (2016) and Koijen et al. (2016), we use a Markov process to model the health evolution over time. We denote the 4×4 transition probability matrix at period t by P_t, where its element $\pi_t(i, j)$ denotes the transition probability from the health state $H_t = i$ in period t to the health state $H_{t+1} = j$ in period $t + 1$:

$$\pi_t(i, j) = \text{Prob}(H_{t+1} = j \mid H_t = i).$$

This stylised health model allows us to study the impact of three key risks faced by retirees: longevity, critical illness, and long-term care. In our main health transition model, we assume that there is no recovery to the healthy state from being critically ill or needing long-term care because there is limited data to estimate the recovery rates. We also assume that there are transitions between the critically ill state and the long-term care state. Since there is limited data to estimate such transitions, we assume that the transition probabilities between those states are the same as those from the healthy state to the critically ill or from the healthy to the long-term care state, respectively. We test the sensitivity of this assumption in Section 4.2.

The transition probabilities are calibrated separately for both men and women using official tables for mortality and critical illness and estimates for long-term care transitions based on the data from the China Health and Retirement Longitudinal Survey (CHARLS). We set the age-specific transition probability from healthy to critically ill, using the critical-illness incidence rates provided by the China Banking and Insurance Regulatory Commission (CBIRC). We set the age-specific probability of death in the healthy state by an adjusted CBIRC mortality curve for the pension industry. The adjustment is made to exclude the deaths that occurred in the critically ill or long-term care state, and we follow the insurance practice (Partner Re, 2016) to calculate these adjusted mortality rates.

We calibrated the transition probabilities related to long-term care based on the CHARLS data. For each gender, we tested the ordered probit model, following Koijen et al. (2016) and Yogo (2016), but we only included the health state and the age as explanatory variables. We also tested ordered logit and multinomial logit models and the formulation with the complementary log-log link function. We selected a multinomial logit model based on the Akaike Information Criterion to estimate the long-term care transition probabilities.[1] Table A.1 summarizes the calibration method for each health transition in our model. A better approach would be to estimate the full transition model based on the same data. However, surveys like the CHARLS do not provide sufficient information to accurately identify the critically ill state and it is not possible to estimate the transition probabilities related to this health state in a reliable way. Also, following standard life-cycle model assumptions (e.g., Koijen et al., 2016), we assume that the health transition probabilities are exogenous and do not vary according to economic variables, such as pension amount or wealth. We also note that the health transitions in our benchmark life-cycle model are not the same as those used for product pricing. This fact reflects pricing practices in the industry, and we investigate the sensitivity of the assumptions for health transitions in Section 4.2. We consider the case where health transitions used for insurance pricing and in the life-cycle model are the same in Section 4.3.

[1] These transition probabilities are period transition rates. Cohort transition probabilities are not available due to data limitations.

Table A.1. Calibration sources for the health transition probability matrix

From	To	Notation	Calibration source
Healthy	Healthy	$\pi_t(1,1)$	$1 - \pi_t(1,2) - \pi_t(1,3) - \pi_t(1,4)$
	Critically ill	$\pi_t(1,2)$	CBIRC incidence rates
	Long-term care	$\pi_t(1,3)$	CHARLS estimates
	Dead	$\pi_t(1,4)$	Adjusted from CBIRC mortality rates for pension business to exclude deaths occurred in other states
Critically ill	Healthy	$\pi_t(2,1)$	0
	Critically ill	$\pi_t(2,2)$	$1 - \pi_t(2,1) - \pi_t(2,3) - \pi_t(2,4)$
	Long-term care	$\pi_t(2,3)$	CHARLS estimates
	Dead	$\pi_t(2,4)$	Adjusted from CBIRC mortality rates and incidents rates
Long-term care	Healthy	$\pi_t(3,1)$	0
	Critically ill	$\pi_t(3,2)$	CBIRC incidence rates
	Long-term care	$\pi_t(3,3)$	$1 - \pi_t(3,1) - \pi_t(3,2) - \pi_t(3,4)$
	Dead	$\pi_t(3,4)$	CHARLS estimates
Dead	Healthy	$\pi_t(4,1)$	0
	Critically ill	$\pi_t(4,2)$	0
	Long-term care	$\pi_t(4,3)$	0
	Dead	$\pi_t(4,4)$	1

Notes: The China Banking and Insurance Regulatory Commission (CBIRC) provides the official mortality rates and incidence rates of critical illness (CBIRC, 2016, 2013). The CHARLS estimates are the estimated transition probabilities related to long-term care based on the China Health and Retirement Longitudinal Survey (CHARLS) in 2011, 2013 and 2015 waves. $\pi_t(,)$ denotes the transition probability from one health state H to the other at time t.

Appendix B. Additional results

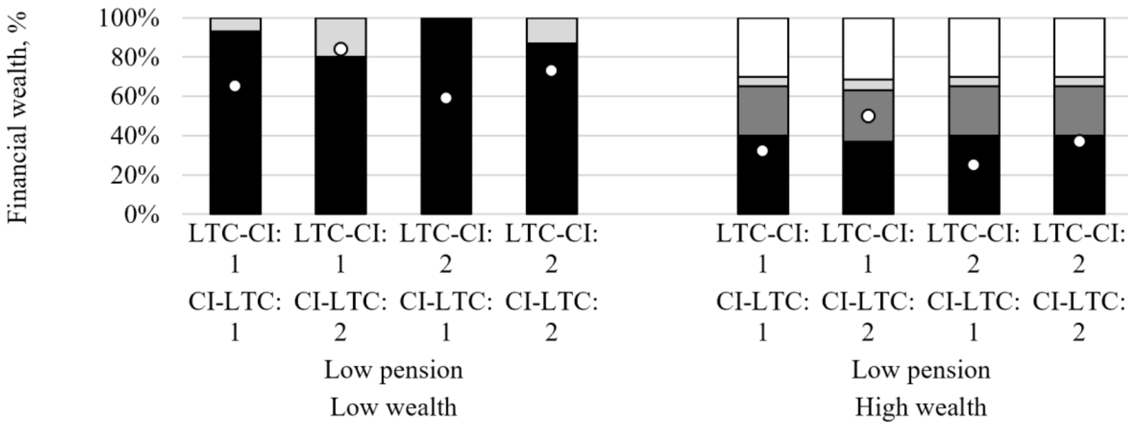
B.1. Health transitions

Critical illness and LTC are key features in our model. To generate our benchmark results, we assume (because of data limitations) that the age-specific probabilities of transitioning to the LTC state are the same for the healthy and the critically ill state. We make a similar assumption for the transition to the critically ill state. In the following, we test the sensitivity of the benchmark results by considering higher transition probabilities between poor health states than from the healthy state to poor health.

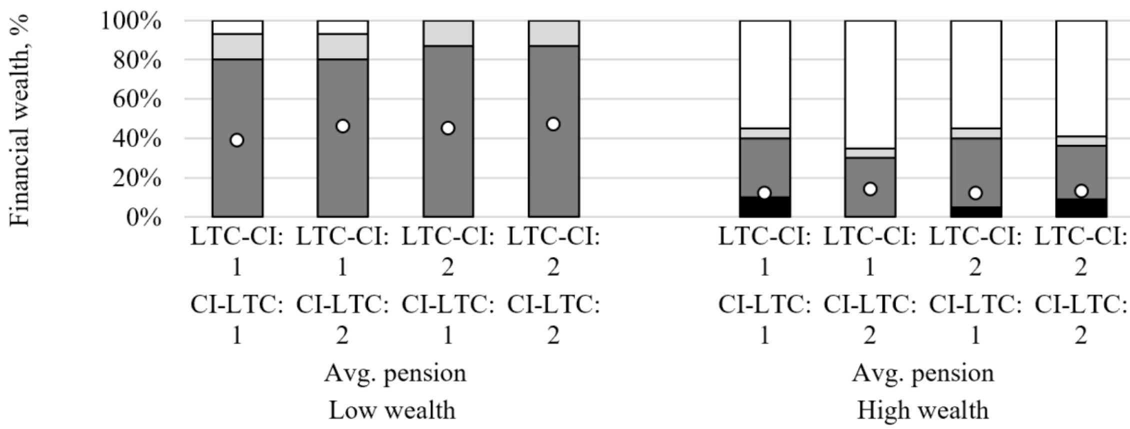
First, we assume that the age-specific probabilities of transition from the critically ill state to the LTC state are twice that from the healthy state to the LTC state. Next, we assume that the transition probabilities from the LTC state to the critical illness state are twice that from the healthy state to the critical illness state. Last, we assume that the previous two assumptions hold simultaneously. The calibration procedure for the remaining health transition matrix is the same as that in the benchmark model.

Figure B.1 compares the optimal insurance choices under the alternative health transitions with the benchmark results for male retirees.[2] Overall, the impacts of the transition assumptions are small to moderate. The demand for LTC insurance for retirees with low wealth increases when we increase the transition probabilities to the LTC state in the critical illness state but decreases when we lower the transition probabilities to the critically ill state. Higher transition probabilities

[2] In a small number of cases where the financial wealth needed to generate the same utility with optimal insurance is more than twice the initial financial wealth, we do not calculate the exact value to avoid potential bias when extrapolating splines outside the fitting range. Instead, we report the welfare gain as ">100%" of initial wealth.



□ Savings account	0%	0%	0%	0%	30%	30%	30%	30%
□ LTCI	7%	20%	0%	13%	5%	5%	5%	5%
■ CII	0%	0%	0%	0%	25%	25%	25%	25%
■ Annuity	93%	80%	100%	87%	40%	35%	40%	40%
○ Welfare gain	65%	84%	59%	73%	32%	50%	25%	37%

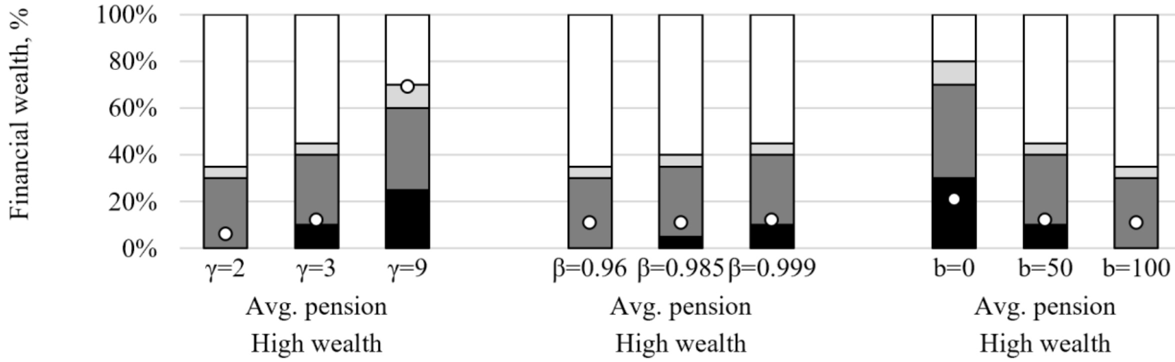


□ Savings account	7%	7%	0%	0%	55%	65%	55%	65%
□ LTCI	13%	13%	13%	13%	5%	5%	5%	5%
■ CII	80%	80%	87%	87%	30%	30%	35%	30%
■ Annuity	0%	0%	0%	0%	10%	0%	5%	10%
○ Welfare gain	39%	46%	45%	47%	12%	14%	12%	13%

Fig B.1. Optimal insurance with alternative assumptions for health transition processes

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men aged 60 with different pension and financial wealth levels (low pension: 1,000 CNY per month; average pension: 3,000 CNY per month; low wealth: 150,000 CNY; high wealth: 1 million CNY). For each economic profile, we compare the benchmark results (with transition probabilities between the CI and the LTC states the same as that from the healthy state to the CI/LTC state), LTC–CI: 1 and CI–LTC: 1) against three alternative assumptions for the transition probabilities between the CI and LTC states. For example, “CI–LTC: 2” indicates that the transition from the CI state to the LTC state is twice the transition from healthy to the LTC state. Welfare gain is marked by white circles.

B.2. Risk aversion, time discount, and bequest motives



	γ=2	γ=3	γ=9	β=0.96	β=0.985	β=0.999	b=0	b=50	b=100
□ Savings account	65%	55%	30%	65%	60%	55%	20%	55%	65%
□ LTCI	5%	5%	10%	5%	5%	5%	10%	5%	5%
■ CII	30%	30%	35%	30%	30%	30%	40%	30%	30%
■ Annuity	0%	10%	25%	0%	5%	10%	30%	10%	0%
○ Welfare gain	6%	12%	69%	11%	11%	12%	21%	12%	11%

	γ=2	γ=3	γ=9	β=0.96	β=0.985	β=0.999
□ Savings account	80%	60%	50%	65%	65%	60%
□ LTCI	5%	10%	15%	10%	10%	10%
■ CII	15%	30%	35%	25%	25%	30%
■ Annuity	0%	0%	0%	0%	0%	0%
○ Welfare gain	1%	7%	72%	6%	7%	7%

Fig B.2. Optimal insurance with alternative assumptions for risk aversion (γ), time preference (β), and bequest motives (b).

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men at age 60 with specified pension and financial wealth levels. A high wealth of 1 million CNY and an average pension income of 3,000 CNY are considered for the test of the above preferences parameters. Welfare gain is marked by white circles.

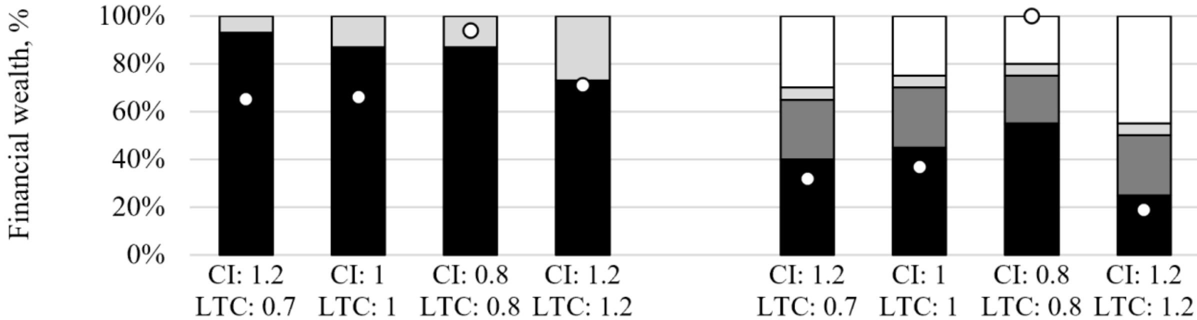
between the critically ill or LTC states reduce the annuity demand for retirees with an average pension and high wealth. The welfare gains are generally robust with respect to the alternative health-transition assumptions but with some variation for retirees with a low pension.

B.3. State-dependent utility

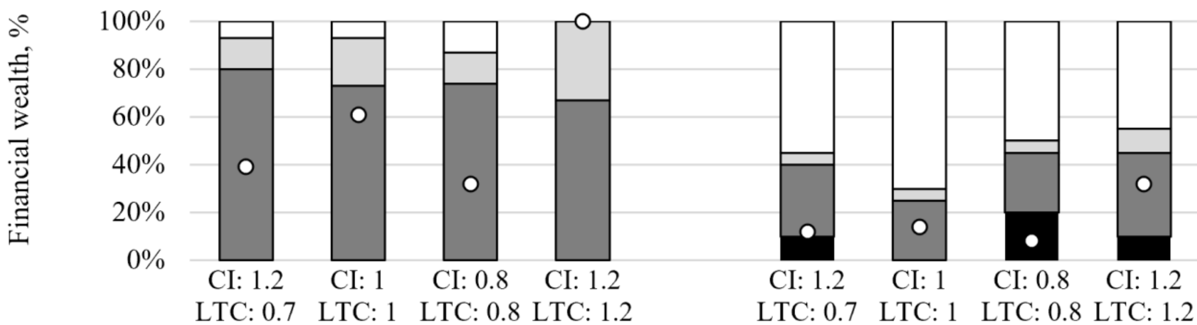
First, we analyze how the results vary if we assume that utility is not state-dependent by setting the weight parameter for the marginal utility of consumption η_{Ht} to 1 in all health states. The results reported in Figure B.3 (second bar in each chart) show that the optimal insurance allocations are relatively similar to the benchmark results, with changes of less than 10 percentage points—except for retirees with high levels of wealth and an average pension, for whom the annuity demand falls from 10% of initial financial wealth to zero, while savings increase from 55% to 70%

Second, we assume that the marginal utility of consumption is lower in both poor health states than in the healthy state by setting $\eta_{Ht=2} = \eta_{Ht=3} = 0.8$ (see Figure B.3, third bar in each chart). Compared with the benchmark results, the changes in allocation for critical illness and LTC insurance are less than ten percentage points for any of the economic profiles. However, annuity demand increases from 40% to 55% for retirees with a low pension and high wealth and increases from 10% to 20% for retirees with an average pension and high wealth.

Third, we assume that η_{Ht} equals 1.2 in the poor health states such that the marginal utility of consumption is higher than in the healthy state (see Figure B.3, fourth bar in each chart). Comparing with our benchmark results, for retirees with low wealth, the demand for LTC insurance increases while that for annuities or CI insurance decreases; for retirees with high wealth, the insurance demand is more stable. Specifically, for male retirees with a low pension and low wealth, annuity demand drops from 93% to 73% of initial financial wealth, while LTC insurance demand increases from 7% to 27%. For those with an average pension and low levels of wealth, the demand for LTC insurance increases from 13% to 33% and critical illness insurance demand drops from 80% to 67%. For retirees with a low pension but high levels of wealth, the annuity demand drops from 40% to 25%, while the demand for health-contingent insurance is stable. For those with an average pension and high levels of wealth, annuity demand remains at 10%, while the demand for critical illness and LTC insurance increases from 30% to 35% and from 5% to 10%, respectively.



	Low pension, Low wealth				Low pension, High wealth			
	CI: 1.2 LTC: 0.7	CI: 1 LTC: 1	CI: 0.8 LTC: 0.8	CI: 1.2 LTC: 1.2	CI: 1.2 LTC: 0.7	CI: 1 LTC: 1	CI: 0.8 LTC: 0.8	CI: 1.2 LTC: 1.2
□ Savings account	0%	0%	0%	0%	30%	25%	20%	45%
□ LTCI	7%	13%	13%	27%	5%	5%	5%	5%
■ CII	0%	0%	0%	0%	25%	25%	20%	25%
■ Annuity	93%	87%	87%	73%	40%	45%	55%	25%
○ Welfare gain	65%	66%	94%	71%	32%	37%	>100%	19%

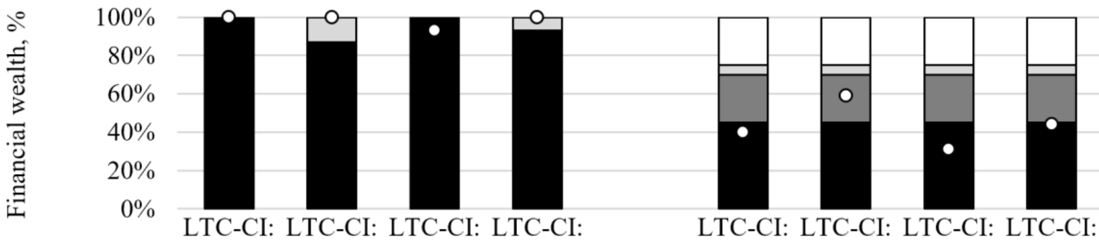


	Avg. pension, Low wealth				Avg. pension, High wealth			
	CI: 1.2 LTC: 0.7	CI: 1 LTC: 1	CI: 0.8 LTC: 0.8	CI: 1.2 LTC: 1.2	CI: 1.2 LTC: 0.7	CI: 1 LTC: 1	CI: 0.8 LTC: 0.8	CI: 1.2 LTC: 1.2
□ Savings account	7%	7%	13%	0%	55%	70%	50%	45%
□ LTCI	13%	20%	13%	33%	5%	5%	5%	10%
■ CII	80%	73%	73%	67%	30%	25%	25%	35%
■ Annuity	0%	0%	0%	0%	10%	0%	20%	10%
○ Welfare gain	39%	61%	32%	>100%	12%	14%	8%	32%

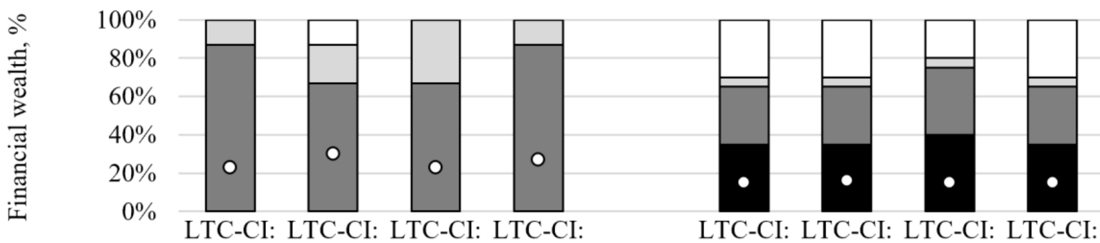
Fig B.3. Optimal insurance with state-dependent utility

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men aged 60 with different pension and financial wealth levels (low pension: 1,000 CNY per month; average pension: 3,000 CNY per month; low wealth: 150,000 CNY; high wealth: 1 million CNY). For each economic profile, we compare the benchmark results (with utility weights CI: 1.2, LTC: 0.7) against three alternative assumptions for the utility weights for the CI and LTC states. Welfare gain is marked by white circles.

B.4. Pricing



	Low pension, Low wealth: LTC-CI: 1, CI-LTC: 1	LTC-CI: 1, CI-LTC: 2	LTC-CI: 2, CI-LTC: 1	LTC-CI: 2, CI-LTC: 2	Low pension, High wealth: LTC-CI: 1, CI-LTC: 1	LTC-CI: 1, CI-LTC: 2	LTC-CI: 2, CI-LTC: 1	LTC-CI: 2, CI-LTC: 2
□ Savings account	0%	0%	0%	0%	25%	25%	25%	25%
□ LTCI	0%	13%	0%	7%	5%	5%	5%	5%
■ CII	0%	0%	0%	0%	25%	25%	25%	25%
■ Annuity	100%	87%	100%	93%	45%	45%	45%	45%
○ Welfare gain	>100%	>100%	93%	>100%	40%	59%	31%	44%

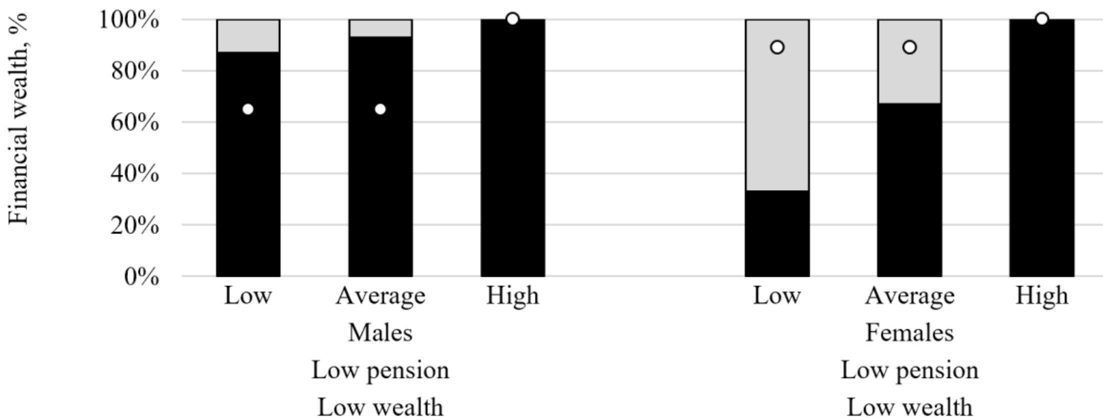


	Avg. pension, Low wealth: LTC-CI: 1, CI-LTC: 1	LTC-CI: 1, CI-LTC: 2	LTC-CI: 2, CI-LTC: 1	LTC-CI: 2, CI-LTC: 2	Avg. pension, High wealth: LTC-CI: 1, CI-LTC: 1	LTC-CI: 1, CI-LTC: 2	LTC-CI: 2, CI-LTC: 1	LTC-CI: 2, CI-LTC: 2
□ Savings account	0%	13%	0%	0%	30%	30%	20%	30%
□ LTCI	13%	20%	33%	13%	5%	5%	5%	5%
■ CII	87%	67%	67%	87%	30%	30%	35%	30%
■ Annuity	0%	0%	0%	0%	35%	35%	40%	35%
○ Welfare gain	23%	30%	23%	27%	15%	16%	15%	15%

Fig B.4. Optimal portfolio with insurance priced by a joint health transition matrix, evaluated under alternative assumptions for health transition processes.

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men aged 60 with different pension and financial wealth levels (low pension: 1,000 CNY per month; average pension: 3,000 CNY per month; low wealth: 150,000 CNY; high wealth: 1 million CNY). The insurance products are priced by the same joint health transition matrix, such that the health transitions for pricing and in the life-cycle model are the same. For each economic profile, we compare the benchmark results (with transition probabilities between the CI and the LTC states the same as that from the healthy state to the CI/LTC state), LTC–CI: 1 and CI–LTC: 1) against three alternative assumptions for the transition probabilities between the CI and LTC states. For example, “CI–LTC: 2” indicates that the transition from the CI state to the LTC state is twice the transition from healthy to the LTC state. Welfare gain is marked by white circles.

B.5. Consumption floor



	Males Low	Males Average	Males High	Females Low	Females Average	Females High
□ Savings account	0%	0%	0%	0%	0%	0%
□ LTCI	13%	7%	0%	67%	33%	0%
■ CII	0%	0%	0%	0%	0%	0%
■ Annuity	87%	93%	100%	33%	67%	100%
○ Welfare gain	65%	65%	>100%	89%	89%	>100%

Fig B.5. Optimal insurance with the amount of consumption floor set to three levels of monthly government subsidy: low (491 CNY), average (benchmark, 687 CNY), and high (1,170 CNY).

Notes: The bars and their corresponding percentages show the optimal allocation of the initial financial wealth into a savings account, long-term care insurance (LTCI), critical illness insurance (CII), and an annuity, as predicted by our life-cycle model. Results are for men at age 60 and women at age 55 with the specified pension and financial wealth levels (low pension: 1,000 CNY per month; low wealth: 150,000 CNY). We find no impact of subsidy on insurance demand for retirees with more financial wealth and public pension income. Welfare gain is marked by white circles.

Appendix C. Distribution of health-related cost

C.1. Cost of critical illness

The cost of critical illness in China is often immediate and catastrophic to families because of urgent life-extending treatments and hospitalisation. We follow related public health literature and model the out-of-pocket cost of critical illness using a lognormal distribution (e.g., Wu et al., 2018), which captures the fact that the cost is typically right-skewed with a large variation.[3] To calibrate the lognormal distribution, we use individual medical expenditure data collected directly from healthcare systems rather than through household surveys. This is because household survey data is likely to underestimate the cost because individuals with severe diseases are less likely to participate, and surveys such as CHARLS do not provide details of disease severity, nor sufficient measures to estimate full expenses due to critical illness.

We estimate the expected value of the lognormal-distributed cost according to the average median of the out-of-pocket costs for critical illness in Beijing (the capital of China) and Zhaoqing (an inland city with a larger reimbursement rate and a larger cap amount than that of an average city in China) in 2014 (Fang et al., 2018). We select these cities because the medical expenditure there is more likely to represent the cost of receiving adequate treatments for illness due to their high income or reimbursement rate and the access to advanced medical services. Otherwise, individuals can be financially constrained and their reported costs will underestimate the medical cost of critical illness. Here we assume that the cost is exogenous and everyone prefers to receive adequate medical services.[4] We adjust the cost to 2020 prices using medical cost inflation net of

[3] The exact cost of critical illnesses is often difficult to access. The average individual inpatient cost is much larger than the median (Zhang et al., 2019), and the coefficient of variation for personal health expenditure is approximately 7 (Zhao, 2019).
[4] See Yogo (2016) and reference therein for life-cycle models with endogenous mortality and health investment.

the general consumer price index (CPI) from 2015 to 2020 in China.[5] The adjusted expected value of the cost is 216,000 CNY, representing a sufficient level of medical expenditure to access adequate medical services.[6]

To calibrate the standard deviation of the lognormal cost of critical illness, we rely on individual-level inpatient billings from hospital data. The data includes more than 20,000 hospitalisation cases as per Wu et al. (2018). It does not include individuals' ages or disease severity, but the total time for inpatient care is recorded. We include in the estimation sample only those individuals with an inpatient time of more than 25 days, which is about the average length of inpatient time for those aged over 60 (Yin et al., 2019). The calibrated lognormal distribution for the out-of-pocket cost of critical illness is:

$$CostCI \sim \text{Lognormal}\ (11.860,\ 0.920^2).$$

We further assume a maximum out-of-pocket cost of 800,000 CNY. This value is based on an approved reimbursement of 1,500,000 CNY from private medical insurance in 2019.[7]

C.2. Cost of long-term care

In this paper we consider the cost of informal care because family support is the main care model in China. We model the cost of long-term care as a lognormal function of age and

[5] Based on the Willis Towers Watson Global Medical Trends Survey Report 2016, 2017, 2020. The value in 2020 was a forecast. See https://www.willistowerswatson.com/en-US/Insights/2019/11/2020-global-medical-trends-survey-report.
[6] For example, the total medical expenditure for a COVID-19-infected patient with severe symptoms was, on average, approximately 400,000 CNY as reported by the government in 2020. We consider this amount as adequate. Assuming a 50% reimbursement rate, the out-of-pocket cost was around 200,000 CNY, which is close to our estimation.
[7] Due to a lack of data, we do not incorporate an auto-regressive process for the out-of-pocket cost of critical illness. Modelling this is likely to reduce the demand for critical illness insurance because of lower expected costs.

calibrate the cost based on data from the CHARLS Wave 3, collected in 2015[8]. We note that this cost represents the financial cost of informal care as paid public or private long-term care services are not yet available in most cities in China. CHARLS reports the hours of informal care each participant received and the cost of hiring a nurse for the participant. In 2020, the minimum hourly wage ranged from 12.5 CNY to 25.3 CNY at the provincial level.[9] We use an hourly wage of 20 CNY to estimate the cost of hours spent on informal care. This approximates the cost of paying a home health aide, and we add that to the cost of hiring a nurse to calculate the implied total monthly financial costs for long-term care. During the estimation, we excluded respondents that were long-term care dependent but reported zero cost (e.g., receiving no informal care or not hiring a nurse). We find that a linear model captures the association between the logarithm of the total monthly long-term care expenditure and the age of the survey participants reasonably well, and the residual plot shows no evidence of heteroscedasticity. The estimated monthly cost of long-term care has the following lognormal distribution with respect to age:

$$CostLTC\ (Age) \sim \text{Lognormal}\ (6.130 + 0.019 * Age,\ 1.460^2).$$

We also assume a maximum monthly long-term care cost of 8,000 CNY, which is about twice our model-predicted long-term care cost at age 60, and is much higher than the cost of (pilot) institutional care, which is about 5,000 CNY according to Lu et al. (2017). Finally, we multiply the monthly cost by twelve to derive the annual cost of (informal) long-term care.

[8] The 2018 wave of the CHARLS survey was not available at the time of the research.

[9] The data can be found at http://www.mohrss.gov.cn/SYrlzyhshbzb/laodongguanxi_/fwyd/202111/t20211119_428287.html.

Appendix D. Insurance product pricing

In our model, the life annuity, critical illness insurance, and long-term care insurance can be purchased by men and women at the age of 60 and 55 by making a one-off payment, respectively. We priced the three products in an actuarially fair way based on gender and age and then added a 15% loading for each product. We assumed a real discount rate of 1.5% for each year in the future due to a constant 3.5% nominal discount rate (the maximum discount rate allowed by the CBIRC) and a constant 2% inflation rate (approximately a ten-year average of the CPI during 2010–2019 in China).

We used the official mortality rates and disease incidence rates provided by the CBIRC to price life annuities and critical illness insurance products separately (CBIRC, 2016, 2013). For the life annuity, we used the mortality curves for the pension business for men (women) starting at age 60 (55). For the critical illness insurance, we used the incidence rate curves and the mortality curves for the health insurance business for 25 diseases for men (women) starting at age 60 (55). We note that insurance companies in China also use the mortality curves for the pension business for a more defensive price for potential adverse selection.

For long-term care insurance, there is no official health transition table in China's insurance market. Therefore, we estimated the health transition rates based on data from the CHARLS surveys in 2011, 2013, and 2015.[10] A two-year transition, that is, from 2011 to 2013 or from 2013 to 2015, was observable at each age for both genders by the longitudinal survey design. As the sample size is limited at certain age cells, we pooled the first (2011–2013) and the second (2013–2015) transition data together. After that, we estimated the two-year health transition at each age

[10] The insurance industry in China prices annuities and critical illness insurance separately based on regulated official tables. For LTC insurance, both the census data and longitudinal surveys like the CHARLS have been used to estimate the health transitions relevant for pricing. However, the definitions of LTC state are not consistent across providers.

for each gender. We only used data for respondents in the starting years (2011 or 2013) who were at least 35 years old. We conducted sensitivity tests using a subset with ages between 45–84 and using aggregated data with a 10-year age group starting from 35–45. The impact on product pricing was immaterial. We excluded observations with missing information for activities of daily living (ADL) status or death information.

We defined four health states: Healthy, Fair (1–2 ADLs), Disabled (3 or more ADLs, long-term care insurance payable), and Dead. Different from the health states used in the life-cycle model, the inclusion of a Fair state here was to control the result such that the estimation of the transition Healthy–Long-term care was close to the insurance population. We modelled the health transitions in a Markov framework. We used a multinomial logit model to estimate the relevant health transition probabilities. The dependent variable was each respondent's health state observed in the follow-up wave (2013 or 2015), and the explanatory variables were the respondent's age and health state in the initial wave (2011 or 2013).[11]

We predicted the two-year transition rates by gender from age 60 (men) or 55 (women) to age 104 based on the fitted multinomial logit model, and we closed the transition table at age 105. We calculated the one-year transition probability matrix at age *x* based on the Markov property with the following conversion formula:

$$\boldsymbol{P}_x^{2-\text{year}} = \boldsymbol{P}_x^{1-\text{year}} \times \boldsymbol{P}_{\boldsymbol{x}}^{1-\text{year}}, \tag{7}$$

where $\boldsymbol{P}_x^{1-\text{year}}$ is the probability of a 1-year transition at each state at age *x*.

The insured period was lifetime for all three products. However, for critical illness insurance, the contract ended with one insurance claim, and for long-term care insurance, the payments would

[11] We tested a probit model, which had been used to estimate the transition probabilities in a similar context in the US by Yogo (2016) and Koijen et al. (2016), and we also tested ordered logit, probit, and cloglog models. In the end, the multinomial logit model was selected according to the Akaike Information Criterion.

only be made when conditions with three or more ADLs were triggered, i.e., needing long-term care. For simplicity and a cleaner interpretation, we assumed that the curves and estimated transition rates used for pricing the three insurance products were unchanged in the future.

For bundled products, we used the calibrated health transition matrix (Appendix A, Table A.1) and set the post-illness mortality to be an average of the mortality table used for pension business and the mortality in the critically ill state to represent a pooled healthier population. We assumed the same 1.5% real discount rate and the 15% loading. 2,000,000 simulations were used to calculate the price for each insurance component.

Appendix E. Numerical solution

The original optimisation problem in our study (Equation 3 in Section 2.5) has four choice variables: consumption at each period c_t, allocations for a life annuity ω_a, critical illness insurance ω_c, and long-term care insurance ω_l. However, our problem has a nested structure. To use the engeneous gridpoints method (Carroll, 2006), we first solve the optimal consumption problem conditioning on exogenous insurance states, and then we conduct a grid search under budget constraints for the optimal insurance choice based on the already obtained policy functions in each exogenous insurance state. To see that, the Bellman equation in our optimisation problem is:

$$V_t(M_t, H_t) = \max_{c_t,\, \omega_{Annuity},\, \omega_{CII},\, \omega_{LTCI}} E_t\left(u(c_t, H_t) + \beta\left[\sum_{H_{t+1}=1}^{4} \pi_t(H_t, H_{t+1}) V_{t+1}(M_{t+1}, H_{t+1})\right]\right)$$

s.t.

$$A_t = M_t + P_t - CostCI_t - CostLTC_t + Annuity_t + CII_t + LTCI_t - c_t,$$

$$M_{t+1} = R \times A_t,$$

$$A_t > 0,$$

$$c_t \geq S,$$

$$\omega_{Annuity}, \omega_{CII}, \omega_{LTCI} \geq 0,$$

$$\omega_{Annuity} + \omega_{CII} + \omega_{LTCI} \leq 1.$$

The optimal solution to the above problem can be obtained by solving the sub-problems in each exogenous insurance state $(\omega_{Annuity}, \omega_{CII}, \omega_{LTCI})$ defined below and finding their maximum:

$$V_t^{\omega_{Annuity}, \omega_{CII}, \omega_{LTCI}}(M_t, H_t) = \max_{c_t,} E_t \left(u(c_t, H_t) + \beta \left[\sum_{H_{t+1}=1}^{4} \pi_t(H_t, H_{t+1}) V_t^{\omega_{Annuity}, \omega_{CII}, \omega_{LTCI}}(M_{t+1}, H_{t+1}) \right] \right)$$

s.t.

$$A_t = M_t + P_t - CostCI_t - CostLTC_t + Annuity_t + CII_t + LTCI_t - c_t,$$

$$M_{t+1} = R * A_t,$$

$$A_t > 0,$$

$$c_t \geq S.$$

The notation $V_t^{\omega_{Annuity}, \omega_{CII}, \omega_{LTCI}}$ represents the value function with exogenous insurance states. We use a three-dimension grid to discretise the insurance amount from 0 to 100% of the initial wealth. We use a minimum amount of 50,000 CNY for allocation in the case of 1 million CNY financial wealth, and 10,000 CNY in the case of 150,000 CNY financial wealth. Next, we solve the sub-problem for each of the exogenous insurance states to derive the optimal consumption. After that, we use 10,000 simulations to project future scenarios for a retiree based on the derived policy functions and calculate the realized lifetime utility of consumption for each simulation. The optimal insurance choice is the insurance state that yields the maximal average utility across all simulated scenarios and is within the budget constraint. This two-step approach essentially transforms the original problem with four control variables to a number of three-dimension grid sub-problems where the standard endogenous gridpoint method (Carrol, 2006) can be applied. We also use an adaptive grid to focus on the most dedicate part that needs fine-tuning and test the size of the grid. We finally deploy the algorithm on the computing clusters provided by UNSW Katana to speed up the simulations.

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