Research on Longevity Risk and Its Relevant Issues

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Abstract. China entered an aging society as early as 1999. With the constant improvement of death rate increasing average life expectancy and rapid decline of fertility rate, the aging problem is more and more serious, and the longevity risk in China's pension system is increasingly emerging. This inevitably brings new challenges for insurance companies, pension fund and government. Therefore,many scholars at home and abroad carry out diverse research on issues caused by longevity risk, mainly including mortality prediction model and longevity risk measurement. The paper analyzed the longevity risk from the aspect of its identification, measurement and management, and preliminarily explored the financial derivatives and the management strategies to defuse longevity risk in order to offer relevant experience reference for further studies.

Keywords: Mortality; Longevity Risk; Longevity Insurance; Longevity Bonds; Pensions; Securitisation;

1. Introduction

With the rapid development of economic society and continuous improvement of medical technology and people's health consciousness, the death rate has dropped significantly and the birth rate continued to fall, which leads to increasing aging population and the decline of fertility and death rate. What's worse, the adjustment and configuration of resources may generate a series of macroeconomic effect and inevitably bring aging problem including higher social security payments for the elderly, the decline of working-age population, shortage of labor supply, increasing labor costs and so on, which will affect the long-term development of China's economy.

Increasing life expectancy has become a common phenomenon around the world. According to the National Bureau of Statistics, the average life expectancy of Chinese people rose from 67.8 years in 1981 to 76.7 years in 2017, an increasing of 10 years in less than 40 years. Over the long term, human life expectancy has been steadily rising and the longevity risk brought by it cannot be ignored. Longevity risk makes a profound influence on insurance industry, pension system and social security system in all countries: longevity risk makes the balance of payments of pension security system unsustainable under the background of high fertility and low life, brings heavy financial burden for government, and makes the social security fund face a huge gap that will have a negative effect on the development and improvement of social security. Therefore, studies on longevity risk have been paid more and more attention at home and abroad. Blake and Burrows (2001) creatively proposed that survival bonds could be used to avoid longevity risk. Subsequently, in order to further measure longevity risk, many related researchers conducted studies from the prediction model of mortality and pricing method of longevity risk. At present, how to deal with and control longevity risk in the future, not only to solve the government's solvency dilemma, but also to promote economic growth, is also a problem that needs to be considered thoroughly. This paper reviews the existing studies on longevity risk and its related issues in order to provide references and suggestions for further research.

2. The Concept of Longevity Risk

Longevity risk means that the average actual life expectancy of the population in the future is higher than the expected life expectancy. It is caused by the uncertainty of the long-term trend of mortality. According to the existing foreign research literature, longevity risk is usually understood from individual and overall levels (MacMinn, Brockett and Blake, 2006; Stallard, 2006). Longevity risk at the individual level refers to the possibility that an individual's actual life expectancy in the future may be higher than that of currently expected, which leads to a gap in income and expenditure as a result of inadequate financial provision for retirement. Individual longevity risk can be dispersed, which can be managed through participating in endowment insurance plans and purchasing annuity products. Longevity risk at whole level usually refers to the fact that the actual future payment of an insurance plan, such as the pension annuity insurance plan of an insurance company, the social insurance plan of the government and the pension insurance plan of an enterprise, may be higher than the predicted payment based on the current estimate of the future average life expectancy. Such aggregated longevity risk cannot be dispersed according to the law of large numbers and shows systemic risk characteristics (Milevsky, Promislow and Young, 2006; Cairans, Blake and Dowd, 2006b). Mikaelson and Mulholland (2014) estimate the potential scale of the global longevity risk market for pension liabilities is between $60 trillion and $80 trillion. Pigott & Walker (2016) also estimates longevity risk in the private sector is around $30 trillion.

Many authors have proposed models to assess and hedge longevity risk and its impact on pension funds or life insurance. Antolin (2007) studied how longevity risk affects pension plans offered by employers in 2007. Researchers have developed hedging tools for longevity risk, such as the life swap proposed by Blake and Burrons (2001). Blake (2008) divided Longevity Risk into Aggregate Longevity Risk and Specific Longevity Risk. Meanwhile, The public sector can hedge and transfer aggregate longevity risk, while the private sector can hedge and transfer specific longevity risk. Fung and other people (2019) proposed a random mortality model with age-related drift and volatility, and they derived an analytical formula for the price of longevity derivatives. Hari and other people (2008) analyzed the importance of longevity risk to the solvency of pension annuity portfolios and distinguished two types of death risk: micro longevity risk which quantifies the risk associated with uncertainty about the time of death, while macro long-term longevity risk which is due to uncertain future survival probability.

3. The Measurement and Pricing of Longevity Risk

The measurement of longevity firstly cannot succeed without the prediction of mortality. Stallard (2006) pointed out that existing population data and mortality models have provided necessary conditions for the prediction of mortality, so that longevity risk can be quantified. Therefore, how to accurately estimate future mortality or survival rate is the key to longevity risk measurement and the basis of longevity risk management.

3.1 The Prediction of Mortality

Mortality models have a long history. Since Nepertz published his law of mortality in 1825, various mortality models have been proposed and introduced. Most mortality prediction methods are extrapolative, taking advantage of the common regularity in age patterns and trends over time. This method includes inference from traditional and relatively simple synthetic measurements, such as the Lee-Carter method. Lee and Carter (1992) first applied the stochastic discrete model to estimate life expectancy. This model is not only simple and easy to use, but also can obtain relatively accurate mortality and population prediction data. However, it is a single-factor model, which does not consider the birth year effect that may lead to inaccurate fitting of historical data. In addition, the original Lee-Carter model lacks smoothness in estimating the age effectβx. Therefore, many subsequent researches have improved the Lee-Carter model to solve these problems. Renshaw& Haberman firstly proposed the stochastic mortality model including the birth year effect (M3 model), and Currie proposed the age-period-cohort model (APC model) in 2006, avoiding the stability problems in M3 model parameter estimation (Cairns et al, Dowd et al). Cairns, Blake and Dowd (2006) proposed the cairns-blake-dowd model (CBD model) after considering both birth year effect and secondary age effect. Subsequently, Cairns et al (2007) expanded the CBD model after empirically analyzing eight random mortality models using population data from England, Wales and the United States.

In addition to this, some scholars also explored other mortality prediction models. Milevsky and Promislow first proposed to use random continuous model to estimate mortality rate. Then, Dahl and Moller (2006) proposed the single-factor mortality model. Cairns et al. (2009), Plat (2009), Debon Neuil (2010) also studied and extended the continuous random model. In addition, if a mortality prediction method (CMI) using penalty Splines (P-splines) is popular in the UK, and this model can obtain a high overall fitting degree, so that it has been proved to be effective. Hyndman and Ullah proposed a Functional Demographic Model in 2007, which predicted mortality rate by age based on functional data analysis and non-parametric smoothing and steady statistics.

3.2 Pricing Methods of Relevant Derivative Products

Due to the incomplete market and unreliable mortality data, longevity risk and related derivatives can not be priced by using non-arbitrage analysis method that we usually use. According to existing literature, following pricing methods are mainly used for longevity risk:

3.2.1 Wang Transformation

In 1991, Venter proposed the method of Distortion of Distribution, that is, risk is priced by the losing distortion of distribution. In 2000 and 2002, Wang applied the distortion of distribution method to the pricing of financial and insurance risk respectively, and proposed a new transformation method, where normal distribution and T-distribution are used to replace the above transformation function, namely single-factor and two-factor Wang transformation. Compared with CAPM model and Black-Scholes share option pricing formula, it is concluded that Wang transformation can copy CAPM model and Black-Scholes share option pricing formula. Lin and Cox (2005) first used Wang transformation to price survival bonds and obtained the market price of longevity risk. Cox, Lin and Wang (2006) studied the pricing of survival bonds and death risks issued by Swiss insurance company and showed that this method could be applied to the pricing of mortality index derivative securities. Dowd et al. (2006), Denuit, Devolder and Goderniaux (2007), and Lin and Cox (2008) made further studies.

3.2.2 The approach of Risk-Neutral

According to the theory of financial economics, in an incomplete securities market, assuming that there is no arbitrage opportunity, there is at least one risk measure that can be used to determine the fair price of securities, which is called risk-neutral measure Q, and it corresponds to the actual probability measure P. Milevskyand Promislow (2001), Dahl and Moller (2005), Biffis (2005) et al applied the risk-neutral method to study the pricing of mortality index derivative securities. Deng et al [45] used the risk-neutral assessment method to price q forward contracts and believed that as long as an appropriate risk-neutral measure was selected, parameters such as mortality model jump and risk market price could be obtained, so that q forward contracts could be priced. In 2015, Yang et al considered parameter error, process error and model error from an overall perspective through modified semi-parametric re-sampling method, and found that model selection has an important impact on risk-neutral assessment.

3.2.3 Instantaneous Sharpe Ratio

This method was firstly proposed by Milevsky, Promislow and Young (2005), assuming that the party holding non-dispersible longevity risk needs to get risk premium return, then the party has multiple (instantaneous Sharpe ratio) standard deviation combinations, the risks of small samples have been dispersed, and the standard deviation is derived from an assumed mortality changing process. Additional studies include Young (2008) and Bayraktar et al (2009). The Sharpe ratio (SR) is the most important parameter in this method and represents the risk premium required to assume an asset. In contrast to the Wang transformation, the Sharpe ratio is a pre-set exogenous parameter, while the risk market price is an endogenous variable derived by calculating the market annuity price.

3.2.4 Other methods

Chen et al studied the stability of the above three kinds of longevity risk pricing method in 2010, and compared the relationship and difference of the three methods through the theoretical analysis and mathematical reasoning. It shows that that the smaller the sensitivity absolute value is, the steadier the method is. Risk-neutral evaluation and sharp rate method are beneficial to the operation of short-term bonds, and Wang transformation method is more suitable for long-term bonds. After comparative analysis of Wang transformation and risk-neutral assessment method, Li proposed to use maximum entropy method as an alternative method to price mortality linked securities, and believed that the advantage of this method is that it doesn't require any subjective judgment of users.

In addition, many scholars are studying other pricing methods. Liao et al used Credit Tranche Techniques to price long-lived bonds in 2007. In 2011, in order to avoid parametric risk and model risk, Li and NG used the basically non-parameter "Canonical Valuation" method to price the mortality index derivative securities. Kim and Choi used the "Percentile Trenching" method in 2011. Based on the Lee-Carter model, Tian Meng and Deng Yinglu (2013) measured the longevity risk of the Chinese population using the double exponential jump diffusion model (DEJD model), and obtained q forward pricing in China.

4. Financial products design based on Longevity risk

Besides the traditional risk retention, reinsurance and annuity methods to disperse the risk, longevity risk can also be securitized and transferred to the capital market. Longevity risk securitization refers to the construction and issuance of financial products and derivatives connected with longevity risk through the capital market, and the product income is linked with mortality or survival rate. The risk of both sides achieves the segmentation and standardized of risk by means of securitization, and the longevity risk is transferred to the capital market. Compared with traditional longevity risk, longevity risk securitization does not only provide additional market capacity, sufficient liquidity and transparency, but also bring price discovery and information asymmetry decline. The more participants there are in the capital market, the more risk will be spread and it is easier to manage risk. The existing securities related to longevity risk generally include longevity bond, longevity swap, longevity option, longevity futures, Q forward and so on.

4.1 Longevity bonds (LBs)

Longevity bonds (LBs) are bonds that coupons or principal are linked to the survival probability of a specified group of people. The longevity risk of pension funds or annuity insurance companies is transferred to investors in the capital market, so as to achieve the purpose of dispersing the risk. Blake and Burrows(2001) first proposed issuable Longevity Bond hedging Longevity risk. Then, Lin and Cox(2005),Blake et al.(2006),Bauer et al. (2010),Blake et al. (2013) on this basis developed theoretical research of Longevity bonds design mechanism and price. According to different patterns of pay, Longevity bonds are divided into Continuous bond and Trigger bond.

In November 2004, the European Investment Bank (EIB) issued an EIB longevity bond with an amount of 540 million pound, which was the first continuous longevity bond. However, because this longevity risk didn't attract enough investors, it eventually failed to issue in the market. Blake et al. (2006) and Biffis and Blake (2009) discussed in depth the issuance arrangement and the reasons for the failure, and summarized that EIB longevity bonds cannot fully hedge the longevity risk faced by pension funds for a long time, cannot cover the longevity risk of different ages and genders, and the high threshold of bond investment can't attract enough investors to buy.

4.2 Longevity swaps

Longevity swaps are financial derivatives based on the future survival index of specific target groups. The original theoretical exploration of longevity risk swap contract began with Lin and Cox

(2005).Then Dowd and others proposed vanilla survivor swaps in (2006). If one party trades fixed cash flows for floating cash flows of the other, it is commonly known as a longevity swap.

Compared with Longevity bonds, Longevity swap has the advantages of low issuance cost, high clause flexibility and easy hedging. Therefore, its prospect of market development is better than that of longevity bonds. The world's first capital market-based longevity swap took place in July 2008. It was conducted by J.P. Morgan and Canada life in the UK (transaction risk, 2008). Longevity risk was transferred from Canada life to J.P. Morgan and then directly transferred to investors. This transaction brought investors in the capital market into the longevity market for the first time. Barrieu and Albertini (2009) elaborated longevity risk and J. P. Morgan's longevity risk transaction.

4.3 Longevity futures, options

Longevity future is a standardized contract of the object closely related to mortality. According to the different objects, it can be divided into annuity futures, longevity bond futures and survival index futures. Among them, the futures market of longevity bonds shows high price transparency, strong volatility, and strong demand for hedging and speculation.

The same or similar underlying assets as longevity options can be chosen as longevity futures. Annuity insurance companies obtain the right to buy and sell basic assets at a certain price in the future by paying option fees. There is a non-linear relationship between option return and the price or index change of underlying assets, which can effectively manage the adverse impact in changes of contract underlying assets after the purchase of options. Futures are usually standardized contracts, and the contract form of options is flexible. Blake, Cairns and Dowd(2006) preliminarily studied the longevity futures and options.

4.4 Q- forward

Q forward is a simple capital market tool used by pension funds and insurance companies to hedge longevity risk and death risk. It is a forward agreement based on the life metrics mortality index compiled and released by J. P. Morgan. Both parties agree to exchange the contract for calculating cash flow based on the actual (floating) mortality and agreed (fixed) mortality of a specific population at a certain point in the future, and replace the uncertain future real mortality with the determined current expected mortality. Annuity insurance company and J.P. Morgan are the payers of actual floating mortality and expected fixed mortality respectively. The expected fixed mortality rate can be calculated according to the mortality time series model when the Q forward contract is signed, and the actual floating mortality rate is determined by actual life metrics mortality index when the contract expires. At maturity, only one party pays the net cash amount according to the relative level of expected fixed mortality and actual floating mortality. If longevity risk occurs, the actual mortality on the maturity date of the Q forward contract is lower than the fixed mortality, and the annuity insurance company obtains net cash inflow, so it can make up its operating loss caused by paying too much annuity (Coughlan et al., 2007). Q forward contract has good flexibility. Annuity insurance companies can dynamically adjust the degree and direction of hedging transactions according to new information, so it can also be used as an important basic component of other longevity risk financial derivatives, which helps to improve the liquidity of longevity risk market (Biffis and Blake, 2009; Deng et al., 2012).

5. Macroeconomic effects of longevity risk and policy suggestions

5.1 Macroeconomic effects of longevity risk

Macroeconomic impacts caused by longevity are major practical problems in current economic development. While benefited from a long life, individuals and society also need to seriously consider how to reasonably adjust and allocate the economic resources caused by longevity, which will produce a series of macroeconomic effects.

First of all, the extension of life cycle makes people face a longer period of old age, and there may be a risk of insufficient pension resources. However, rational actors have the ability to coordinate life cycle resources. They will fully consider the impact of the extension of life expectancy, and adjust their life cycle behaviors such as consumption, savings and retirement accordingly. This will affect the accumulation of material capital, labor supply and employment, thus affecting macroeconomic growth. Secondly, the extension of life expectancy also means that individuals can prolong their years of education, so as to enjoy the high returns of human capital investment in the future, but at the same time, they also have to pay more investment costs, which will change the educational investment behavior of families and individuals, thus affecting the accumulation of human capital. Thirdly, the impact of longevity risk will also make the payment balance of the old-age security system established under the background of high fertility and low life difficult to sustain, which will bring a heavy financial burden on the government. The social security fund may face a huge gap, which will have an adverse impact on the development and improvement of social security.

Life extension will also have an important impact on pension revenue, expenditure and the safe operation of the pension security system. According to various existing estimates, under the impact of longevity risk, the gap between pension revenue and expenditure will continue to expand. Sin (2005) believes that China's social security pooling account has been unable to make ends meet, and there will be a deficit in the social security individual account from 2032 to 2050. The dual payment pressure of individual account and pooling account exist in the pension system. The reform of pension security system to deal with longevity risk has also attracted much attention. At present, a large number of studies mainly focus on the economic effect or economic efficiency of pay as you go system and fund accumulation system. Samuelson (1958), diamond (1965), Aaron (1966) and others believed that the introduction of pay as you go pension insurance system can improve the level of social welfare. Feldstein (1985), Alba & Kotlikov (1987), Kotlikoff (1996), Lassila & Valkonen (2001) and other scholars analyzed the macroeconomic effects and welfare level of the fund accumulation system, argued that the fund accumulation system could solve the shortage of the pay as you go system, and suggested reforming the old-age insurance system. Some scholars also suggested that China is more suitable for the partial fund accumulation system - "combination of unified accounts". For example, Liu Zunyi (2003) proposed that China should design an old-age security system combining social basic pension and individual account accumulation; Williamson & Deitelaum (2005) believed that China's "unified account combined" pension insurance is a correct direction of reform, but it will be restricted by regional segmentation, income gap and system. Considering the reform of old-age insurance in dealing with the risk of longevity, although the existing literature has conducted various and multi angle research on China's old-age insurance system, the opinions of scholars are still controversial. The reform of the old-age security system should absorb the advantages of the old-age insurance system with accumulation function and the old-age security system with redistribution function at the same time, which can not only solve the government's payment dilemma, but also promote economic growth and take into account social equity, which is the focus of researchers and the basis of system design. The reform of China's old-age security system should also follow these basic principles.

5.2 Policy suggestions to deal with longevity risk

At present, the academic community has made some achievements in the understanding, estimation and management of longevity risk, but at the same time, we should see that there are many deficiencies in the research of longevity risk. For example, although various and multi-angle research has been conducted on China's old-age insurance system, the opinion of scholars are still controversial. In view of the relatively rough statistical data of population death in China, it is urgent to improve the existing mortality modeling methods to obtain accurate prediction data. In addition, the research on longevity risk securitization is still in the stage of introducing overseas theoretical development trends and practical experience, and there is a lack of in-depth research on China's securitization.

Longevity bonds have failed to be issued many times, and the advantage of transferring longevity risk through capital market management tools is not apparent.

In the face of the increasingly serious risk of longevity, all parties need to improve their understanding. First, relevant government agencies need to strengthen the financial knowledge to educate people, gradually recognize the existence of longevity risk, study the longevity risk existed in various risk subjects as soon as possible and formulate countermeasures. In addition, the government should provide financial and legal support for insurance companies to build longevity risk asset securitization products and develop longevity risk capital market. Second, the banking and insurance regulatory authorities should pay attention to the significant impact of longevity risk on the solvency of the overall insurance industry, clarify the products and departments that is involved in longevity risk in the insurance industry, measure the corresponding risk degree, and formulate reasonable longevity risk solvency capital indicators. At the same time, regulatory authorities also need to formulate a long-term mechanism for longevity risk supervision, improve the supervision system, speed up the revision of actuarial methods, and reduce the risk losses caused by unreasonable actuarial methods. Third, insurance companies need to actively develop corresponding products to create market demand and attract investors. The insurance industry and government pension institutions need to strengthen cooperation, including longevity risk identification, data sharing, mortality prediction and risk management. Only with the joint cooperation of all stakeholders can the increasingly serious longevity risk be alleviated and solved. Fourth, for individuals, Chinese people need to study more financial management knowledge, understand the longevity risk, allocate their personal assets reasonably, and manage their longevity risk by purchasing financial derivatives of longevity risk.

To make a long story short, How to effectively manage this new and increasingly serious social risk still has a long way to go. Although China's longevity risk management faces problems such as insufficient understanding of longevity risk, lack of data, difficulty in estimation of mortality, fuzzy insurance supervision and single risk management mode, if all parties related, including the government, insurance companies, individuals and other relevant departments work together to solve the existing problems, the increasingly serious longevity risk is expected to be effectively managed.

References

[1] Longevity/Mortality Risk Modeling and Securities Pricing [J]. Yinglu Deng, Patrick L. Brockett, Richard D. MacMinn. Journal of Risk and Insurance. 2012 (3)

[2] Tsai C C L, Zhang Y. A Multi-dimensional Bühlmann Credibility Approach to Modeling Multi-population Mortality Rates[J]. Scandinavian Actuarial Journal,2019,2019(5): 406 − 431.

[3] Chen, L., Cairns, A.J.G. & Kleinow, T. (2017). Small population bias and sampling effects in stochastic mortality modelling. European Actuarial Journal, 7, 193–230.

[4] STALLARD E. Demographic Issues in Longevity Risk Analysis, the Journal of Risk and Insurance, 2006, 73(4): 575-609.

[5] Ming Zhao, Haijie Mi, Xiaojun Wang. Change trend of China's population mortality and research of Longevity risk measurement[J]. population sciences in China.2019(3): 67-79

[6] CHEN B Z. Longevity risk is not the same as population aging [N]. Bank of China Insurance News, 2019-11-28 (002). (in Chinese)

[7] DUAN B G, LU J W. Effect of longevity risk on the pricing of insurance company annuity products - empirical analysis based on block bootstrap methodology [J]. Journal of Shanxi University of Finance and Economics, 2015,

[8] Sithole, T., Haberman, S., Verrall, R. J. An investigation into parametric models for mortality projections, with applications to immediate annuitants’ and life office pensioners’ data [J]. Insurance: Mathematics ＆ Economics,2000, (3): 285 − 312.

[9] Blake, D. and Harrison, D. And Death Shall Have No Dominion: Life Settlements and the Ethics of Profiting from Mortality, Pensions Institute Report [EB/OL]. Available at pensions - institute.org /DeathShallHaveNoDominion _ Final _3July08. pdf. July,2008 /2015 - 12 - 18.

[10] Lin, Y, T. shi, and A. Arik, Pricing Buy-ins and Buy –outs[J]. Available at SSRN, 2016.

[11] Deng, Y., Brockett, P., and MacMinn, R. Longevity /Mortality R isk Modeling and Securities Pricing [J]. Journal of Risk and Insurance,2012, (79): 697 - 721.

[12] Blake, D., Cairns, A., Coughlan, G., Dowd, K. and MacMinn, R. The New Life Market[J]. Journal of Risk and Insurance. 2013,80(3): 501 - 558.