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Trends in the Chinese Annuity Market and the Management of Longevity Risk

December 2018

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EXECUTIVE SUMMARY

With great transformation of China's society and economy, China's pension system has transformed from traditional retirement system based on command economy to modern pension system based on market economy, which basically guarantees the living standards of retirees. At present, China's pension system consists of three tires, the government-sponsored basic pension insurance, employer-sponsored occupational pensions, and commercial life annuity provided by the insurance market. With economic growth slowing down and population ageing, pension benefit from social insurance has showed a decreasing trend. At the same time, the occupational pension plans and commercial annuity are both underdeveloped in China. By the end of 2017, the occupational pension fund accounts for 1.56% of China's GDP. The number of participating employees increased to 23.315 million, accounting for only 5% of the urban employed population. In addition, there are fewer life annuity products in the commercial insurance market, and most of the annuity products are subject to time or age restrictions, such as annuity products with a 20-year period or an annuity product under the age of 80. On the other hand, Chinese households have a high level of savings, but most families are reluctant to annuitize their assets to guarantee their income after retirement. Therefore, how to develop the annuity market and how to manage the longevity risk has become an urgent problem that China needs to solve.

This report mainly studies the development of China's commercial annuity market and its long-term risk management issues in the context of population aging, slowing economic growth, and lower interest rates. First, we study the current situation of China's pension system and evaluate its adequacy and sustainability. And then analyze the demand for commercial annuity under the multi-tier pension system. Secondly, combining the international experience of the annuity market with the development of the Chinese annuity market, the future development trend of the China's Commercial Annuity market will be analyzed. On this basis, this report analyzes the annuity puzzle problems existing under the voluntary annuity selection, and explores the reasons for the weak supply and demand of commercial annuities, combing the factors affecting the supply and demand of annuity. Thirdly, based on the basic experience of the insurance company's longevity risk measurement and management, a mortality prediction model for Chinese mortality data is constructed to measure longevity risk. At last,

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some suggestions are given to promote the development of commercial annuity market and the risk management of longevity.

There are 6 parts in this study. Part 1 presents the research background of the report, including China's aging population, economic environment and policy environment. Part 2 introduces China's pension insurance system, and analyzes the adequacy and sustainability of basic pension insurance, DC occupational pension plan allocation issues and personal annuity market issues. Part 3 draws on the international experience of the commercial annuity development market, and combines the development history and current situation of the Chinese annuity market to analyze the possible future development trend of China's annuity market. Part 4 focuses on the factors affecting the supply and demand of annuities. It mainly analyzes the influencing factors that hinder the development of the annuity market from the perspective of demand and analyzes the inherent risks of annuity products from the perspective of supply, and emphasizes that special attention should be paid to longevity risks. Part 5 summarizes the longevity risk prediction model and the longevity risk management method from the perspective of risk management. Part 6 is conclusions and recommendations.

Main conclusion

1. In the context of population aging, slowing economic growth, and lower interest rates, the basic pension insurance faces challenges in terms of adequacy and sustainability. However, these challenges have provided sufficient development space for the development of China's Commercial Annuity market, and also set forth the inevitable requirements and urgent needs for its development.

2. From the point of development and current annuity market, annuity products including longevity risk have developed slowly for a long time while new types of insurance such as universal and participating annuity are developing rapidly and occupying the main annuity market. From the perspective of development trend, it is gradually clear that annuity products return to the long term and longevity risk security trend.

3. Both supply and demand for commercial annuity market is insufficient. From the perspective of annuity supply, the development of commercial annuity market is plagued by longevity risk, investment risk, credit risk, liquidity risk, business risk and so on. Among them, the longevity risk restricts insurers to develop the pension business to a great extent. From the perspective of annuity demand, the development of commercial annuity market is plagued by bequest motives, adverse selection, the crowding-out effect of government pensions, lack of understanding, tax-favored competing assets and so on. In the quantitative analysis of annuity supply and demand, Scholars have shown that the design of annuity products, the performance of financial markets and the characteristics of individuals (like personal education level, wealth at hand, health status and so on) have a greater impact on a person's willingness to buy an annuity.

4. Mortality prediction is the core issue of longevity risk measurement and management, and has an important impact on the government pension system, employer occupational pension and commercial life annuity. In the longevity risk measurement, a Bayesian hierarchical mortality model is

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recommended. Judging from the forecast results, the mortality rate in China is obviously declining, and the risk of longevity in the future is still outstanding.

In summary, under the current circumstances, the development of commercial annuity market is imminent option. This report gives recommendations for promoting the development of China's commercial annuity market and longevity risk management.

Main recommendations

1. The insurance supervision department can strengthen supervision and policy guidance to further promote the development of long-term guaranteed annuity products in the commercial annuity market, and make sure the annuity products return to its essence. With the trial of individual tax-deferred pension and the business model of starting from pension services for insurance company, it's expected to form a new pension industry to promote its industrial upgrading.

2. The government continues to vigorously develop the economy and increase the disposable income of residents. From the quantitative analysis of the supply and demand of commercial annuities, the personal wealth of residents has a greater impact on the demand for commercial annuities, therefore, continuing to vigorously develop the economy is also a major driving force for the development of the annuity market.

3. Governments and insurance companies can increase the publicity of commercial annuities to give people a correct understanding of annuity products. Therefore, relevant departments can increase publicity on commercial annuities and their products. Communication channels include television, internet, newspapers, community lectures, campus lectures, etc.

4. The government can reduce the proportion of basic pension insurance contributions, decrease the crowding-out effect of basic pension insurance. At the same time, reducing the proportion of basic pension insurance contributions also cuts down its payment pressure, and improves the sufficiency and financial sustainability.

5. Drawing on international experience, we will gradually implement longevity risk securitization in China and transfer longevity risks through reinsurance. How to deal with the longevity risk is the key to promoting the development of China's annuity market. Applying international experience and combining the development of China's capital market, longevity risk can be attempted through risk securitization, reinsurance, design related annuity products such as longevity risk dividend annuity. In the process of longevity risk management, on the one hand, the regulatory body can improve the supervision system; on the other hand, the insurance institution can increase the actuarial talents and commercial pension insurance development professionals; finally, the government can give relevant tax support, and Actively publicize and guide the people to correctly understand commercial endowment insurance.

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1 INTRODUCTION

Under the trend of population ageing and economic slowdown, China's pension systems face the challenge of unsustainable development. How to actively adjust the pension system structure, and how to give full play to the role of the market to vigorously develop commercial annuity market, are the major issues that need to be resolved urgently in the current and future China's old-age security system. For commercial annuity, analysis the factors affecting its supply and demand, comprehensively analyzes the longevity risk measurement and management methods faced by insurance companies, summarizes the development status and problems of domestic and international commercial annuities, etc., are very important research topics.

The contents of this report include: the current demographic, economic and policy environment for the development of commercial annuity in China; the development status and challenges of China's pension systems; the international experience of the commercial annuity market and the current status and trends of China's commercial annuity development; factors affecting the supply and demand of annuities and the annuity supply and demand dilemma; longevity risk measurement and management experience; suggestions for the development of China's commercial annuity market.

This section briefly reviews China's population aging trends, the economic environment and policy environment for the development of commercial annuities.

1.1 Population Ageing

With the development of social economy, China’s population fertility is reduced, the life expectancy is prolonged and the trend of population ageing is inevitable. According to international standards, any country or region with the proportion of the population over 65-years-old exceeding 7 %, or more than 10 % of the total population aged 60 or over, belongs to the ageing countries or regions. Table 1 shows China’s age structure and the dependency ratio for elder persons over 65-years-old. Obviously, the proportion of the population aged over 65 has gradually increased since 1964. In 2001, the proportion of the population over 65-years-old exceeded 7%. By 2017, the number of the elderly population reached 158 million, took up 11.40 % of the total population. Meanwhile, the dependency ratio increased from 7.44 % in 1953 to 15.88 % in 2017. As the absolute number and relative proportion of the elderly population increase, there is a higher demand for elderly services, medical treatment and health-care services.

Table 1 Age structure in China unit: %

Year	Aged 0-14	Aged 15-64	Aged 65+	Dependency Ratio
1953	36.28	59.31	4.41	7.44

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1964	40.69	55.75	3.56	6.39
1982	33.59	61.50	4.91	7.98
1990	27.69	66.74	5.57	8.35
2000	22.89	70.15	6.96	9.92
2001	22.50	70.40	7.10	10.09
2010	16.60	74.53	8.87	11.90
2011	16.45	74.43	9.12	12.25
2012	16.46	74.15	9.39	12.66
2013	16.41	73.92	9.67	13.08
2014	16.49	73.45	10.06	13.70
2015	16.52	73.01	10.47	14.34
2016	16.64	72.51	10.85	14.96
2017	16.79	71.81	11.40	15.88

Source: China Statistical Yearbook-2017 & The Statistics Communique on National Economy and Social Development of China 2017

In order to alleviate the pressure of population ageing, the Third Plenary Session of the 18th Central Committee of the Communist Party of China proposed: adhere to the basic national family planning policy, improve the population strategy, fully implement the policy of a couple to have two children, and actively respond to aging phenomenon and promote sustainable population development.

In December 2015, the Standing Committee of the National People's Congress adopted the population and Family Planning Act, which explicitly shows the state encourages a couple to have two children. The relaxation of the birth-control policy helps to raise the fertility rate and contributes to relieve population ageing pressure. At the same time, the development of social economy increases the cost of raising children, reduces people's will to procreate and finally limits the fertility. According to the 2017 United Nations' projections[1], the proportion of the elderly population over the age of 65 will increase steady in the coming decades, reaching 17.1% by 2030 and 30.5% by 2060. The aged dependency ratio (ratio of the population ages 65+ and the population ages 15-64) rises from 25.3% in 2030 to 54.8% in 2060. What's more, the dependency ratio between people ages 65 or more and people ages 20-64, will reach 27.7% by 2030 and 60.2% by 2060. As a result, China faces more severe challenge with ageing population in the coming decades, and the pace of population ageing will accelerate.

1.2 Economic Environment

[1] https://esa.un.org/unpd/wpp/DataQuery/

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During the past 40 years, China's economy has grown rapidly. China's gross domestic product grew from 458.7 billion yuan in 1980 to 82 trillion yuan in 2017, and its GDP per capita increased from 465 yuan in 1980 to 59,000 yuan in 2017. In the meantime, people have enjoyed the rapid accumulation of national wealth. In 2017, the disposable income per capita was 26,000 yuan (36,000 yuan in the urban area and 13,000 yuan in the countryside), and the consumption per capita was 18,000 yuan (24,000 yuan in urban area and 11,000 yuan in countryside). Figure 1 shows China's GDP per capita between 2002 and 2016 and the household savings rate from 2002 to 2015. The household savings rate is calculated based on the method given by the People's Bank of China[2], the household savings rate equal to total savings in the household sector / disposable income in the household sector. It's clear to see GDP per capita and household savings rate kept rising. From 2011 to 2015, the household savings rate has declined, but it still remained at a high level. In addition, the Engel coefficient of China's residents dropped down significantly. In 2017 the Engel coefficient was 29.3%. The decline of the Engel's Coefficient and the high household savings rate in China mean that the consumption structure is rapidly upgrading to the developmental and service-oriented one, the concept of health and safe has been deepened, which will lead to the continuous innovation and the development of financial insurance products.

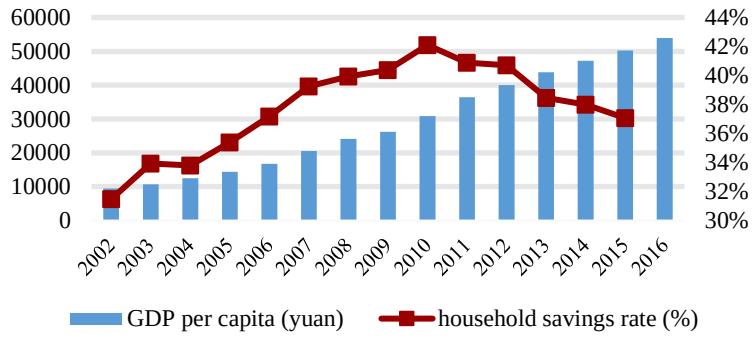

Figure 1 GDP per capita and household savings rate from 2002 to 2016

Source: China Statistical Yearbook (2002-2017)

1.3 Policy Environment

In 2014, the State Council issued Several Opinions on Accelerating the Development of Modern Insurance Service, emphasizing that commercial insurance should play an important role in the social security system. In July 2017, the China State Council executive meeting adopted Several Opinions on the Development of Commercial Annuity, which encourages eligible insurers to join the individual tax deferred Commercial Annuity pilot scheme. On 12th April 2018, the Notice on the Pilot Project of Personal Tax Deferred Commercial Annuity Insurance was officially issued, and has taken effect since 1st May 2018 in Shanghai, Fujian (including Xiamen) and Suzhou Industrial Park. In the pilot area, if an individual purchases eligible commercial annuity through his Commercial Annuity fund account, he will

[2] http://zhengzhou.pbc.gov.cn/zhengzhou/124247/2742548/index.html

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enjoy a pre-tax defer to some extent according to his/her tax-defer eligibility. Personal income tax will not be levied on the investment gains in his Annuity account, but will be levied on the benefits. Later, a group of insurance companies introduced tax deferred annuity products. Therefore, the implementation of the personal tax deferred annuity will promote the development of commercial insurance.

1.4 Scope and Structure of the Report

The subject of this study is the commercial annuity market and the longevity risk management issues it faces. On the basis of the study for the status quo of China's pension system and the adequacy and sustainability of the public pension system, we analyze the commercial annuity demand under the multi-tiers pension systems; On the basis of the study for international annuity market experience and current situation in China, we analyze the development trend of China's annuity market; On the basis of the study on annuity supply and demand affecting factors, we analyze the reasons for the weak supply and demand of commercial annuity; On the basis of study on the longevity risk measurement model and management experience, we build the mortality model for Chinese population; Finally, on the basis of summarizing the full text, we give relevant advice on the development of China's annuity market and longevity risk management.

This report has six chapters. The first one is the introduction, which points out the background, the purpose and the main content of this study. The second part analyzes the pension systems and annuity demand of China. In the third section, we summarize the development trend of the annuity market at home and abroad. The fourth section analyses the factors affecting the annuity insurance supply, and points out that the risk of longevity is the main risk to annuity insurance. The following section summarizes the study over longevity risk and deals with the model selection, risk measurement and risk management for China’s data. The sixth section gives the conclusion and makes some suggestions on the development of annuity market. In addition, Annex 1 sorts out the status of China's annuity market products, and Annex 2 combs the theoretical studies on mortality models and longevity risk management.

2 PENSION SYSTEMS IN CHINA AND ANNUITY DEMAND

2.1 Pension Systems in China

The current pension systems in China include the basic pension insurance sponsored by the government, the occupational pension sponsored by the employer and the commercial annuity provided by the market. Among them, the basic pension is divided into three types according to the types of people covered: the social pension for urban workers, the social pension for civil servant and other public employee and the social pension for urban and rural residents.

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2.1.1 Basic Pension Plans

2.1.1.1 Social Pension for Urban Workers

The country's basic pension scheme is sponsored, managed and provided by the government. The goal is to provide basic pensions for all workers and residents after retirement. The basic old-age insurance was established after the founding of New China in 1950. In the 1980s, with the reform of the economic, pension system reforms were implemented. In 1991, multi-tier pension structure for urban workers was specified, which includes basic pension scheme, enterprise supplementary pension scheme, and personal savings plan. In 1993, the basic pension system for urban workers was established for the integration of social pooling and individual accounts. In 2000, Pilot projects to implement funded individual accounts have been carried out in three provinces in Northeast China. In December 2005, the State Council issued the decision on improving the basic pension system for enterprise workers on the basis of pilot experience. The coverage of the basic pension system for urban worker has been extended to all types of workers in cities and towns, including atypical employment. It is stipulated that the individual account shall be fully funded, and the pension benefit consists of two parts: basic pension benefit and individual account benefit. In practice, with the transfer cost, rising levels of benefit and the covered population aging, individual accounts remain empty. After that, the nominal individual account became the model for the operation of the individual account. At present, the basic pension plan for urban workers adopts the pay-as-you-go financing model. The employer pays 20% of the total salary, and the employees pay 8% of their salary between up and floor. For self-employee, the contribution base is 20% of the average salary in last year, of which 8% is credited to the personal account. The minimum contribution year is 15 years. The social basic pension benefit is linked to the number of years of contributions, contribution salaries and social average salaries, and the individual account pension is determined by the balance of the personal account at the time of retirement and the prescribed annuity factor. The statutory floor and up limit of contributions is 60%-300% of the average salary.

2.1.1.2 Social Pension for public employee

For public employee, the retirement system established in the 1950s lasted until 2015. Pension benefit are based on pre-retirement salaries and financed by fiscal fund. According to the regulations of the Ministry of Finance and the former Ministry of Personnel in 2006, the retirement benefit shall be calculated on the basis of service years and final salary before retirement. For those who have 35 years of service, the retirement benefit is 90% of final salary. For those whose service years are between 30 and 34, they will receive 85% of final salary for the pension. And for those whose working life shall be 20 to 29 years, the proportion is 80%. The pension is adjusted according to the wage growth rate of the employees at the same level. In March 2008, the State Council approved in principle the "Pilot Program for the Reform of the Pension Insurance System for Public Employees in Public Institutions", which adopted a pension insurance scheme similar to that for enterprise employees. In 2015, the "Decision of the State Council on the Reform of Pension System for Staff and Institutions ([2015] No. 2)" unified the

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basic pension system of public institutions in the framework of basic pension for urban employees. At present, the basic pension of government agencies and institutions has adopted the same institutional model as the basic pension for urban employees, but the basic pension fund of government agencies and institutions has operated independently and has not been coordinated with the basic pension fund for urban employees.

2.1.1.3 Social pension for Urban and Rural Residents

The pension systems for famers have been slowly in practice since the 1980s, and farmers rely on family, collectives, land security and social assistance to support their retirement. In September 2009, the State Council issued the guide on the implementation of New Rural Social Pension Pilot (No. 32[2009]) and decided to launch a pilot project on a new type of rural social pension (new rural pension for short) starting in 2009. The new rural basic pension system adopt the personal account to record contribution and interest income and plan to cover all rural residents of the right ages by 2020. In 2010, the Social Insurance Law was published, proposing that the state establish and improve the social pension system for urban residents. The residential basic pension pilot was officially launched on 1 July 2011, and in 2014 the State Council issued a document on the establishment of a unified system of basic pension system for urban and rural residents (No. 8[2014]). Among these, the basic pension is subsidized by the government, and the personal account is paid by the individual. By the end of 2017, 918 million people were covered by the national basic pension system, which basically achieved the full coverage of the basic pension system.

2.1.2 Occupational Pension Plans

2.1.2.1 Enterprise Pension Plan for worker

Enterprise pension plan is sponsored by employer and has tax advantages for contribution and investment return. It is a defined contribution plan. Employer and employee contributions are credited to the personal accounts and are managed in a market-based fiduciary fund. When the employee retires, he may choose to have the benefit by lump-sum, by annuity, or by stage withdraw

In 2000, the State Council's pilot program on improving the social security system in cities and towns (No. 42[2000]) formally renamed the Enterprise Supplementary Pension as "enterprise pension plan". After 2004, the former Ministry of Labor security and the Banking Regulatory Commission, the Securities Regulatory Commission and the CIRC have issued a series of documents for the administration of enterprise pension plans, and have clarified the DC-type trust management model for the enterprise pension plans. In June 2009, in the announcement of the Ministry of Finance and the State Administration of Taxation, contribution rate within 5% of the total salary of employees is tax deferrable. The "measures for the administration of the Enterprise Pension Fund" of February 2011(Ministry of Human Resources and Social Security of the People's Republic of China Order No. 11) further regulates the operation of an enterprise pension fund. The Enterprise Pension Scheme (Ministry of Human Resources and Social Security of the People's Republic of China, decree no. 36 of

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the Ministry of Finance) of December 2017 further regulates the issues of fund-raising, management and supervision of enterprise pension plan, increase the enterprise contribution of enterprise pension to not exceed 8% of the total wages of the employees each year. The combined contributions of enterprises and workers do not exceed 12% of the total wages.

2.1.2.2 Occupational Pension Plan for public employee

The decision of the State Council on the reform of the pension System for public employees (No. 2[2015]) clearly defines the reform of the pension systems for the employees of the public institutions. It is proposed to establish a system of occupational pension plan on the basis of the basic pension plan, the contribution for employer is 8% of the individual's salary, and the individual contribution rate is 4% of the individual contribution salary. In the State Council No. 18, 2015, which specifies that occupational pension plan for public employee are managed in the form of personal accounts, in which individual contributions are accumulated in the form of actual fund accounts.

The contributions of employer, whose incomes entirely come from government fiscal budget, are recorded, and nominal interest income is calculated annually according to the nationally announced bookkeeping interest rate. The contributions of employer, whose incomes partly come from fiscal budget, are accumulated in the form of actual fund accounts. The occupational pension fund implements market-oriented investment operations and carries interest based on actual income. At present, the personal accounts of occupational annuities in public institutions basically adopt the nominal accounting method, and the mechanism of market-oriented operation has not yet been established.

2.1.3 Individual Saving Retirement Plan

In China, Individual Saving Retirement Plan usually refers to the Commercial Annuity. The development of Commercial Annuity is in the initial stage. The overall development of China's insurance industry is fast. The scale of premium, total assets and other indicators have reached new highs. From 2000 to 2017, China's market premium revenue increased from 15.96 billion yuan to 3.66 trillion yuan, which means an annual increase of 20.23 percent. The year-on-year increase in 2017 was 18.16%. According to the China Insurance Regulatory Commission’s 2017 report on the development of the insurance market, the insurance industry provided 415.4 trillion yuan of risk protection for the entire society in 2017, an increase of 75% year on year. However, the commercial annuity that can withstand the risk of longevity has a very small share in the insurance industry, and the benefits that can be provided in the multi-level pension system are minimal.

2.2 Pension Adequacy and Annuity Demand

2.2.1 The Basics of Social Pension for Urban Workers

Social pension plans for urban workers has the widest coverage and financed mainly by contribution; the social pension plan for government institutions has a short start-up time and is mainly dependent

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on public finance. The social pension plan for urban and rural resident relies mainly on financial subsidies and in fact is a form of welfare pension.

According to the coverage of the national pension system, the number of pensioners in 2016 was 253.73 million (101.03 million retirees + 152.70 million urban and rural residents), which exceeds the number of people over 60 years of age (230.86 million) and is close to the number of women over 55 years of age and the total population of men over 60 years of age (267.25 million). It can therefore be considered that the current social pension plan provides full coverage for the elderly. For the working age population, the 2016 social pension covered population of 887.77 million is about 90% of the population aged 25 and over (989.59 million). Thus, the basic pension system has basically achieved full coverage.

The coverage of basic pension plan for urban workers has continued to expand, with the coverage of the urban working population increasing from 31% in 1990 to 69% in 2017. After 2000, as more and more workers were covered by the system, the dependency ratio in the system remained roughly 1/3. There was a slow increase in the dependency ratio after 2014. The system support ratios slowly declined from 5.39 in 1990s to 2.65 in 2017, indicating a slowing ageing trend within the system. Table 2 and Figure 2 show the coverage and the structure of the insured population for the period 1990-2017.

Table 2 The coverage rate and dependency ratio of basic pension system for urban workers in 1990-2017 years Unit: ten thousand people; %

Year	Coverage	Active participant	Retiree	Urban employment coverage rate	Dependency ratio	Support ratio
1990	6166	5201	965	31	19	5.39
1991	6740	5654	1087	32	19	5.20
1992	9456	7775	1682	44	22	4.62
1993	9848	8008	1839	44	23	4.35
1994	10574	8494	2079	46	24	4.09
1995	10979	8738	2241	46	26	3.90
1996	11117	8758	2358	44	27	3.71
1997	11204	8671	2533	42	29	3.42
1998	11203	8476	2727	39	32	3.11
1999	12485	9502	2984	42	31	3.18

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2000	13617	10448	3170	45	30	3.30
2001	14183	10802	3381	45	31	3.19
2002	14737	11129	3608	44	32	3.08
2003	15507	11647	3860	44	33	3.02
2004	16353	12250	4103	45	33	2.99
2005	17488	13120	4368	46	33	3.00
2006	18766	14131	4635	48	33	3.05
2007	20137	15183	4954	49	33	3.06
2008	21891	16588	5304	52	32	3.13
2009	23550	17743	5807	53	33	3.06
2010	25707	19402	6305	56	32	3.08
2011	28391	21565	6826	60	32	3.16
2012	30427	22981	7446	62	32	3.09
2013	32212	24177	8041	63	33	3.01
2014	34124	25531	8593	65	34	2.97
2015	36361	26219	9142	65	35	2.87
2016	37930	27826	10103	67	36	2.75
2017	40293	29268	11026	69	37	2.65

Source: According to the data released by the National Bureau of Statistics of China

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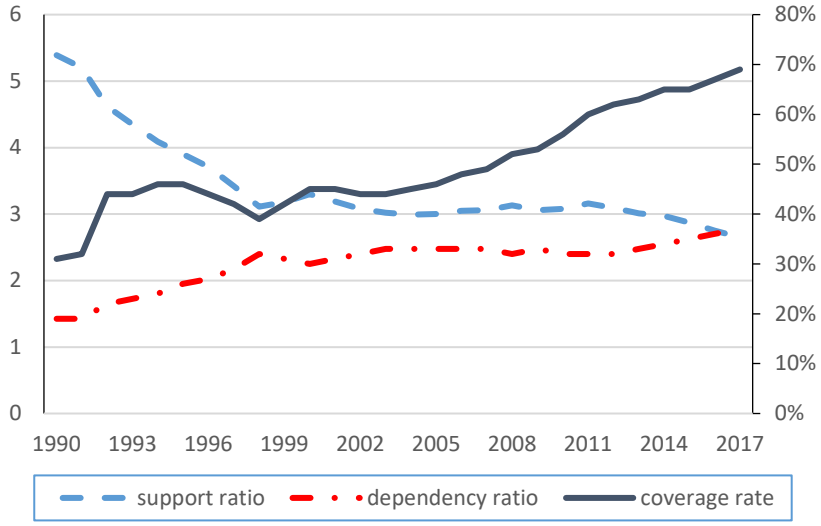

Figure 2 Coverage rate and age structure of the insured population for the period 1990-2017

Source: According to the data released by the National Bureau of Statistics of China

The benefit of the basic pension for urban workers has been gradually raised, but the replacement rate, as measured by the average social wage, tending to decline as a result of the growth of per capita wages in excess of the increase in the average pension. The average replacement rate in 2015 was 46%, and in 2016 it was increased to 50%. The disposable income replacement rate is maintained at more than 85%. Table 3 and Figure 3 show the basic pension contributions and replacement levels for urban workers.

Table 3 The benefit of basic pension system for urban workers Unit：yuan/person, month, %

Year	Expenditure(per capita)	Contribution (per capita)	Social average salary	Replacement rate of social average salary	Disposable income of urban residents(per capita)	Replacement rate of disposable income
2002	657	191	1031	64	642	102
2003	674	218	1164	58	706	95
2004	711	244	1327	54	785	91
2005	771	274	1517	51	874	88
2006	880	308	1738	51	980	90
2007	1003	356	2060	49	1149	87
2008	1161	403	2408	48	1315	88

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2009	1276	448	2687	47	1431	89
2010	1395	477	3045	46	1592	88
2011	1558	539	3483	45	1817	86
2012	1742	597	3897	45	2047	85
2013	1914	642	4290	45	2206	87
2014	2110	667	4697	45	2404	88
2015	2353	732	5169	46	2600	91
2016	2805	824	5630	50	2801	100
2017	2875	951	-	-	3033	95

Source: According to the "Statistical Bulletin on the Development of Human Resources and Social Security" published by the Ministry of Human Resources and Social Security of China, and the average wages and disposable income of residents issued by the National Bureau of Statistics of China.

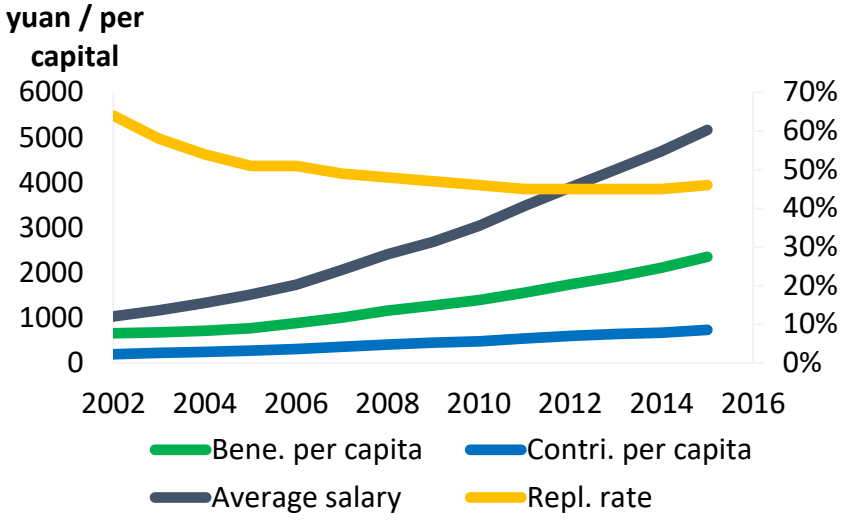

Figure 3 The benefit of basic annuity insurance for urban workers

Source: According to the "Statistical Bulletin on the Development of Human Resources and Social Security" published by the Ministry of Human Resources and Social Security of China, and the average wages and disposable income of residents issued by the National Bureau of Statistics of China.

The basic pension fund for urban workers has been increasing from 255.1 billion yuan in 2002 to 3.3 trillion yuan in 2017, and the expenditure on benefit increased from 284.3 billion yuan in 2002 to 3.8 trillion yuan in 2017. The fiscal subsidy for basic pension fund are becoming ever larger at national level, from 40.8 billion yuan in 2002 to 800.4 billion yuan in 2017. If fiscal subsidies are deducted, there

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will be an annual balance shortfall starting in 2014. In 2016, the basic pension fund was subsidized by the national treasury, accounting for 1/4 of the total basic pension annual expenditure and 1/5 of the annual expenditure of basic pension for urban workers. Table 4 and Figure 4 show the annual income and expenditure of the basic pension fund for urban workers.

Table 4 Annual income and expenditure of basic pension funds for urban workers

Unit: billion yuan

Year	Total revenue	Contribution	Financial subsidies	Other income	Total expenditure	Accumulated balance	Annual balance	Balance
2002	3172	2551	408	213	2843	1608	329	-292
2003	3680	3044	530	106	3122	2207	558	-78
2004	4258	3585	614	59	3502	2975	756	83
2005	5093	4312	651	130	4040	4041	1053	272
2006	6310	5215	971	124	4897	5489	1413	318
2007	7834	6494	1157	183	5965	7391	1869	529
2008	9740	8016	1437	287	7390	9931	2350	626
2009	11491	9534	1646	311	8894	12526	2597	640
2010	13420	11110	1954	356	10555	15365	2865	555
2011	16895	13956	2272	667	12765	19497	4130	1191
2012	20001	16467	2648	886	15562	23941	4439	905
2013	22680	18634	3019	1027	18470	28269	4210	164
2014	25310	20434	3548	1328	21755	31800	3555	-1321
2015	29341	23016	4716	1609	25813	35345	3528	-2797
2016	35058	26768	6511	1779	31854	38580	3204	-5086
2017	43310	33403	8004	1903	38052	43885	5258	-4649

Source: According to the "Statistical Bulletin on the Development of Human Resources and Social Security" published by the Ministry of Human Resources and Social Security of China.

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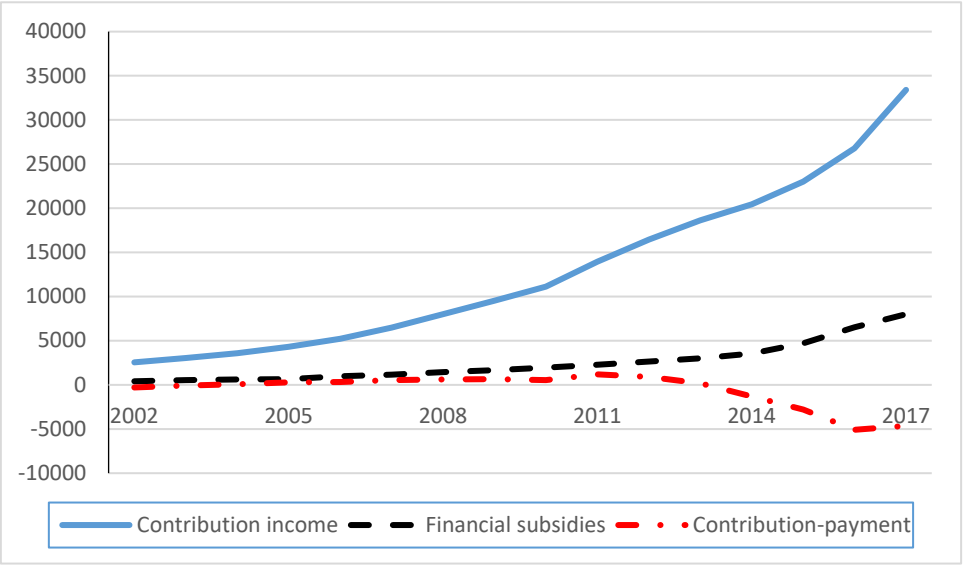

Figure 4 Annual income, expenditure and financial subsidies for basic pension system for urban workers (100 million yuan)

Source: According to the "Statistical Bulletin on the Development of Human Resources and Social Security" published by the Ministry of Human Resources and Social Security of China.

2.2.2 Financial Sustainability of Social Pension Plan for Urban Workers

In the future, with the aging of the population in the system, the sustainability of the social pension fund is going to face challenges. The cost of pay-as-you-go system is determined by the average replacement rate and the population dependency ratio within the system. With the increase of dependency ratio, the cost rate of maintaining a certain level of replacement rate will continue to rise.

According to the UN's population projection, the aging process of population will continue in the future. Table 5, Figure 5 and Figure 6 show the median age and age structure of Chinese population in 2020-2100 years. As can be seen, the median age of population will increase from 38.7 years of 2020 to 49 years in 2065, and will remain at 49 years. The proportion of the elderly population is increasing. After 2040, the proportion of the population over 60 years old is over 30%. After 2060, the proportion of the elderly population aged 65 or above is above 30%. The proportion of the working age population gradually declined, raising the dependency ratio of the elderly population gradually. The 60-year-old dependency ratio increased to 55% after 2055. The dependency ratio of the elderly over 65 increased to more than 60% in 2060. The proportion of people over 80 years of age was over 10% after 2055.

Table 5 The median age and age structure of Chinese population in 2020-2100 years

Year	Median age	Proportion of 60+	Proportion of 20-59	60-year dependency ratio	Proportion of 65+	Proportion of 20-64	65-year dependency ratio	Proportion of 80+

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2020	38.7	18%	59%	30%	12%	65%	19%	2%
2025	40.6	21%	57%	37%	14%	64%	22%	2%
2030	43.0	25%	54%	47%	17%	62%	28%	3%
2035	45.4	29%	52%	55%	21%	59%	35%	4%
2040	47.0	30%	51%	59%	24%	57%	42%	5%
2045	47.8	32%	50%	64%	25%	56%	44%	6%
2050	48.0	35%	46%	76%	26%	55%	48%	8%
2055	48.1	36%	45%	81%	29%	52%	57%	10%
2060	48.5	36%	45%	81%	31%	51%	60%	10%
2065	49.1	36%	45%	80%	30%	51%	59%	10%
2070	49.5	36%	45%	80%	30%	52%	58%	12%
2075	49.5	37%	45%	83%	30%	51%	59%	13%
2080	49.3	37%	44%	85%	31%	51%	61%	13%
2085	49.1	38%	44%	86%	31%	50%	63%	12%
2090	49.2	38%	44%	86%	32%	50%	64%	12%
2095	49.4	38%	44%	86%	32%	50%	64%	13%
2100	49.6	38%	44%	87%	32%	50%	64%	14%

Source: United Nations World Population Prospects，HTTPS://ESA.UN.ORG/UNPD/WPP/DATAQUERY/

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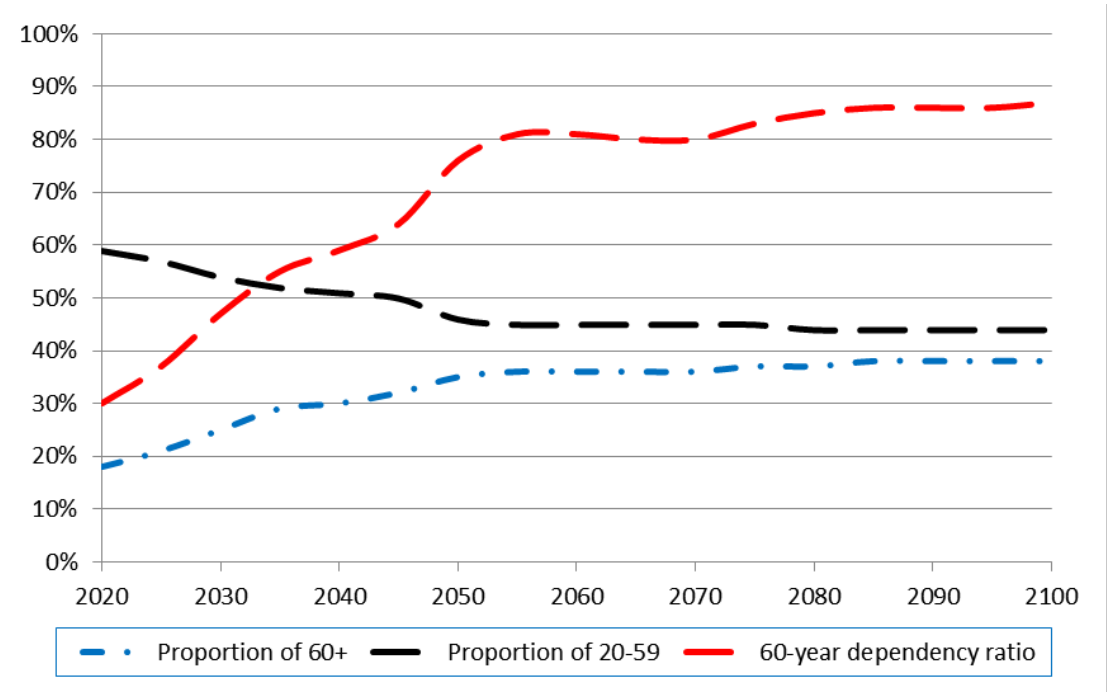

Figure 5 The median age and age structure of Chinese population in 2020-2100 years (60-year)

Source: United Nations World Population Prospects，HTTPS://ESA.UN.ORG/UNPD/WPP/DATAQUERY/

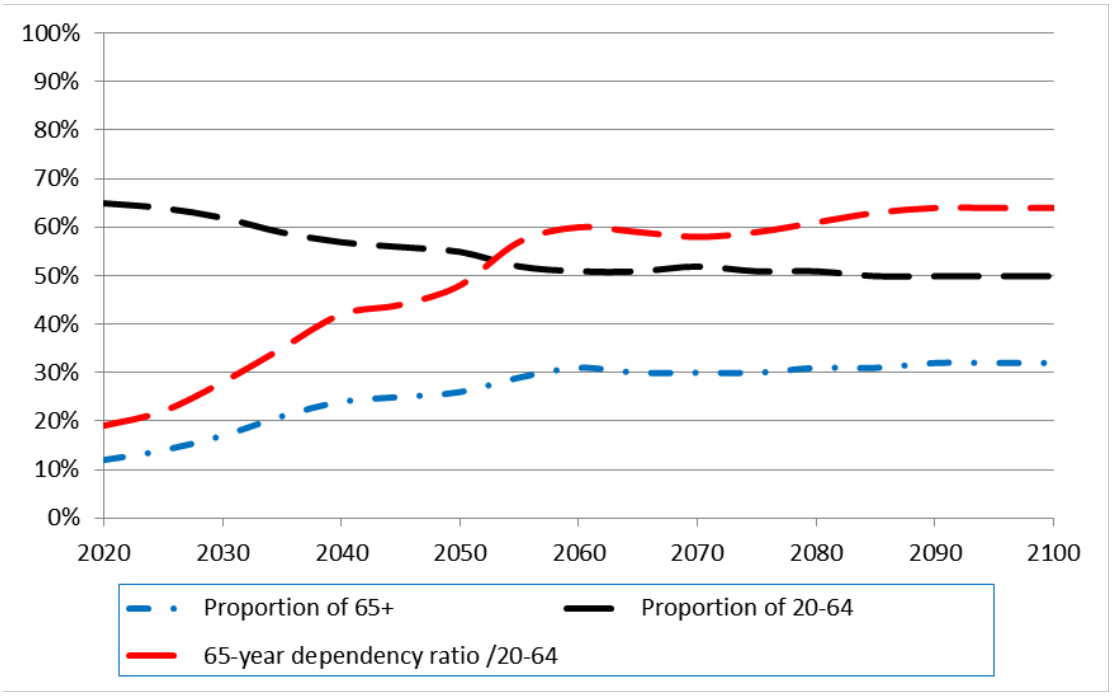

Figure 6 The median age and age structure of Chinese population in 2020-2100 years (65-year)

Source: United Nations World Population Prospects，HTTPS://ESA.UN.ORG/UNPD/WPP/DATAQUERY/

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Given the absence of actual data, assuming that the future insured population structure is the same as that of the population above, it is assumed that the future average pension replacement rate will remain at 50% of the 2016 level, and the cost rate of social pension plan will gradually increase. Assuming that the actual contribution rate in the future remains at 15% of the 2016 level, figure 7 shows the trend of the future cost of China's basic pension insurance under the assumption of 60-year-old retirement and 65-year-old retirement. The difference between the cost rate and the contribution rate is the balance rate of the system. It can be seen that if the retirement age is 60 years old, there will be a payment gap from 2020, and the payment gap will continue to increase over time. If the retirement age is raised to 65, the cost and balance rate of the system will be significantly reduced, but the payment gap will still occur after 2030, and the scale of the gap will continue to expand after 2030.

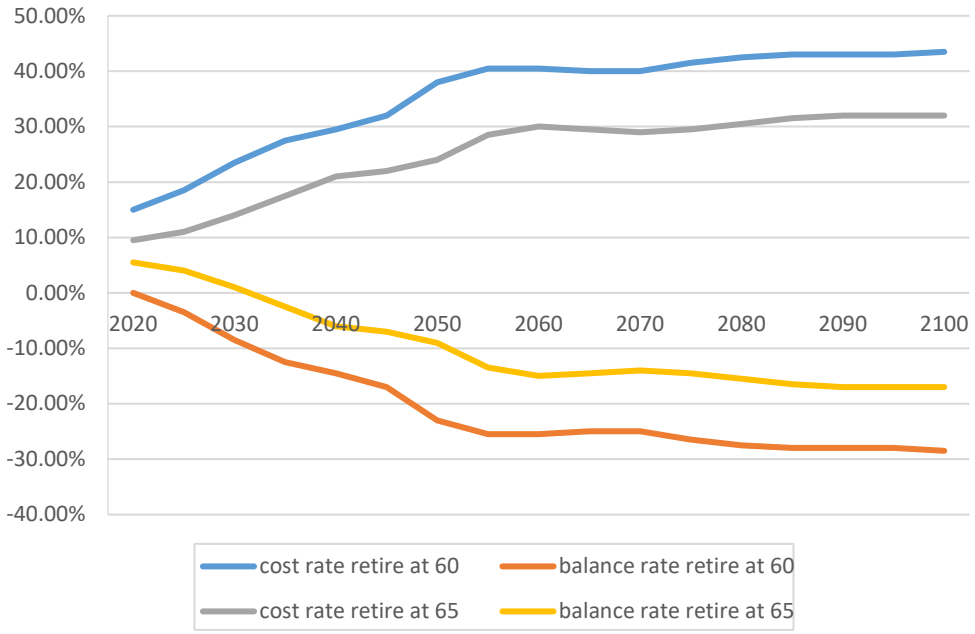

Figure 7 Cost and balance rates for retirement at the age of 60 and 65

Source: Calculated from the data in Table 5

In order to balance the burden of the basic pension fund for workers in different regions, in July 2018, the State Council decided to establish a central adjustment fund, on the basis of provincial-level pooling fund of the basic pension for workers.

2.2.3 The Commercial Annuity Demand under the Multi-tier System

The challenges in the adequacy and sustainability of the basic pensions fund necessarily require the development of a multi-tier pension system. China's pension systems have the highest coverage for social pension, but the coverage for occupational pension and individual pension is very limited and also adopt the personal saving accounts model. At retirement, most of retiree will choice lump-sum

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payment or by installment which are no life time payment protection. The annuity payment choice for occupational pension depends on the development of the commercial annuity market.

In February 2018, the Ministry of Human Resources and Social Security of the People's Republic of China and the Ministry of Finance, in conjunction with the State Development and Reform Commission, the State Administration of Taxation, the People's Bank of China, the China Banking Regulatory Commission, the China Securities Regulatory Commission and the China Insurance Regulatory Commission, set up a leading group and start to establish the third pillar of annuity insurance, marking the formal entry of the third pillar of the private savings pension and Commercial Annuity into the start-up phase of the system.

In April 2018, the China Insurance Regulatory Commission and the Ministry of Finance, the Ministry of Human Resources and Social Security and the State Administration of Taxation jointly issued the circular "Guidelines for the development of personal tax deferred Commercial Annuity products " (No. 20 [2018] of the China Banking Regulatory Commission), individual tax deferred Commercial Annuity products of several life insurance companies were approved for listing. It marked the official launch of the commercial annuity market supported by government tax.

2.3 Brief Summary

Since the establishment of the basic annuity insurance for urban workers, it has provided the retirees with a higher level of pension benefits. At the same time, its coverage rate has kept increasing and its fund size has been expanding. But as China's population ages with startling speed, the dependency ratio of the basic pension system for urban workers continues to rise and the gap between the income from contributions and expenditure on pension is expanding. Therefore, the basic pension system faces a great challenge of insufficiency and unsustainability. As a result, the Chinese government began to push forward the third pillar of the annuity insurance system process.

3 ANNUITY MARKET

3.1 Annuity Market: International Experience

As an insurance product that can avoid longevity risks, commercial annuity should play an important role in people's pension system. However, in the world's major developed countries, the development of commercial annuity market is different. George A (2006) found that the annuity market in Chile, the Netherlands, Switzerland, and the United Kingdom is relatively large, and the United States and Canada have some annuity markets. The share of annuities in other countries is relatively small.

The development of the annuity market in different countries is closely related to their pension system structure. Affected by specific socio-economic, cultural, and political backgrounds, there are some different characteristics in the pension structure of countries around the world, but it can be basically classified as three layers, which include social pension plans sponsored by the government,

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occupational pensions sponsored by employers and commercial annuities offered by the insurance market. The first one, the social pension plan, adopts the pay-as-you-go financing, which can provide basic living support for retirees through intergenerational transfer and income redistribution. The second one, the occupational pension, which reflects the responsibility of the employers, aims to offer additional pension protection for employees and improve the pension replacement rate of the retired employees. There are two types in occupational pensions: the Defined Benefit (DB) plan and the Defined Contribution (DC) plan. Nowadays, the DC plan is more and more popular. In this plan, both employers and employees jointly contribute on a regular basis into individual accounts whose future benefits fluctuate on the basis of investment earnings. Furthermore, this plan allows employees withdraw the money either in a lump sum or by installment with multiple times, and employees even can convert the amount into annuities. The last one, the commercial annuity, is generally bought by individuals and families voluntarily. Governments always encourage the development of commercial annuity through the tax incentive mechanism. There is a substitution effect from the source of three kinds of pensions. If the social pensions and the occupational pensions provide adequate needs, there will be less demand for commercial annuities. However, the share of the annuity market will be relatively high, provided that the occupational pensions are DC plans and that a mandatory annuitization mechanism exists at the contribution stage.

3.1.1 Mandatory annuitization -- the United Kingdom

The UK's pension system consists of four levels, including: The Basic State Pension Scheme (BSP), The State Second Pension Scheme (S2P), and Occupational Pension Schemes, (OP) and Personal and Stakeholder Pension Schemes. Among them, the National Basic Pension and the National Second Pension Plan are sponsored and enforced by the government, and the pay-as-you-go system is adopted, which is funded by employers and individuals. The S2P was introduced in 2002, which is a national supplemental pension plan associated with individuals' income on the basis of the BSP. But many middle- and high-income people have taken part in the OP or the PSP, so the government stipulates that under certain conditions, such as the OP and the PSP must be able to provide the required minimum treatment, employers and employees can choose to contract out the BSP. The development of the OP and the PSP is promoted by this stipulation. Before 2011, from 1956 to 2011, the UK government required the accounts of DC-style occupational pensions and personal pensions, subjected to tax incentives, to annuitize 75%-100% of its amounts by the end of the age of 75 years. As Edmund (2011) point out that the main determinant of purchases of annuities in the compulsory market is the number of individuals reaching retirement age and their pension wealth.

In fact, the requirement of mandatory annuitization simulates the growth of annuity markets. After 2011, however, as this requirement was placed too many restrictions on pension financing by legislators, it began to weaken it. In 2011, the government set a rule that if the minimum income requirement (MIR) has reached a certain level (£20,000), the restriction of mandatory annuitization can be canceled. Furthermore, the UK government canceled this mandatory requirement in April 2015. Edmund (2016) points out that there is a dramatic decline in the demand of annuities after cancelling

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the requirement of mandatory annuitization, and compared to the compulsory annuity markets, the share of voluntary one is rather small. In fact, from a global perspective, as long as the annuity in the region is purchased voluntarily, the market size is very small (Brown, 2001). Also, whether the private annuity market can develop well depends on the market capability of providing products (Mitchell and McCarthy, 2004).

3.1.2 Non-mandatory annuitization --Australia, Chile, and Switzerland

Australia's three-tier pension system consists of government-sponsored basic pension financed by general taxes and have means-tested requirement, and DC-type occupational pension established by the employer's contribution, voluntary personal annuities and other forms of savings that enjoy tax advantages.

The social pension plan sponsored by the government provides basic pension benefits, and the retirees who pass the income test receive basic pensions from the age of 65. From 2017, the age for receiving basic pensions is postponed to 65.5 years, and is extended by 6 months every two years. The age of receiving pensions by 2023 is postponed to 67 years. There are differences in the level of basic pensions received by residents of different income and asset levels, and the lower the income, the higher the level of the pension benefit, but the basic pension will not be paid after the income and assets exceed the threshold. The pension received by an individual is approximately 28 per cent of the average male income and the pension received by the couple amounts to approximately 41 per cent of the average male income. Over the basic pension system, about one in two have access to the full amount, one in four receives 50 per cent of the full amount, and the remaining 1/4 have incomes and assets exceeding the threshold and will receive nothing from the basic pension system.

Mandatory occupational annuities require employers to establish a supplement occupational pension for their employees and every employee has an individual account. In 2015 the mandatory occupational annuity contribution rate for employers is 9.5% and is expected to rise to 12% by 2025. At the same time individuals are encouraged to make voluntary contributions. The insured has the right to choose the investment tools and take the investment risk, and the compulsory saving solves the problem of pension coverage. Employees can begin to apply the benefit when they retire, suffer permanent disability, end-of-life illness and medical treatment. Occupational pension do not require annuitization, and the vast majority of employees opt for lump sums withdraw and phase withdraws after retirement, thus leaving out the longevity risk-protection mechanism.

The voluntary pension system does not require mandatory annuitization, and most people opt for a lump sum withdraws when they retire. So, the Australian annuity market is small.

Reform of the pension system in Chile in the 1980s had transformed the old system of social integration of pay-as-you-go pension systems into a fund-building system for personal accounts, managed by private financial institutions. In the early years after the reform, fund accumulation led to high returns on investment. However, full DC accumulation has brought many problems, especially after the global financial crisis in 2008. The system exposes many problems such as high cost of

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management, low replacement rate, large gender difference and low coverage. Current Chilean pension system is also a three-tiered structure. Tier 1 is the basic solidarity pension (PBS), a basic pension for low-income people without other pension sources, is paid from the age of 65. On top of this, there is a supplementary welfare pension named Solidarity Pension Payment (APS), which is offered to people with other pensions plans but have lower replacement ratio.

The second tier is the reformed compulsory accumulation of DC in 1981, at a rate of 10 percent at the employer's expense. The system was mandatory for all public and private sector employees, but self-employed persons and informal employment, as well as those who chose to remain in the old system, could participate voluntarily. After the reform in 2008, all self-employed persons are required to participate in this DC plan.

The third tier is the voluntary savings DC scheme, whereby the employer can pay for the employee under the voluntary DC scheme. Retirement personal accounts are paid by the Insurance Company for annuities or by phase withdraw. The annuity market is bigger because Chile offers a tendentious annualized access in a way that most people would opt for annuitization rather than an entirely voluntary option in Australia at the distribution stage.

Swiss pension system is also a three-tiered structure, the first is a basic government-sponsored pension scheme, the second is an employer-run fund that every employee has an individual accumulated fund and the third tier is voluntary private savings. Similar to Australia, Swiss occupational annuities are mandatory and are paid in the same amount by both employers and employees. Self-employed persons may join the scheme voluntarily. Occupational annuities provide a regular pension after retirement and can also be taken out early if the employee is disabled or serious illness. Most of Switzerland takes the form of annuitization.

The high willingness of annuitization in Switzerland and Chile is determined by a combination of factors. Butler and Staubli (2011) summarized three main reasons. First, the products in the annuity market have higher money worth rate (MWR). MWR is the ratio of the present value of annuity to the price of annuity. In Switzerland, the ratio is more than one, well above the OECD average. Second, behavioral attitudes have a big impact: people tend to accept the default option. In many companies' pension plans, conversion to annuities is the default option. At the same time, in the annual statement of the fund for each employee, a reference is made to the accumulated value and the money received after retirement, but the description of the latter would be much larger than the former, and therefore, in the mindset of many employees, the focus is not on the cumulative value of their pension funds, but on the amount they can receive each month after retirement. Third, there are the "crowding out effect" of the first pillar. Sweden's first pillar will have a means-tested mechanism, and when the total assets are lower than a certain threshold, the government adds a certain amount each month. This pattern is in line with Teppa (2007) who show that the probability of annuitizing increases with the accumulated wealth.

In Chile Ruiz and Mitchell (2011) point out that the high MWR and relatively transparent online bidding mechanism of annuity products is a favorable guarantee for people to choose annuity. However, the

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first pillar of the Chilean pension system is weak and relies heavily on the cumulative fund of the second pillar. In recent years, with the decline in the rate of return on investment and the significant increase in life expectancy, the replacement ratio is dropping quickly and had a huge negative impact on the annuity market.

The reverse is true in Australia, where few people opt for annuitization when they retire, but prefer lump sums and phase withdraws. Bateman and Piggott (2011) think that the relatively "generous" first tier led to this phenomenon. For a single person, whether or not he had a job before the age of 65, he could receive the equivalent of 28 per cent of the average salary of a full-time employee, as long as he meets the income test, the figure is 41 percent for a couple. In addition, since there has never been a traditional DB pension system in the history of Australia, even for workers with pension needs, their focus is on the amount of money that can accumulate in their own funds, not on the amount that will give him a steady cash flow for the rest of his life in the future, and the absence of government incentives for annuitization have hastened the demise of the traditional annuity market in Australia.

3.1.3 High dependence on traditional social security – Japan and Germany

The pension systems of Japan and Germany have a high similarity: they all have a strong first pillar, and the national pension mainly relies on the government-supported pension system. The commercial annuity market is generally small.

There are three layers in Japanese pension system, consisting of national pension schemes (NP), welfare pension schemes and complementary pension plans. The basic level is founded by the government, using pay-as-you-go system. The second layer requires that employees in large and medium-sized private enterprises and civil servants join compulsively. And for fees, they are linked to the personal income, and paid by employees and employers jointly. Also, administrative expenses are managed by the government. The last one, it can be chosen by enterprises and individuals voluntarily.

The complementary pension plans for individuals are based on the mandatory NP. This plan has the characteristics of a unified level and a uniform premium rate, now becoming the main pension type for Japanese citizens, which includes three categories. The first category includes four statutory plans: the National Pension Funds (NPFs), the Farmers' Pension Fund (FPF), the Individual-type DC, and the Employees' Asset Building Promotion Scheme. The second one consists of annuity products provided by life insurance companies, agricultural cooperatives, mutual insurance companies. The last group is bank deposits and some financial vehicles provided by securities institutions. But the prevalence of the first two categories in Japan is relatively low. According to the survey published by Life Insurance Culture Centre in 2009, about 23% of the households have purchased annuity products, and in the financial tools that people rely on after retirement, annuity products only account for 16.3%. But bank deposits and financial instruments provided by securities companies are very popular in Japan, more than 40% of Japanese households regarding these products as the most reliable savings tool (Junichi, 2011).

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Junichi (2011) believes that there are four main reasons why annuity products are not popular in Japan. First, people lack insurance and actuarial knowledge and think that the commission and rate of annuity products are too high. Second, in Japan, life annuity products, the insured is often allowed to convert the annuity into a one-off product. In practice, many people make a one-time choice; third, people's preference for liquidity. Compared with the purchase of old-age pensions, people are more willing to use banks to manage wealth. Fourth, under the current tax system, there is not enough tax-optimized policy for purchasing annuity products.

Germany is the one of the first country to establish an old-age insurance system. In 1889, Disability and Annuity Insurance Act was promulgated, and it began to provide regular income protection for retirees aged 70 or over or the disabled who have lost their ability to work. The current old-age insurance system in Germany also includes three levels: the statutory pension scheme, the corporate pension plan and the private annuity insurance. The source of pensions for German retirees mainly depends on the first level of statutory pension scheme. However, as the financial burden of German government is getting heavier, the situation of overreliance on the first pillar is gradually changing in recent years, with the trend that the government has started to encourage the development of individual pensions. Particularly, Elderly Income Act was entered into effect in 2005. The Germany existing annuity insurance plan has been re-divided in terms of taxation, so the supplementary position of occupational annuity and individual old-age pension has been significantly improved, resulting in a development of the commercial annuity market. Data from GDV (2007) show that the number of new annuity products sold in 2007 accounts for 50% of that of all new contracts in Germany in that year.

In the German annuity market, the typical product is the single life nominal participating annuity, which consists of a guaranteed portion and a profit portion. Furthermore, the existing two main schemes of profit participation in this market are composed of a dynamic participation scheme and a so-called flexible participation scheme. From the perspective of MVR, the level of German annuity products is the same as international experience, usually between 0.90 and 1.10, and that products with period-certain guarantees in Germany have a good value for MVR (Barbara, 2011).

3.2 Most common types of annuity products in OECD countries

The development of the annuity market varies from country to country, and the main types of annuity products are different, this section begins with a description of several annuity products and their sales in several of the more representative countries, followed by the most popular type of annuities in the OECD national insurance market.

3.2.1 Traditional annuities

Traditional annuity products refer to the level annuities, which are fixed amount of money for each annuity payment. In addition, traditional annuity products may also refer to escalating annuities which payment is scheduled to increase (escalate) or decrease (de-escalate) over time by a defined amount.

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The popularity of traditional annuities varies greatly across OECD countries, with 12% share of the U.S. market in 2012(OECD, 2016) and In the United Kingdom, level immediate annuities accounted for 67.5% of compulsory conventional annuity sales in 2014, with escalating payment annuities representing less than 3% of all sales (The Chartered Insurance Institute,2015). In Australia, however, traditional annuities have been nearly vanished.

3.2.2 Longevity annuities

Longevity annuities are deferred annuities which tend to be bought around retirement age with payments deferred to begin at a more advanced age, usually over age 75. The premium is usually non-refundable and the insured will receive the first payment at the deferred age if he or she can survive to this age. The advantage of these products for the customer is that they provide longevity insurance at a significantly cheaper price compared to purchasing an immediate annuity providing the same level of income.

Longevity annuities represent a very small portion of the annuity market in the United States, with annual sales making up less than 1% of total annuity sales, though sales have been increasing rapidly since the product was introduced to the market (IRI, 2013) These types of annuities are not available in the UK.

3.2.3 Enhanced annuities

Enhanced annuities pay out a higher income level to annuitants deemed to have a shorter life expectancy. Qualification for such an annuity can be based on the existence of health impairment, such as high blood pressure or diabetes, or based on lifestyle factors such as tobacco use or socio-professional category.

The largest market for enhanced annuities is in the United Kingdom, where the market has grown rapidly. These products represented nearly 30% of total annuity contracts sold in 2014 compared to only 7.7% in 2007 (The Chartered Insurance Institute, 2015). The US market, where these types of annuities are known as substandard annuities, is much smaller.

3.2.4 Inflation indexed annuities

Inflation indexed annuities are annuities whose payments change depending on the rate of inflation each period. Compared to fixed level annuities, these annuities offer a much lower initial level income as payments will change in line with inflation each period. In part as a result of lower initial payments, these types of annuities tend to be less popular than their level counterparts despite the added insurance of having a stable purchasing power.

3.2.5 Participating life annuities

The participating life annuities have a fixed minimum amount for each period and additional payments are made on the basis of the company's investment income. Both the insurer and the insured share the

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risk of investment, thereby reducing the cost of the product's price. However, because of the uncertainty of dividends, it also has an uncertain effect on the future earnings of the insured. Participating life annuities have been found in the insurance markets of major OECD countries, and were very popular before the financial crisis and their market share exceeded traditional annuities. But with the recently low return of rate, the market share of participating life annuities has been shrinking.

3.2.6 Variable annuities

A variable annuity is an annuity product that provides a certain level of payment guarantee, but the actual amount of payment is variable according to the level of risk. Variable annuities are generally divided into two phases, namely, accumulation period and distribution period. In the accumulation period, each contribution will enter an investment fund. The policyholder can choose the investment strategy according to his bear of risk. At the time of distribution, the policyholder still has the option of annuitization or not. For policyholders, there are three benefits to variable annuities. One is to provide tax deferred income, the other is to obtain tax deductions when transferring funds in different investment accounts, and the third is to obtain death payment guarantees, surrender guarantees, an annuity guarantee or a minimum lifetime guarantee.

Variable annuities first appeared in the 1950s, and there are two main types of guarantees provided by variable annuities (Ledlie et al. 2008). One is the minimum death benefit guarantee that occurred in 1980s, which provides a minimum guarantee for the insured's death benefit (Guaranteed Minimum Death Benefit, GMDB). The other is the guaranteed minimum survival benefit that occurred in the late 1990s (Guaranteed Minimum Living Benefits), including the guarantee maturity payment and the cumulative value during the accumulation period(GMMB/GMAB).

The United States represents the largest market for variable annuities, and while sales decreased significantly during the crisis they subsequently rebounded to pre-crisis levels, reaching over USD 150 billion in 2011 (Geneva Association, 2013). Variable annuities represented 60% of all annuity sales in the second quarter of 2015. (IRI, 2015). Sales of segregated funds in Canada and Japan follow a sales pattern similar to that of the United States. Variable annuities and their guarantees were introduced in Europe as well but have not proven to be very popular and the growth of the market has been slow.

3.2.7 Fixed indexed annuities

As a result of the financial crisis, individuals are aware that products such as variable annuities are more sensitive to the financial environment of large markets and therefore seek products that are still profitable but less risky. Fixed indexed annuities are then become popular. Fixed indexed annuities will have a guaranteed minimum rate. Even in the case of a loss in the account, the value of the account will not decrease.

Sales were USD 48 billion in the United States in 2014, an increase of nearly 24% from the previous year (Insured Research Institute, 2015). Although the variable annuities are still dominant, fixed indexed annuities are becoming more and more popular and the market share may exceed the variable

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annuities in the future. The most common types of annuity products found in selected OECD countries are showed in Table 6.

Table 6 Most common types of annuity products found in selected OECD countries

Country	Most common product
Australia	Individual immediate fixed payment annuity with 10 year guaranteed period
Austria	Individual fixed payment deferred annuity
Belgium	Individual immediate annuity
Canada	Individual immediate fixed payment annuity
Chile	Individual inflation-indexed immediate annuity
Czech	Individual indexed deferred annuity
Denmark	Group participating deferred annuity
Estonia	Individual participating deferred annuity
Finland	Individual participating deferred annuity
Greece	Individual fixed payment annuity
Hungary	Individual deferred fixed payment annuity
Israel	Individual annuity indexed to government bonds
Italy	Individual participating deferred annuity
Mexico	Individual inflation-indexed immediate annuity
Portugal	Individual fixed payment annuity
Spain	Individual fixed payment immediate annuity
Sweden	Participating deferred annuity
United Kingdom	Individual immediate fixed payment annuity
United States	Individual deferred variable annuity

Source: OECD Delegates to the WPPP/IPPC

3.3 The development of Annuity Market in China

3.3.1 The Development of the Commercial Annuity Insurance

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According to the insurance product information from the Insurance Association of China[3](IAC)，there are 2,114 annuity products in China at present, 294 of them are old age annuity[4]and 1,820 are not; 648 are traditional products[5] while 1,466 are new products, as shown in Table 7.

Table 7 Annuity products in 2017

	Total	Traditional	New
Short term annuity	1820	561	1259
Annuity with longevity protection	294	87	207
Total	2114	648	1466

Source: IAC http://www.iachina.cn/art/2017/6/29/art_71_45682.html

The development of China's commercial annuity can be roughly divided into three stages according to the most active product types in the market, from whole life annuity in past to term annuity at present.

Stage 1 (before 2006): At the end of high interest rate era, the passion for long-term products is exhausted gradually.

Since the late 1990s, the annuity market has entered the era of high interest rates. The annuity products are mainly based on traditional life annuity with longevity risks, such as the additional annuity from Sino-US United MetLife Insurance Company Limited (2005). After 2001, with the development of participating insurance[6], the proportion of participating annuity has increased while that of annuity products with high longevity risk has begun to decrease. To 2006, although there are some kinds of long-term annuity and children's education annuity continuing the features of high interest rate products, which can provide customers with longevity risk security and have a higher long-term investment return, such as Pingan Innovation Century Account Group Annuity (2006). However, the development trend of participating annuity is stronger. Annuity market is about to change.

[3]http://www.iachina.cn/art/2017/6/29/art_71_45682.html

[4]According to "Measures for the Administration of Insurance Clauses and Premium Rates of Personal Insurance Companies (2015 Revision)" Article 10, pension annuity insurance is annuity insurance for old-age security. Pension annuity insurance shall meet the following conditions: (a) The age agreed upon in the insurance contract for paying survival benefit to the insured is not lower than the retiring age prescribed by the state; (b) The interval between two consecutive payments does not exceed one year. For example, Ping An Lexiangfu Pension(A) is pension. The rest of the annuity products are non-pension, such as Ping An Lexiangfu Pension(B).

[5]According to "Measures for the Administration of Insurance Clauses and Premium Rates of Personal Insurance Companies (2015 Revision)" Article 17, the design types of personal insurance shall include but not be limited to general type, participating type, unit-linked type and universal type. Among them, the general type is the traditional type, whose main function is security, such as Sunshine Life Kangzunwuyou Annuity. Participating type, unit-linked type and universal type are new products, which have investment function but slightly lack security function, such as Tai Ping Fortune-growth Xingfuban Annuity (participating type), Taikang Ying-e-sheng Type A Annuity (unit-linked type), PICC Pinzhijin Account Annuity(universal type).

[6] Participating insurance: a system of insurance by which policyholders receive dividends from the company's profit or surplus.https://www.collinsdictionary.com/zh/dictionary/english/participating-insurance

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Stage 2 (2007-2012): It's successful to attempt to add short-term saving products to annuity market.

At this stage, annuity is generally biased towards wealth management products. There is no distinction between annuity and endowment insurance, whose policy year is shorter than other insurance's. The annuity with high longevity risk has hardly developed, while the participating and universal annuity has developed rapidly. In the first quarter of 2011, affected by the new accounting standards and factors such as inflation expectations, the participating annuity products are developed rapidly. The growth rate of participating annuity premium income is 14.9%, accounting for 78% of the life insurance business, leading to its important status[7]. Between 2011 and 2012, there were five companies offering variable annuities: AXA-Minmetals Assurance Baodeying Annuity (variable annuity), MetLife Bubuwenying Annuity (variable annuity), Huatai Life Jinianbaoli Annuity (variable annuity), Skandia-BSAM Ruitaifuxiangjinsheng Annuity (variable annuity), ICBC-AXA Baodeying Annuity (variable annuity). Due to the short policy term, weak capital market, poor performance and other reasons, they are not good enough to become the mainstream of the market.

Stage 3 (2013-2017): Short and medium duration, quick return products and additional universal account products have a leap development.

After 2013, with the impact of premium rates reform[8] and asset-driven liabilities, the traditional and universal annuity products with a short and medium duration have been developed by leaps and bounds, gradually moving away from the essential long-term guarantee attribute.

（1）Traditional annuity: The quick return type insurance with high cash value or high pricing rate (4.025%), such as the famous products of China Life Xinfuniannian Annuity and the Series Life and Wealth of Fude Life.

（2）Universal annuity: Under the asset-driven liability style, emerging platform companies focus on developing universal annuity products. The products have high cash value as well as short and medium duration[9]. For example, Fude Life Wealth Management No. 3 Annuity (universal type), China Life Xin Account Annuity (universal type), Qianhai Investment Wealth Management Annuity (universal type), etc.

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[7]http://www.iachina.cn/art/2011/5/16/art_793_88047.html

[8]According to "Notice of the China Insurance Regulatory Commission on Relevant Matters concerning the Policy Reform of Premium Rates of Ordinary Personal Insurance", the CIRC decides to implement the policy reform of premium rates of ordinary personal insurance. The assumed interest rates of ordinary personal insurance shall be determined by insurance companies in accordance with the principle of prudence. http://lawinfochina.com/display.aspx?id=14892&lib=law&SearchKeyword=&SearchCKeyword=

[9]According to "Notice of the China Insurance Regulatory Commission on Issues concerning the Regulation of Personal Insurance Products with Short and Medium Duration", the term "products with short and medium duration" means the personal insurance products with the sum of the cash value (account value) of their insurance policies by the end any policy year in the first four policy years and the cumulative survival insurance benefits exceeding the cumulative insurance premiums paid thereon, and the expected duration of more than 60% of whose policies is less than five years, excluding investment-linked insurance products and variable annuity insurance products. http://lawinfochina.com/display.aspx?id=22144&lib=law

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At this stage, the annuity products with high longevity risk have shrunk sharply again. The development of annuity insurance has deviated far from the original intention of long-term protection and turned into short-term and financial management tools. However, the new policy premium scale of annuity market has completed the leap-forward development at this stage. It's because that the direct perception of longevity risk for clients is not strong, but they focus more on the sense of no money, no one offering service such as elderly endowment, treatment, and nursing. Therefore, the security demand for annuity eventually project onto the claim to the return on investment.

Therefore, the development of annuity insurance, in addition to some long-lived risk, long-term child education and pensions, is basically a product that meets the short-term and long-term savings functions. In recent years, through quick return annuity and account the annuity has an explosive growth, but its function has been away from annuity property.

3.3.2 Annuity Market in China: Possible Future Trend

3.3.2.1 Individual tax-deferred pension

In June 2017, the executive meetings of the State Council explicitly increased fiscal and tax policy support for the first time and accelerated the trial of individual tax-deferred Commercial Annuity. In February 2018, the Ministry of Human Resources and Social Security and the Ministry of Finance jointly established the Leading Group for Commercial Endowment Insurance with the National Development and Reform Commission, the State Administration of Taxation, the People's Bank of China, the China Banking Regulatory Commission, the China Securities Regulatory Commission, and the China Insurance Regulatory Commission. In April 2018, a number of ministries and commissions jointly issued a notice on the "Guidelines for the Development of Personal Tax Deferred Commercial Endowment Insurance Products" (No. 20 [2018] of the China Banking Regulatory Commission and the China Insurance Regulatory Commission). Subsequently, a number of life insurance companies' personal tax extension commercial pension insurance products were approved for sale. The pilot of the tax-deferred commercial pension insurance and its comprehensive nationwide promotion will definitely promote the development of China's commercial annuity market.

Individual tax-deferred pension, in essence, is the state that gives preferential tax to individuals who buy pension products in the policy. Existing pension tax policy is that the policyholders need to pay tax at the moment in buying insurance, not a pre-tax deduction (T), and the investment return and pensioners are tax exempt (E). So the tax mode is TEE. While the greatest feature of individual tax-deferred pension is that the policyholders don't need to pay part of individual income tax because of deduction (E) and investment income is also tax exempt (E). Income tax (T) is to be levied on future benefit. The individual income tax mode changes from TEE to EET.

Individual tax-deferred pension has a positive impact on both individuals and insurance companies.

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First of all, low tax rates. Under the condition of using general progressive tax rate, the personal tax rate increases with the income level. The pension that an individual receives when he retires is usually lower than the wage. So the tax rate is lower, with deferred tax giving the individual a lower tax rate.

Second, investment income is exempt from taxation. In the EET model, the current investment income or capital appreciation is exempt from tax, and the tax is levied only when it is paid, which can bring the excess benefit to individuals.

Finally, Commercial Annuity companies will be the biggest beneficiaries. With the implementation of individual tax-deferred pension, the insurance companies with life annuity business will have a major benefit. Although the share of different life insurance companies in the life annuity market is not the same, in general, insurance companies play a very important role. Furthermore, individual annuity accounts for a considerable proportion in the assets of insurance company, thus once the individual tax-deferred pension is implemented, it will be beneficial to insurance companies.

3.3.2.2 New exploration on the retirement industry

According to data released by the National Bureau of Statistics, at the end of 2017, China's population over 60 years old exceeded 240 million, accounting for 17.3% of the total population, and the population over 65 years old was 158 million, accounting for 11.4% of the total population. In the future, the amount and proportion of the elderly population will continue to increase, and the proportion of the elderly population in the next 40 or 50 years will exceed 1/3, so China will become the world's largest pension insurance market. In addition to supporting qualified commercial insurance institutions to actively participate in the personal tax deferred commercial annuity insurance pilot program, the current government also encourages commercial insurance institutions to invest in the aged care service industry and establish and improve the comprehensive old-age security plan for the elderly. China's insurance institutions are basically in a complementary position in the pension industry chain, and there is a lot of room for development in the coming period. Determining the main line and expansion mode is the primary task of the extension of the commercial annuity insurance industry chain.

At present, insurance institutions can extend the retirement industry from three angles.

The first one is to get involved in elderly finance. The involvement of insurance institutions in the financial industry of the elderly is mainly divided into the development of "housing for retirement", long-term care, insurance trust and enterprise pension. "Housing for retirement" is considered that large insurance company can independently develop with the advantages of asset management while small and medium-sized insurance institutions can develop in the form of bank-insurance cooperation. The development can try to introduce the mechanism of dividends, so that the insured could enjoy the effective benefits of the increase in house value in a certain extent. The long-term care health insurance is thought that insurance object can continue to expand and the path could be retirement community residents group, customer groups such as insurance institutions, other group of older people, young people, and sustainable development step by step. Life insurance trust is suitable for

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large scale of insurance institutions, Customers make the policy as collateral, which is delivered to the insurance institutions, and institutions can deliver customer assets to the company's own assets trust management department to use of long-term planning. It can take advantage of the long-term feature of insurance assets and the flexibility of the trust investment. Annuity market is developed because the trial of individual tax-deferred pension has given more opportunity for insurance company to design life annuity products which can meet the demand of annuitization of enterprises pension and life time retirement protection.

The second one is to get involved in elderly services. Insurance institutions can expand their business scope and service areas by intervening in the managed medical treatment and nursing institutions. The managed medical treatment: it is required to take equity investment to participate in the reform of local public hospitals and take charge of the daily operation and management of hospitals. Equity investment in the funds required for the local public hospitals is relatively small, and the capital competition is small compared to the local resources. What's more, the department involved in the hospital reform is relatively easy to communicate. Equity structure is relatively simple, so equity investment is easy to realize. The nursing institution: for the insurance institutions that have invested in retirement real estate and communities, the retirement community is the best platform. The company can set up its own nursing institutions in the community for the elders or it can introduce the third party of other nursing institutions. Providing special services: insurance institutions can cooperate with relevant institutions suitable for the entertainment of the elderly to provide rich entertainment activities for the elderly. For example, we can cooperate with travel agencies to provide group services for elderly people who like to travel both at home and abroad. They can also work with art groups to arrange regular concerts, reviews, crosstalk and Beijing Opera for the elderly. Giving spiritual care: we can cooperate with professional psychological counseling agencies to adjust the psychological defects of the elderly caused by their children's busy work and lack of family reunion. And the children may also have the situation that they don't understand the mental state of the old person. Professional psychological counseling can also serve as a bridge for the psychological interaction between the elderly and their children.

The last one is to get involved in the elderly real estate. The insurance institutions can explore the innovative mode of "pension product + retirement community". For example, they can regard the total premium of annuity products reaching a certain amount as the condition of staying, and convert the pension payment into the service of the community for the elderly. For large insurance institutions, development mode can be positioned to the customer group with a medium or high consumption level. They can consider associated with real estate developers, building integrated retirement community, large community unit and high-grade institutions shared by multiple large community. So large insurance institutions can make full use their brand and customer advantages, develop a service system for the aged that is integrated with insurance products and financial products and enhance the real estate value of their position with brand value and retirement service characteristics. Also, they can consider renting rooms in high-end hotels for a long time or making a separate home for the elderly in comfortable tourist destinations with a pleasant view and living environment.

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3.4 Brief Summary

From the point of development and current annuity market, annuity products including longevity risk have developed slowly for a long time while new types of insurance such as universal and participating annuity are developing rapidly and occupying the main annuity market, which is closely related to customer perception of risk. At present, the vast majority of customer doesn't have a strong direct perception of "longevity". They concern more about no money, no one to provide pension benefit, healing, nursing after retirement and longevity, so the security demands for annuity eventually project onto the claim to the return on investment. Therefore, participating insurance, universal insurance with features such as short and medium term, savings, return, are more popular.

From the perspective of development trends, due to the influence of the external environment and the relevant provisions of the China Insurance Regulatory Commission on the short-term duration, the trend of long-term and long-term risk protection for annuity products returning to the traditional era is gradually becoming clear. With the trial of individual tax-deferred pension and the business model of starting from pension services for insurance company, the longevity risk and interest rate risk can change to service consumption, completing the change from cost to income. It's expected to promote the true development of annuity products, returning to the nature of life annuity.

4 ANNUITY SUPPLY AND DEMAND ANALYSIS

In theory, commercial annuity, as an important part of the pension system, can provide effective protection for people's retirement. However, in fact, both the market supply and demand for commercial pension funds are not sufficient, the enthusiasm of individuals to participate in commercial endowment insurance is not high, at the same time, insurance companies are not willing to provide life-long annuity products. This section analyzes the factors affecting the supply and demand of annuities.

4.1 Factors Affecting Annuity Supply

There are many clear conclusions about why insurers are not enthusiastic about life annuity businesss. The longevity risk restricts insurers to develop the pension business to a great extent, besides, Mackenzie (2006) concludes that the insurer's development of the pension business is also plagued by investment risk, credit risk, liquidity risk, business risk and so on. It is these factors that limit the expansion of annuity business in the supply side.

4.1.1 Longevity Risk

MacMinn et al. (2006) point out that longevity risk exists at an individual and aggregate level. For the individual, it is the risk of outliving one's accumulated wealth. In the aggregate, it is the risk that the average member of a birth cohort will live longer than expected. MacMinn et al. (2006) also point to the risk of longevity as the main risk of running a life annuity. According to Bauer and Weber (2008)

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and D'Amato et al. (2012), the estimation of the longevity risk of annuity shows the extension of life expectancy will bring great financial risk to the insurers who have the annuity business. In December 2000 , the world's oldest life insurance company, The Equitable Life Assurance Society, was struggling with the risk of longevity and was forced to stop developing new businesses. The insurers lack the effective longevity risk management scheme. Thus, the insurers do not actively expand the annuity business.

4.1.2 Investment Risk

Since the annuity business is a long-term business, the insurer has to consider the investment risks that will be faced when operating the annuity business. It is difficult for annuity insurers to find investment targets that match the life annuity risk and duration in the capital market, and face a large investment risk, which further inhibits the supply of old-age pensions. Brown, Mitchell and Poterba (2001) argue that insurers providing pensions should be based on long-term indexed bond development. Taking China's Treasury bond market as an example, the maturity of treasury bonds issued by the Ministry of Finance of China is only one year, three years, five years, seven years, and ten years, which is obviously shorter than the period of annuities. 20-year and 50-year long-term notes are non-critical-term bonds that are not guaranteed to be issued every year. Therefore, in China, the future cash flow through the investment of government bonds to support the annuity will involve a lot of duration risks.

4.1.3 Business Risk

There is uncertainty in every aspect of the annuity business of the insurers, and the potential loss caused by it, which is called business risk. The most significant risk within business risk is the so-called adverse selection. Thompson (1998) points out that there is a problem of adverse selection of endowment insurance, so the mortality of the insured group is often lower than that of the general population, which also increases the business risk of the annuity insurer.

4.1.4 Credit Risk and Liquidity Risk

Credit risk means that the annuity insurer's counterparty cannot pay the principal or interest of the bond or fulfill its obligations as agreed upon at the end of the transaction. Liquidity risk refers to the inability of a financial asset to trade quickly in a financial market without lowering the market price for a period of time. Usually, the insurer responds to the liquidity risk by retaining a certain reserve. When the reserve is insufficient, the insurer will fall into the liquidity risk. When the reserve is too much, the investment income will be reduced.

4.2 Factors Affecting Annuity Demand

Retirees convert personal savings into lifetime annuities, and no matter how long they live, they will greatly increase their benefits (Yaari 1965; Mitchell et al. 1999; Davidoff et al. 2005). However, so far, few retirees have voluntarily bought annuities, a phenomenon often referred to as "annuity puzzle". Many academics have been trying to explain the slump in the annuity market.

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4.2.1 Bequests and Precautionary Expenditure

The idea that bequest motives affect annuities derives from an influential paper by Yaari (1965). Frideman and Warshawsky (1990), Vidal-melia and lejarraga-garcia (2006) indicate the existence of bequest motives, to a certain extent, will reduce the demand for lifelong annuity. Then Lockwood（2012）constructs a model of bequest motivation, and finds that even a weak bequest motive would completely eliminate the benefits of annuities. It is considered that bequest motivation is the most important factor which limits annuity demand. But many scholars have different views. The difference between levels of the motivation of the estate in families with children and without children is not significant in Hurd (1987). Johnson et al. (2004) find that elderly people with children have the similar amount of pension as those with no children. In the case of bequest motivation, although complete annuitization is no longer the best choice, partial annuitization is still the best option (Davidoff 2005; Hainaut 2006).

4.2.2 Adverse Selection

Austin (1811) observes that adverse selection has an inhibitory effect on annuity demand. Many literatures discuss the unfair pricing caused by adverse selection (Friedman and Warshawsky 1988; Mitchell et al. 1999) on the impact of annuity demand. Brown et al. (2002), by analyzing the purchase of annuities, find that mortality of annuitants is basically lower than in the general population. In general, people with poor health care are less interested in annuities and tend to live longer (Brown 2001; Brown et al. 2007). Dowd and Blake (2006) suggest that adverse selection makes the risk of mortality in the purchase of annuities higher, and insurance companies are forced to raise the price of annuities, which reduces the demand for annuity products.

4.2.3 Public Pension System

The report of OECD in 2004 shows that some public pension schemes can replace a large share of the typical worker's income upon retirement. The crowding-out effect of government pensions (Mitchell et al. 1999; Brown et al. 2000) renders the public pension system a strong competitor in the private annuity market. At the same time, higher level of annuitization from social security or DB pension plan may lead to low demand for additional annuitization (Dushi and Webb 2004).

4.2.4 Lack of Understanding

Smith and the Stewart (2008) prove that the lack of financial knowledge among general public is prevalent. That shows that the lack of understanding by potential annuitants of an annuity's properties deserves a place, and probably a prominent one, among the influences that have inhibited the growth of the annuity market. People may not be aware that the conditional rate of return to an annuity is significantly higher than the rate of return to more conventional fixed interest instruments. Some scholars also prove that lack of financial know-how and annuity demand are negatively correlated (Goedde-Menke et al. 2014; Banks et al. 2015).

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4.2.5 Tax-favored Competing Assets

Most countries provide substantial concessions to the elderly through their income tax system (Gordon and the Edward 2003). The tax systems of many countries reduce the demand for annuities by treating other assets more favorably. In the United States, the purchase of an annuity does not reduce the account holder's liability to tax upon withdrawal of the funds in the account. In Canada, holders of tax-favored savings plans must at age 69 either buy an annuity or set up what is known as a "discretionary managed" withdrawal plan to avoid paying tax on distributions. Haigh (2009) believes that tax incentives are an important reason for the rapid development of corporate annuities. If we consider the tax treatment of the source of pension funds, the OECD national tax system is less favorable to the individual annuity than the pension provided by the employer, which inhibits the demand for personal annuity.

4.2.6 Reverse Mortgage market

Markets for reverse mortgages are found in Australia, the United Kingdom and the United States. As Mitchell and Piggott (2003) suggest, the demand for reverse mortgages may be inhibited by the bequest motive. Whatever form the loan on the property takes, taking out a reverse mortgage means that the consumption of the homeowner can be higher than it otherwise would be, and the size of the potential bequest she could make would be lower. The further growth of the market could stimulate demand for annuities, particularly among childless homeowners, for whom the bequest motive would presumably be less strong.

4.3 Quantitative Analysis of Annuity Supply and Demand

In the previous section, we have analyzed the factors that affect the supply and the demand of annuity. In this part we will further quantify the supply and demand of annuities. By literature study, we can find that the quantitative analysis of the supply and demand of annuities is mainly divided into two categories, one is theoretical analysis based on the model, and the optimal annuity strategy is simulated by constructing the buyer's utility model; the other is empirical analysis based on actual survey data through survey data to determine the relationship between annuity supply and demand and some other variables.

Yarri（1965) constructs a standard life cycle model for rational individuals with only consumption utility. The model's forecast results show that annuities are the best choice for retirees who have no bequest motivation and risk aversion. However, this is inconsistent with the actual situation. Mitchell et al. (1999) and Finkelstein and Poterba (2004) point out that management costs, adverse selection, incomplete market, and other factors lead to higher premium rates for annuity products, thereby reducing annuity requirements. Inkmann et al. (2011) and Lockwood (2012) have improved the accuracy of model predictions by adding utility of bequest to the life cycle model. Ameriks et al. (2011) further add the uncertainty of future medical expenditures in the model to analyze the optimal annuity strategy for retirees.

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Brown et al. (2008) believe that although many studies have introduced one or more of these reasons into the economic model, which can explain the low demand of annuity, but these studies cannot provide a sufficient general explanation. Therefore, some scholars regard the sluggish annuity demand as a behavior-oriented phenomenon. Hu and Scott (2007) discuss from an irrational point of view why annuities are not attractive to retirees. Agnew et al. (2007) find by behavioral experiments that gender has a significant impact on people's annuity decisions, and women tend to be more likely than men to purchase annuities.

In addition to the model analysis, some scholars also analyze and research individual annuity intentions using actual data, and then conduct an empirical analysis of annuity supply and demand. Based on the United States Health and Retirement Survey (HRS: Health and Retirement Survey) Brown (2001) analyzes the annuity of 51 to 61 year olds. Taking the willingness of purchasing annuity as a dependent variable of the probit model, He finds that the utility value AEW of fully annuitization can greatly influence people to purchase annuities, while those who are not married, risk averse and healthy will also be more inclined to buy annuity. The factors such as race, education level, and occupation have a limited effect on the annuitization intention. Butler and Teppa (2007) use the business data of the Swiss Employer Pension Plan to carry out a Tobit Regression to the annuitization intention. The results of the study show that the fully annuity utility measure AEW is a strong and stable influence on the pension annuitization. This is consistent with the conclusion of Brown (2001). Cappelletti et al. (2013) classifies the degree of personal preference for annuitization based on the Survey of Household Income and Wealth (SHIW) and establish an order probit model. The study shows that the demand for annuities will be lowers than average among the poor and the less educated, and that they will have relatively higher price elasticity for annuity products. Chalmers and Reuter (2012) and Previtero (2014) analyze historical data and point out that there is a negative correlation between the return rate of the securities market and the annuity of retirees. The increase in the return of the securities market will reduce people's willingness to purchase annuities. Hagen (2015) analyzes the annuity issue of professional annuities based on the micro data of Swedish occupational annuities and national statistics. Hagen points out that the wealth accumulated during retirement and the individual's expectations of their physical condition will significantly influence people's decision whether to purchase annuities or not. At the same time, the change of annuity price caused by various policies will also influence people's decision.

4.4 Brief Summary

In the quantitative analysis of annuity supply and demand, one idea is to calculate and analyze the individual's optimal annuity purchase decision through the life cycle model. Scholars simulate and analyze an individual's annuity purchase behavior by considering the additional rate of annuity products, the individual's legacy motives, the uncertainty of future medical expenses, and some irrational factors. Another idea is to analyze the impact of various factors on the willingness to purchase an annuity through a qualitative selection model (eg, the probit model). Studies have shown that the design of annuity products, the performance of financial markets, and some individual

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characteristics (education, personal wealth, health, etc.) have a greater impact on an individual's willingness to purchase an annuity.

5 LONGEVITY RISK MEASUREMENT AND MANAGEMENT

5.1 Mortality Trend Worldwide

With the development of social welfare, the mortality rate of the population has been continuously reduced, and the life expectancy of the population has been continuously extended. Although there are differences in the law of mortality changes in different countries in different periods, the overall trend is basically the same.

The changes in mortality over time can be roughly divided into two phases: the first phase has a high level of mortality and long duration from the birth of human society to the outbreak of the industrial revolution; the second phase, from the industrial revolution to the present, has a phenomenon that the total mortality rate of the population has gradually decreased, and the life expectancy has increased substantially. Galor and Moav (2005) points out that human life expectancy in ancient times was roughly 20 to 30 years. By the middle of the 18th century, life expectancy in the developed world was only 40-45 years, and life expectancy has risen by just under 20 years over the past few tens of thousands of years. After the industrial revolution, the decline in human mortality began to accelerate. In the beginning of the 21st century, human life expectancy had reached about 70 years old in the developed countries. From the data we can see the human life expectancy roughly tripled over the course and much of this increase has happened in the past 150 years.

The significant decrease of mortality after the 20th century can be divided into two phases. In the first half of the 20th century, the decrease of infant mortality rate contributes more and the curve of force of mortality, which we usually called it “bathtub curve”, has a sharp drop in the young ages. And in the second half of the 20th century, the decrease of high-age population death rate contributes more and the “bathtub curve” will have a steadier and slow increase in old ages. As for the survival curve, the proportion of the population still alive at some given age increases as we move forward in calendar time and the slope of the survival curve has become more rectangular through time.

Using Netherland mortality data from HMD（Human Mortality Database）, we try to illustrate the trend of mortality rate and life expectancy over time.

5.1.1 Death Rates over age

To describe trends in mortality over age, while avoiding the extremes in specific year, we selected the 5-year age-specific sex-mortality data from the HMD database in the Netherlands for different ages, see Figure 8.

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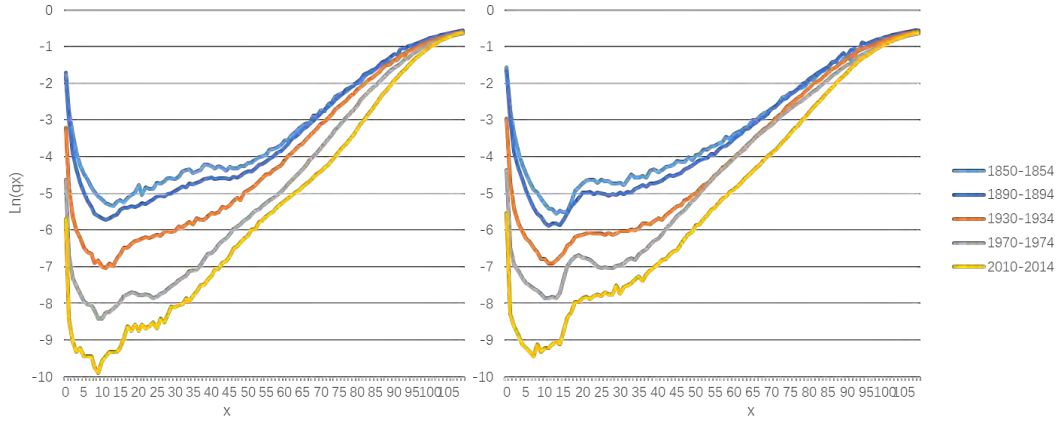

Figure 8 The mortality (on the log scale) for Netherlands females (left panel) and Netherlands males (right panel) from period life tables 1850-1854, 1890-1894, 1930-1934, 1970-1974, 2010-2014.

As can be seen from Figure 8, from the same period, the male mortality curve is higher than the female overall, indicating that the male mortality rate in the same period is greater than the female mortality rate; from different ages, the age-specific mortality rate has improved significantly over time; In terms of age-specific mortality, infant mortality is higher, and mortality during adolescence is lower. There is a rise in mortality in the age of 20, and males are more prominent than females. The main reason is this age. Young people in the segment, especially men, like adventure and high-risk activities such as rock climbing, diving, and jumping and so on. Therefore, they have a high probability of accidents and high mortality. After the age group, the mortality rate showed an overall trend of increasing gradually with age.

5.1.2 Death rates over year

To describe trends in mortality over time, we select four equal spaced specific ages 20, 40, 60, 80 and draw the curve about death rates by year.

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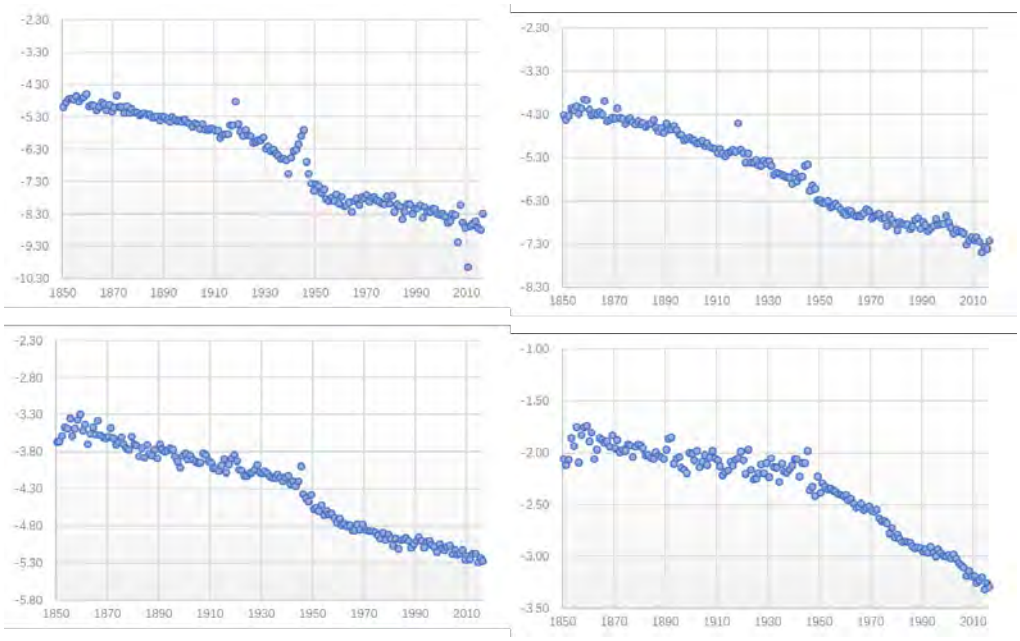

Figure 9 Trends in death rates (on the log scale) for Netherlands females at age 20, 40, 60, 80, period 1850-2016.

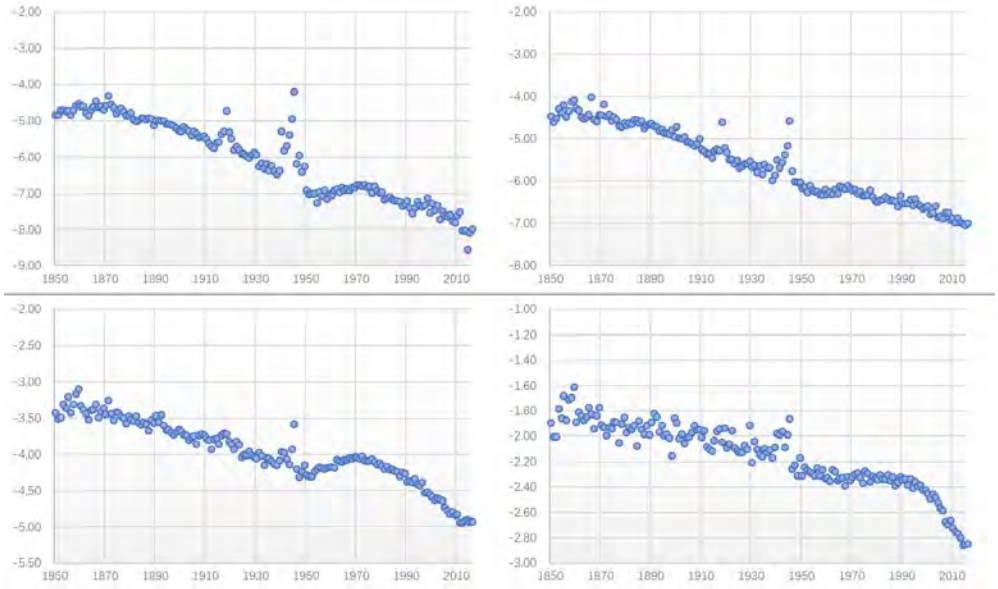

Figure 10 Trends in death rates (on the log scale) for Netherlands males at age 20, 40, 60, 80, period 1850-2016.

From Figure 9 and Figure 10, we can see that death rates at different ages show a downward trend over time, but there was a difference in the rate of decline at different ages in different periods, the

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improvement of death rates has differences in age and time. At the same time, there are random fluctuations in the declining trend of mortality rates. In some years there is a sharp rise in mortality rates. Among them, the sharp in year near 1915 and year near 1940 may have a relation with World War I and World War II.

5.1.3 The rectangularity and extension of the survival curve

With the decrease of death rates, the survival curves become more "rectangular" and "extended". As we see from Figure 11 about the survival curve for Netherlands females and males in different periods, the infant's death rates have a significant improve after 1930 and become flatten in later years. For people in old ages, the decrease of death rates has delayed the age that had a sharp decrease. Since the mortality rate of women is generally lower than that of men, the "rectangularization" of their survival curves is more obvious.

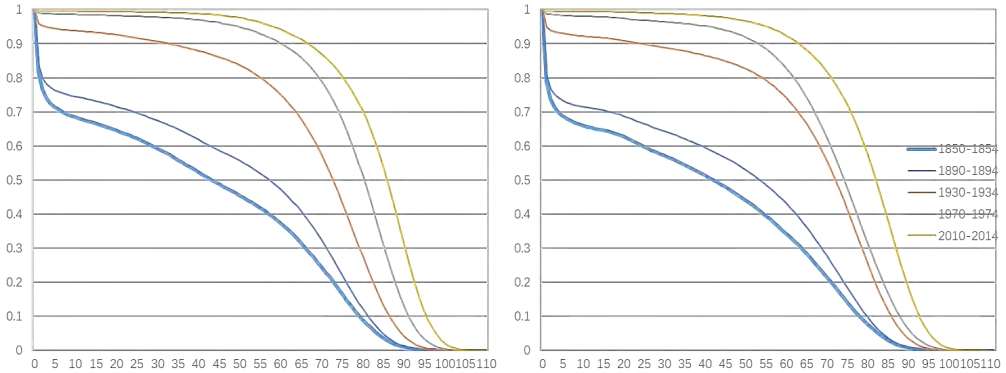

Figure 11 Survival curves for Netherlands females (left panel) and Netherlands males (right panel) corresponding to the 1850-1854, 1890-1894, 1930-1934, 1970-1974 and 2010-2014 period life tables.

5.1.4 Life expectancy

Life expectancy is an important indicator that comprehensively reflects the level of mortality. Figure 12 and Figure 13 display the changes in life expectancy over time at birth (0-year-old) and at age 60 in Netherlands.

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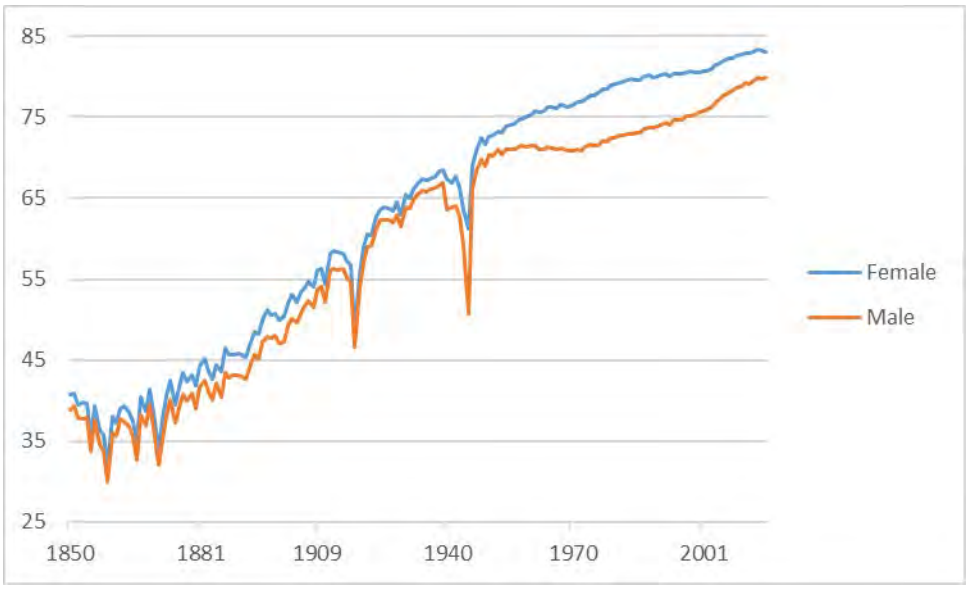

Figure 12 Life expectancy at birth

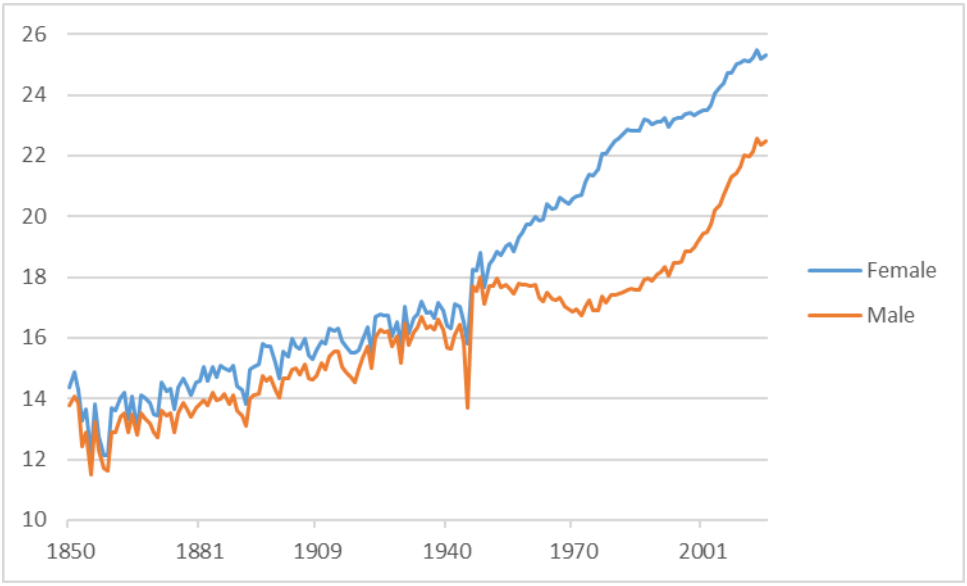

Figure 13 Life expectancy at age 60

We can see that the life expectancy of 0-year-old and age 60-year-old continues to increase over time, and the increase in women is greater than that of men. During World War I and World War II periods, life expectancy also showed downward fluctuations due to rising mortality.

5.1.5 Main conclusion

With the development of society, human mortality has been declining and life expectancy has increased. The survival curve presents an overall trend of "rectangularization" and expansion. The decrease in mortality and the extension of life expectancy show long-term trends and short-term volatility. At the same time, there are differences in the rate of improvement in mortality at different

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ages and in different periods. Due to extreme factors such as war, there may be extreme "jumps" in mortality and life expectancy.

5.2 Mortality Modelling in China

Since the second half of the 20th century, the mortality rate of the whole world has shown a downward trend. The reduction of mortality rate and the extension of life expectancy, especially the unexpected reduction of mortality rate, have brought unpredictable financial pressure to the arrangement of pension system and the financial accounting of pension annuity. Mortality prediction is the core issue of population prediction, pension and health insurance cost and debt assessment, and longevity risk measurement and management. It has an important impact on the government pension system, employer occupational annuity, insurance company's group and individual pension business. In recent decades, new progress has been made in the study of mortality models, from static models describing mortality with age to dynamic models containing age and time factors, to dynamic models containing age, time and birth cohort factors and Bayesian mortality models containing prior information.

Population aging and longevity risk in China are impacting the financial sustainability of the pension system. Many scholars have studied the construction and prediction of mortality rate in China. Zhu Wei et al. (2009) modeled mortality rate of the population of China and predicted the future mortality rate with the Lee-Carter model. Li Zhisheng and Liu Hengjia (2010) analyzed the goodness of fit of various fitting methods of Lee-Carter model, and estimated the average life expectancy of Chinese population in the future. According to Bayesian criterion and likelihood ratio test, Wang Xiaojun and Huang Shunlin (2011) compared and selected several dynamic mortality models and predicted the future mortality on this basis.

Considering that mortality data for population in China is limited, we first used relatively sufficient mortality data from Taiwan and model selection criteria in the literature, evaluated and compared of Biological rationality, robustness, fit and prediction ability of six mortality models commonly used in literature, and chose the mortality prediction models that fit mortality data of China. Then, the actual data of population mortality in mainland China were used for modeling and validation. The data is characterized by a mortality prediction model and predicts future mortality.

5.2.1 Description of data

The Human Mortality Database HMD (Human Mortality Database) provides age-sex Mortality data for different years in 39 countries and regions in the world. Among them, the mortality data of most European countries is over 100 years, and the mortality data chain of Taiwan in China is relatively short, with a total of 44 consecutive years. The data of population mortality in mainland China has not yet entered the database. The age-specific mortality data for the mainland population come from census and sample population data released by the national bureau of statistics, from 1981 to 2016, there were only a total of 26 years of age-sex mortality data. Data for 1981, 1989, 2000 and 2010 came

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from four national censuses, data for 1986, 1995, 2005 and 2015 came from a national sample survey of 1 percent of the population, the sample size of these data is large and the data quality is good. The remaining data come from the sampling survey of population changes of about 1‰ nationwide, the data are highly volatile and need to be corrected before it can be used. In terms of continuous time, there are only 23 years of data from 1994 to 2016.

In the modeling and prediction of the dynamic mortality model and the Bayesian mortality model, in order to capture the variation of model parameters over time, long time series data is usually required. When testing the robustness of the model, it is necessary to change the length of the selected data for analysis, and also requires longer historical data. Considering the short time series of population mortality data in China and the quality of data, then using dynamic mortality model and Bayesian mortality model to model and predict, it usually requires a long time series data for capture the variation rule of model parameters over time. When verifying the robustness of the model, the period length of the selected data needs to be changed for analysis, as well as long historical data. Considering the short time series and data quality of mortality data in mainland China, we assume that the change pattern of mortality rate in Taiwan is similar to that of mainland China, the selected model is compared and evaluated with the population data of Taiwan.

The human mortality database provides data on the number of deaths, risk exposures and death rates in Taiwan from 1970 to 2014 in the age group of 0-110 years. Due to the high volatility of death data over the age of 100 in Taiwan, we used the data of men aged 0-100 in Taiwan for analysis.

5.2.2 Model selection

There are some well-known stochastic mortality models in academic analysis and in practice application. We list the mortality models development and longevity risk management in appendix B. For the previously study mentioned, LC model, RH model, APC model and Plat model, CBD model and its extension is widely used. Cairns et al. (2009, 2011) compared different types of stochastic mortality models and concluded that the BIC ranking of RH model was higher, RH model and CBD model accord with the biological rationality, have the robustness, and have good fitting and prediction effect on the death rate of the aged population. Therefore, we choose LC model, RH model and CBD model for comparative analysis. The above three models respectively represent the benchmark model, cohort effect model and the model to distinguish the influence of old age. In addition, Plat (2009) compared the fitting and prediction effects of LC model, RH model and CBD model and Plat model, and believed that Plat model had significant advantages in fitting prediction. Therefore, the Plat model represented by differentiating the influence of low age was selected for comparative analysis with other random mortality models.

In addition, Bayesian prediction method can also get good results in mortality fitting and prediction. Bayes method is divided into two types. One is to extend the parameter estimation using Bayes method based on the Lee Carter model, such as Pedroza (2006), Girosi and King (2008), Reichmuth and Sarferaz (2008), Li (2014), etc. The other is direct with Bayesian Hierarchical Model using MCMC

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method of the number of deaths and risk exposure estimation and prediction, such as Bryant (2013). Li (2014) pointed out that the combination of LC model and Bayesian method could obtain accurate mortality prediction results, and the method could be modified to apply to limited data. Bryant et al. (2013) pointed out that Bayesian Hierarchical Model can obtain accurate fitting and prediction results, also can apply data from different sources. In view of the above advantages of Bayesian model, we use Bayesian model represented by Bayesian hierarchical model to compare with the above stochastic mortality model.

Five random mortality models and two Bayesian models commonly used in the above literature were selected for comparison. Among them, the first four models are the traditional stochastic logarithmic mortality model; the fifth model is the Bayesian model. Parameter x is age, $\bar{x}$ is average age, t is time, α_x is average effect of mortality, β_x is age effect, κ_t is time effect, γ_{t-x} is cohort effect, $\varepsilon_{x,t}$ is random error, and e is risk exposure number.

5.2.3 Model evaluation

The random logarithmic mortality model, the stochastic difference model and the Bayesian model have their own characteristics. In order to compare the fitting effects of different models, it is necessary to select appropriate criteria for model comparison and evaluation. Both models have their own characteristics. For quantify and compare the fitting effects of different models more accurately, it is necessary to select consistent and appropriate criteria for model evaluation. Cairns et al. (2009) chose BIC criteria and standardized residuals for comparison. Mitchell et al. (2013) chose Root Sum of Squared errors (RSSE) as the evaluation criterion and compared the model of the difference between the model with the traditional LC, RH and other models to fit and predict the results. Here, we use Root Sum of Squared errors (RSSE) as the criteria for model evaluation. RSSE is defined as follows:

$$RSSE = \sqrt{\sum_{x,t} \varepsilon_{x,t}^2}$$

The data of male mortality rate from 0 to 100 years old in Taiwan from 1970 to 2004 were fitted. The improvement of RSSE of each model and the improvement of RSSE vs. LC model of each model are shown in Table 8. When the Bayesian model was applied, the MCMC method was used to conduct a total of 180,000 samples. One sample was taken every 20 times. The first 3,000 samples were discarded, and the remaining 6,000 samples were used to obtain fitting and prediction results. Due to the particularity of the MCMC sampling method, the Bayesian model obtains the empirical distribution of mortality when fitting the mortality rate. When calculating the RSSE of the Bayesian model, the mean value of the fitted empirical distribution is used to calculate the error of the historical data.

In all five models, the RSSE of the LC model was 1.12; except for the CBD model, the RSSE of the other models was smaller than the RSSE of the LC model, and the CBD model had no advantage for the fitting of Taiwan's all-age mortality data. Compared to the LC model, the RSS model of the Plat model is 11% smaller and the best fit is achieved in all models.

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Table 8 Fitted RSSE

Model	RSSE
LC	1.1218
RH	1.0697
CBD	2.2191
Plat	0.9991
Bayes-hi	1.0583

Figure 14 shows the fitting values and prediction intervals of each model. The fit of the model to historical data can be seen intuitively through the fitting graph. For the fitting of historical data, the LC model can better reproduce the average trend of mortality. The prediction range of the LC model is relatively smooth, and the prediction range for each age group is narrow. This is particularly evident at senior age. From the point of view of the volatility of historical data, the 85-year-old mortality rate is more volatile and the forecasting interval is the narrowest. A narrower prediction interval reflects the less uncertainty of the prediction interval and the forecast is more certain. From this point of view, the LC model does not have biological rationality, and does not reflect the volatility of the historical data of the mortality rate of the old age group. This is the fact that the LC model's prediction interval width is proportional to β_x , β_{85} is smaller, so the prediction range is narrower. Combined with the fitting plot and the prediction interval, it can be found that the LC model has a poor fitting and predicting effect on the mortality rate of the senior age group, which is consistent with the research results of Cairns et al. (2011). In addition, the LC model underestimates the mortality rate in the low-age group (0 years old) and overestimates the mortality rate in the high-age group (90 years old).

In order to ensure the reliability of the cohort effect, the RH model eliminated fewer than five observed cohorts during the fitting. From the fitting results, the RH model was able to reproduce the changes in mortality over time for all age groups. The prediction range of the RH model has certain fluctuations. The 5-year-old mortality rate fluctuates abnormally from 2005 to 2007 due to the absence of the cohort effect. When the cohort effect was calculated, the queue born in 2002-2004 was excluded. And this part of the population reached 5 years old in 2007 or so, due to the absence of the cohort effect, the forecast interval appeared to have an anomalous change after the first decline. As for the prediction interval width, the RH model has a narrow prediction range for high age groups (75 years old or older) and does not reflect the volatility of the historical data of mortality among older people. The prediction effect of RH model on the mortality rate of the old age group is obvious promoted.

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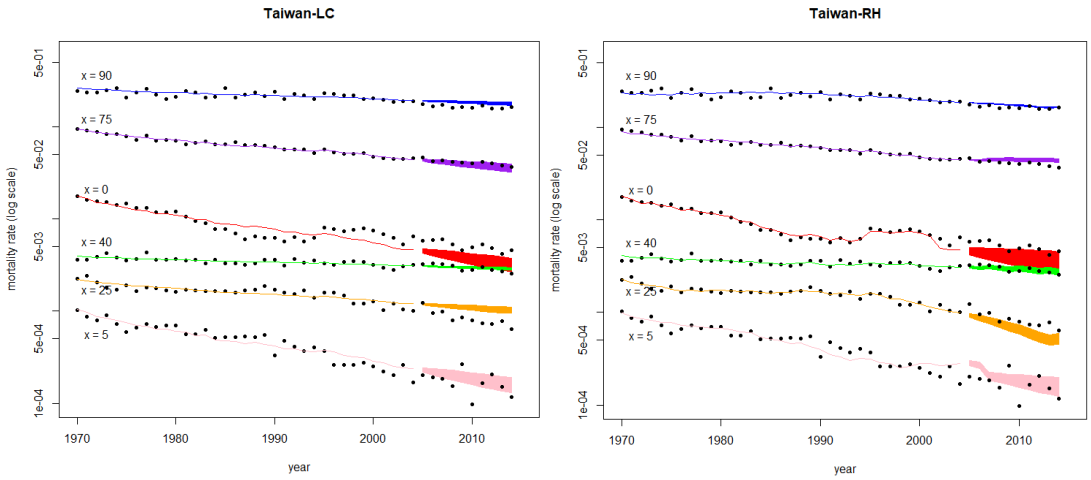
The CBD model was poorly fitted to all age groups, the fit of the low age group was higher than the actual value, and the fit to the high age group was lower than the actual. It is worth noting that the fitting and prediction of the 0-year-old mortality rate in the CBD model (shown by the solid red line and interval) is much lower than the true value. The CBD model does not apply to the fitting and prediction of the full-year mortality rate in Taiwan.

The Plat model has a lower age and cohort effect than the CBD model. The fitting and forecasting results are greatly improved. The fitting value can reflect the fluctuation of the historical data. The prediction interval can cover most of the real values. The Plat model is suitable for fitting and predicting mortality in Taiwan.

The Bayesian hierarchical model can capture the trend and fluctuation characteristics of historical data well. The greater the data volatility, the wider the fitting interval: the fitting interval of the 5-year-old and 90-year-old age groups is wider than other age groups. Beyond the age of 5 and 25, the prediction ranges of other age groups can cover most of the true values, and the slight fluctuations in the prediction interval reflect the volatility of historical data.



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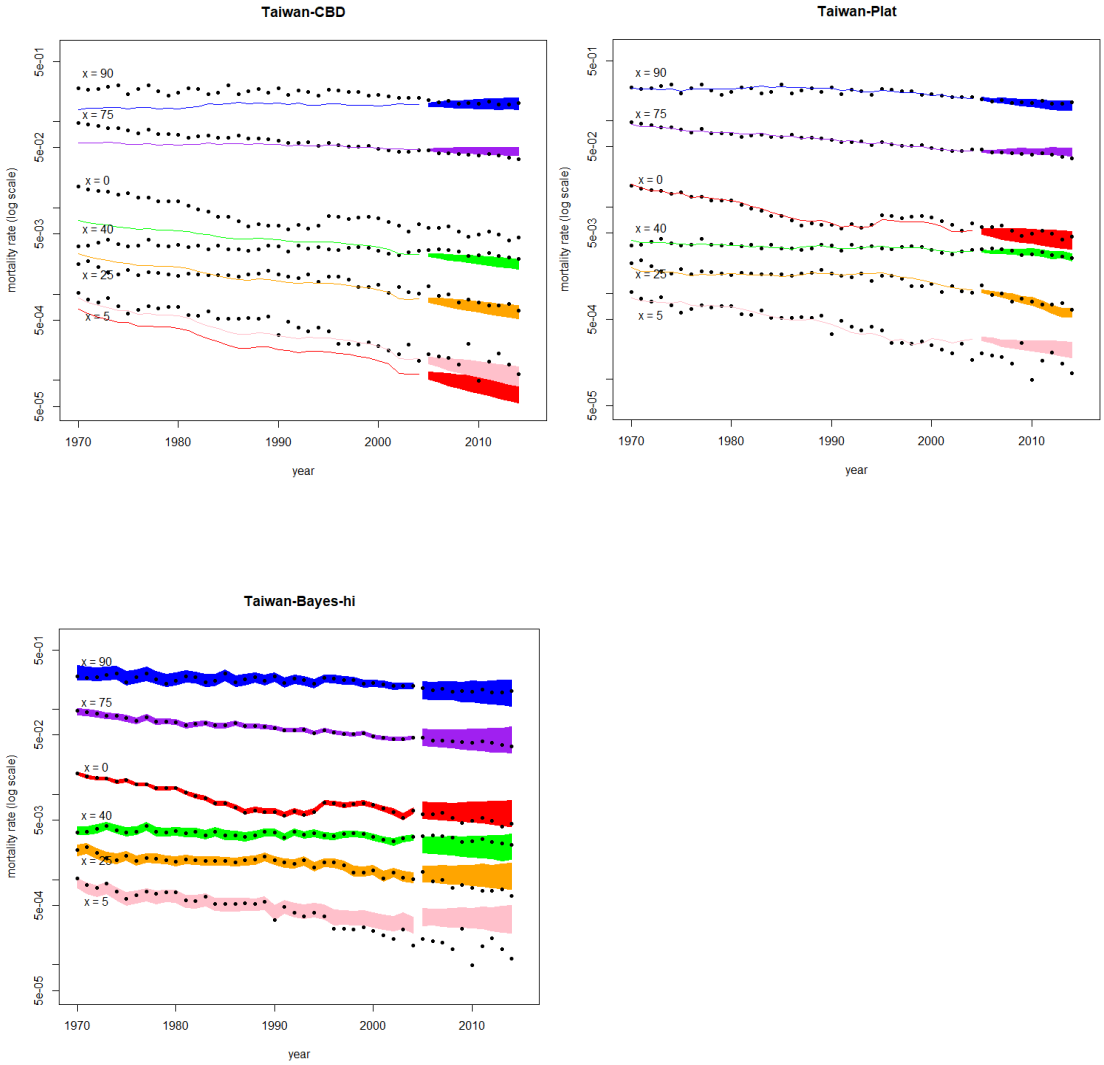

Figure 14 The fitting and prediction of the mortality model

5.2.4 China's Population Mortality Modeling

This section uses the previously selected LC model and Bayesian hierarchical model to model the mortality data in China. The age-specific population mortality data for continuous time in mainland China have a total of 23 years from 1994 to 2016. Among these data, the highest age group in 1996 was 85 years or older, and the highest age group in other years was over 90 years old. For the mortality rate of more than 85 years of age in 1996, we used the split method of the human mortality database to separate. Among them, the historical data of deaths of males aged 60-89 years from 1994 to 2010 were selected to fit the model and the data of 2011-2016 was selected for comparison and prediction. As mentioned above, China's age-specific population mortality data mainly come from the sample survey of the population, and the volatility of the data is relatively large. Figure 15 shows the distribution of age-exposure (a) and mortality (b) for each age group. There was a significant jump in the number of death exposures during the census year and 1% of sample survey years, and mortality fluctuated at different ages.

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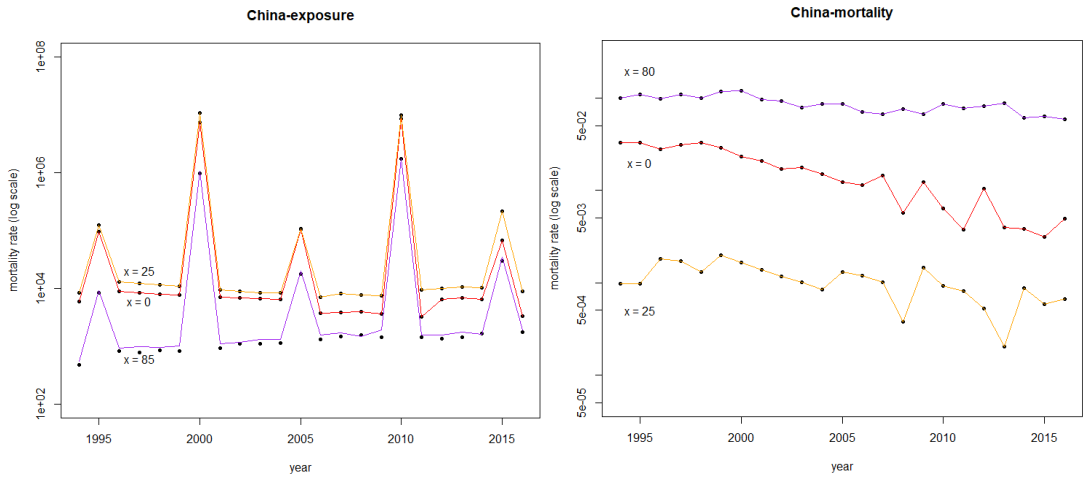
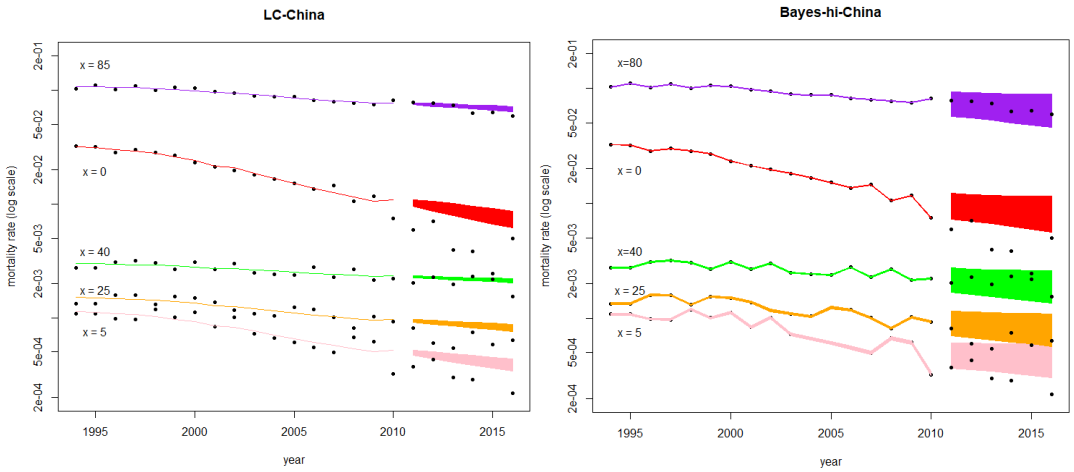


a b

Figure 15 China Population Data

For the comparability of the data, we perform a linear transformation of the mortality risk exposure of the non-census year, dividing the number of exposures for that year by the sampling ratio for that year, and adjusting it to the same magnitude as the census year. The adjusted number of risk exposures multiplied by the death rate to calculate the number of deaths by age and gender. For abnormal fluctuations in mortality rates, we use a treatment method in the human mortality database to smooth the mortality of all ages with cubic splines.

The LC model and the Bayesian hierarchical model are used separately for the processed data. Figure 16 shows the fitting and prediction results of the LC model and the Bayesian hierarchical model for Chinese data. The black dots in the figure indicate the historical mortality data after treatment. After processing, the mortality data of all age groups have the same volatility. However, since the volatility is the same in the logarithmic coordinate system, the data of the 80-year age group appears to be smoother.



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a b

Figure 16 Fitting and prediction of Chinese data smoothing

The LC model has a good fit for historical data of all ages, but it does not capture the volatility of the data and only reflects the average trend of the mortality rate; the LC model has a narrow prediction interval and is generally overestimated for mortality at all ages. We have inferred from the previous modelling of Taiwan mortality data that the LC model itself does not reflect the true volatility of the data in the prediction range of the mortality rate, and the volatility of the mortality data after the smoothing of the domestic mortality data is reduced. The lower the volatility is, the narrower the prediction interval will be. That further reduces the accuracy of LC model prediction.

In contrast, the fitting of the Bayesian hierarchical model can completely capture the volatility of historical data, but the fitting interval is narrower than the fitting interval of Taiwan mortality; the Bayesian hierarchical model has a wide prediction interval and is in the whole age range. In the prediction, except for the overestimation of the mortality rate of the younger age groups (0 years and 5 years old), the prediction of the mortality rate of other age groups is accurate. The prediction range covers all true values and is suitable for application in the management of longevity risk.

5.2.5 Conclusion

We used the mortality data of male population in Taiwan, selected five kinds of mortality models commonly used in the literature, and divided the model into two types: random logarithmic mortality model and Bayesian model. The RSSE and fitted graphs were used to compare the models. The fitting effect was used to test the prediction effect of the model by using the intra-sample prediction of mortality of each model, and the LC model and Bayesian hierarchical model with better fitting and predicting the mortality of the whole age range were selected. Secondly, by observing the robustness of the model by changing the length of the underlying data, the LC model and the Bayesian hierarchical model have better robustness. Finally, the LC model and the Bayesian hierarchical model are constructed by using the age-specific mortality data from mainland China. The results showed that the Bayesian hierarchical model has good effects both in terms of fitting and forecasting. These analyses can lead to the following conclusions:

(1) The fitting error of LC model is relatively small and the prediction interval is narrow. Especially for the older population, the prediction range of mortality is narrow and the prediction is high. The model is robust.

(2) The fitting error of the RH model is larger than that of the LC model. Due to the existence of the queue effect, the forecasting interval of the model presents volatility.

(3) The CBD model cannot accurately fit and predict the low-age mortality data. The fitting value of the historical data of high age mortality can reflect the average trend and fluctuation of the mortality rate. The prediction interval can cover the real value; The Plat model is better to fit and predict the whole

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age range, and the model parameters are more, due to the queue effect. The prediction interval presents a similar RH model to the volatility.

(4) The Bayesian hierarchical model has a good fitting and predicting effect. The fitting interval reflects the volatility of historical data, the prediction interval can cover the real value, and the model has robustness. The less historical data exists, the wider the prediction interval of the Bayesian model will be.

(5) Therefore, the LC model and Bayesian hierarchical model are selected to fit and predict the mortality rate in the whole age range in China. For Chinese data, LC model has narrow prediction interval and high prediction of the mortality rate of the elderly. The prediction results can only cover a small part of the true value of the mortality rate. Bayesian Hierarchy Model captures historical fluctuations in China's mortality data well, and the prediction range better covers the true value of mortality.

In summary, the LC model as the earliest and most commonly used random log mortality model has the advantages of simple implementation and robust prediction, and still has certain advantages over other random mortality models. As a new development model in recent years, the Bayesian hierarchical model has good performance in fitting, prediction, rationality, and robustness, and it performs well in the modeling and prediction the mortality of the elderly in China. In the longevity risk measurement, a Bayesian hierarchical mortality model is recommended.

5.3 International experience on Longevity Risk Management

5.3.1 Longevity Risk Retention

1. Netherlands

In Netherlands, concerning longevity risk retention, insurers' risk mitigating actions include sales stops, product redesign and temporary price increases following the Longevity Principles (NN Life Board, 2015).

In Netherlands, there are mainly two plans to use the combination of a single life annuity and a survivor annuity to hedge against longevity risk (Ralph Stevens et al., 2010):

① Joint-Life plan

In a Joint-Life plan, the participant constructs the right to receive a joint and survivor annuity. Once reaching retirement age, the participant has the option to exchange this annuity for a single life annuity with a higher annual payment (Ralph Stevens et al., 2010).

② Single-Life plan

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In a Single-Life plan, the participant constructs the right to receive a single life annuity. Once reaching retirement age, the participant has the option to exchange part of this annuity for a survivor annuity (Ralph Stevens et al., 2010).

For each of the two plans, longevity risk is considerably lower in case rights are accrued in the form of a joint and survivor annuity than in the form of a single life annuity. Overall, the Joint-Life plan is less sensitive to longevity risk than the Single-Life plan (Ralph Stevens et al., 2010).

2. The United Kingdom

In the United Kingdom, life insurance companies usually provide both life insurance products and annuity products, so there is natural hedging across different lines of business to some extent. However, this hedging to be most effective would require the company's values of life insurance and annuity lines to be cursorily equal, and their new sales values of life insurance and annuities to be cursorily equal. Both requirements limit the usefulness of the natural hedge (Blake and Turner, 2014).

3. The United States

Guo et al. (2017) points out that, the supervision system in the US does not impose strict limits on insurance-funds investment, so insurance funds can be invested in a variety of ways to improve investment return and efficiency. Therefore, insurers in the US can compensate for the loss from longevity risk to some extent by raising their return on investment.

5.3.2 Reinsurance

1. Netherlands

In Netherlands, some insurance companies would build up Cash Flow Indexes, and transfer indexed-based longevity risk to reinsurance companies. In 2014, Nationale Nederlanden Life (NN Life) signed a Stop Loss Cover contract with ING Reinsurance (ING Re), in which Cash Flow Index is established and pension cash flows in the period 2014-2033 would be covered.

2. The United Kingdom

The first international longevity reinsurance transaction took place in June 2011 between Rothesay Life (UK) and Prudential (US) and was valued at £100m (Blake D et al., 2017).

From March 2013 to August 2014, there was a noteworthy increase in activity in the longevity market of the UK, and from September 2013 to August 2014 alone, over £28 billion of longevity risk (PV of liabilities) were transferred to UK's reinsurance market (Munich Re, 2014). These transfers included the largest single transaction up to 2014 – The £16bn Prudential US & British Telecom Pension Scheme deal, written in July 2014 (Munich Re, 2014).

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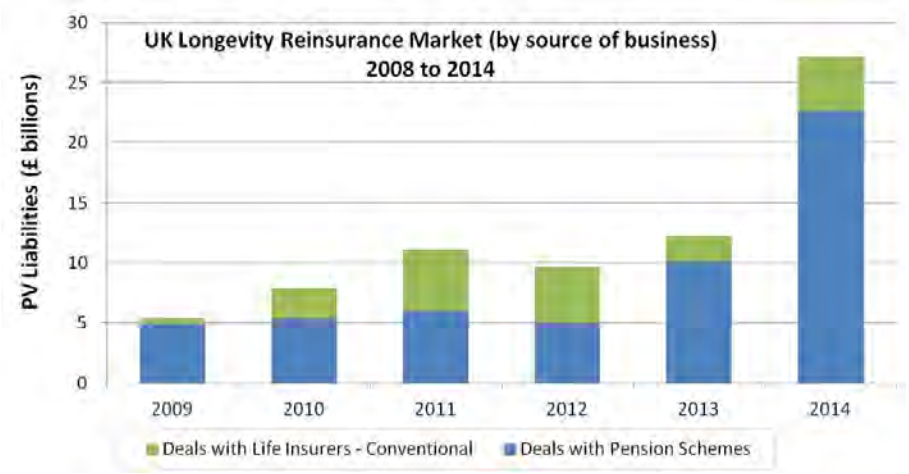

Figure 17 UK Longevity Reinsurance Market from 2008 to 2014 (Munich Re, 2014)

According to the research from Munich Re (2014), there are three main sources of business for longevity reinsurers in the UK: ① Transfers from pension schemes; ② Conventional life insurers – risk transfers from individual annuity providers; ③ Specialist life insurers – risk transfers from enhanced annuity providers. The first source, transfers from pension schemes, has been the most active market since UK DB pension schemes have begun to transfer risk, accounting for approximately half of market volume among the transactions executed in the UK market up to 2014 (Munich Re, 2014).

Munich Re (2014) points out that, there are ten key reinsurance competitors in the longevity market of the UK: Prudential US, RGA, Swiss Re, Hannover Re, Canada Life, Pacific Life Re, Munich Re, XL Re, SCOR, and Royal Bank of Canada.

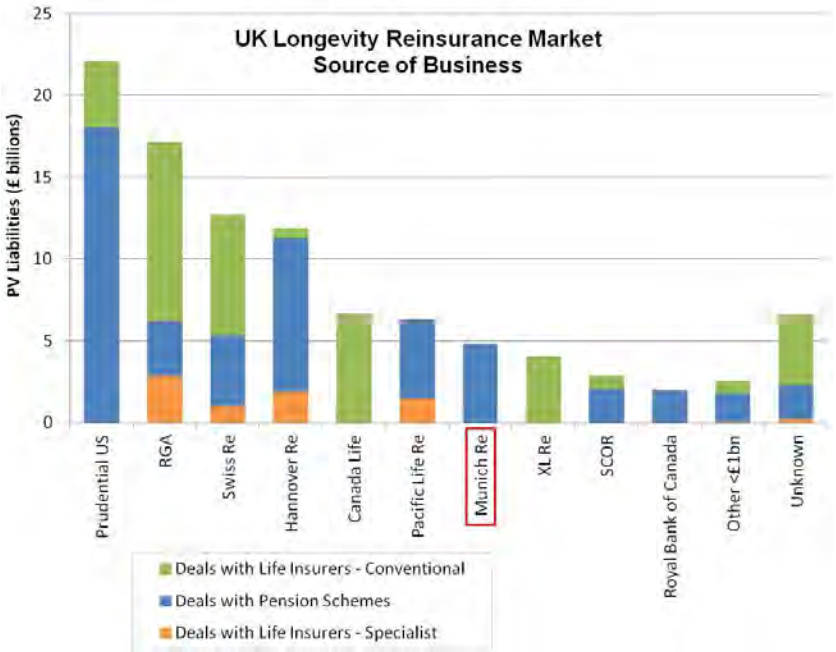

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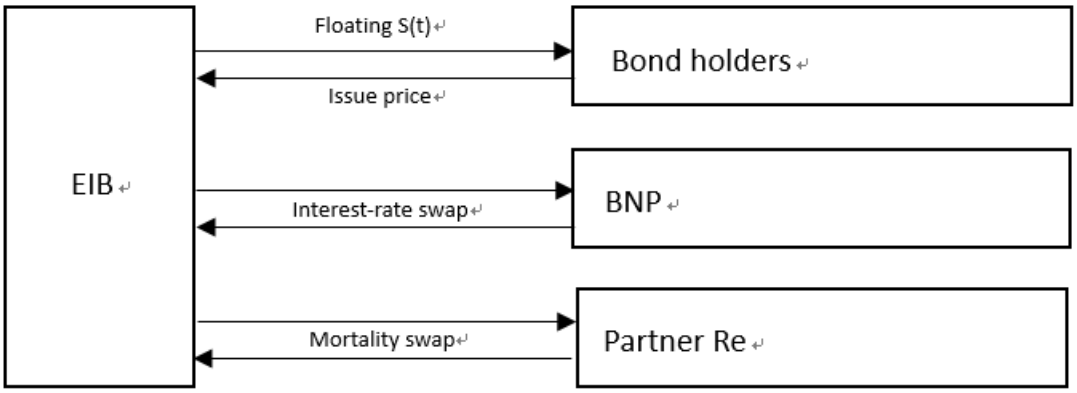
Figure 18 Key Reinsurance Competitors in UK Longevity Market (Munich Re, 2014)

5.3.3 Longevity risk securitization

1. Longevity Bonds

In 2003, Swiss Re established a special purpose vehicle (Vita Capital) that issued USD 400 million in 3-year notes to reduce the company's own exposure to catastrophic mortality events, such as major terrorist attacks, avian flu pandemics, or other natural catastrophes. (Biffis & Blake, 2014)

In November 2004, the European Investment Bank (EIB) announced plans to issue the first longevity bond that would offer coverage for UK pension schemes and life insurers with exposure to longevity risk for the male population of England and Wales. The initial size of the note was GBP 540 million and the maturity of the bond would be 25 years. Although the bond was launched by the EIB, issuance was arranged and managed by BNP Paribas. Under this structure BNP would effectively bear the investment risk and the longevity risk would be covered by Partner Re that had concluded an agreement with BNP. This bond was much closer in nature to the "classical" survivor bond proposed by Blake and Burrows (2001).



However, the bond was only partially subscribed, and was later withdrawn, primarily because the pension industry found the price of coverage on longevity risk too high. In addition, other factors were mentioned such as lacking of sufficient flexibility and transparency, along with the high basis risk (Biffis & Blake, 2014). In 2008 and 2009, World Bank, BNP Paribas, J. P. Morgan and Munich Re, among others, tried to issue long-term bonds in Chile, but encountered obstacles such as the high cost of bonds and the idiosyncrasies of Chilean insurers that eventually led to failed attempts (Coughlan et al., 2007).

In December 2010, based on the lessons learned from the failures, Swiss Re launched a series of eight-year longevity-based ILS notes valued at $50m. To do this, it used a special purpose vehicle, Kortis Capital, based in the Cayman Islands. As with the mortality bonds, the longevity notes are designed to hedge Swiss Re's own exposure to mortality and longevity risk. In particular, holders of the notes are exposed to an increase in the spread between mortality improvements in 75–85-year-old

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English & Welsh males and 55–65-year-old US males, indicating that Swiss Re has life insurance (mortality risk) exposure in the US and pension (longevity risk) exposure in the UK. (As discussed in Blake et al, 2017)

2. Longevity Swap

The first publicly announced longevity swap took place in April 2007: Swiss Re agreed to assume the longevity risk of £1.7bn pension annuity contracts written by Friends' Provident, a UK life assurer, in exchange for an undisclosed premium. However, the risk transfer within this longevity swap is limited to the reinsurance company and the nature of the contract is an insurance compensation contract rather than a capital market transaction.

The world's first capital market longevity swap was executed in July 2008. Canada Life hedged £500m of its UK-based annuity book (purchased from the defunct UK life insurer Equitable Life). This was a 40-year swap customized to the insurer's longevity exposure to 125,000 annuitants. The longevity risk was fully transferred to investors, which included hedge funds and insurance-linked securities (ILS) funds. J. P. Morgan acted as the intermediary and assumes counter-party credit risk.

Forty-eight longevity swaps were completed in the United Kingdom between 2007 and 2016, valued at £75bn and covering 13 insurance companies' annuity and buyout books, 22 private sector pension funds, and one local authority pension fund (some of which executed more than one swap). In August 2011, ITV, the UK's largest commercial TV producer, completed a £1.7bn bespoke longevity swap with Credit Suisse for its £2.2bn pension plan: the cost of the swap is reported as £50m (3% of the swap value). The largest to date, covering £16bn of pension liabilities, was the longevity swap for the British Telecom (BT) Pension Scheme, arranged by the Prudential Insurance Co of America in July 2014. (Blake et al, 2017)

3. Q-Forward

Q-forward contract is an emerging financial derivative based on mortality risk in the international insurance market, which can help insurance companies to effectively deal with the risk of longevity and extreme mortality. The world's first capital market derivative transaction, a q-forward contract between J. P. Morgan and the UK pension fund buy-out company Lucida, took place in January 2008.

4. Longevity Futures and Options

In November 2013, Deutsche Bank introduced the Longevity Experience Option (LEO). It is structured as an out-of-the-money call option spread on 10-year forward survival rates and has a 10-year maturity. The survival rates will be based on males and females in five-year age cohorts (between 50 to 79) derived from the England & Wales and Netherlands LLMA longevity indices. It was reported that Deutsche Bank executed its first LEO transaction with an ILS fund in January 2014. (Blake et al, 2017)

5.4 Low interest rate environment and risk management

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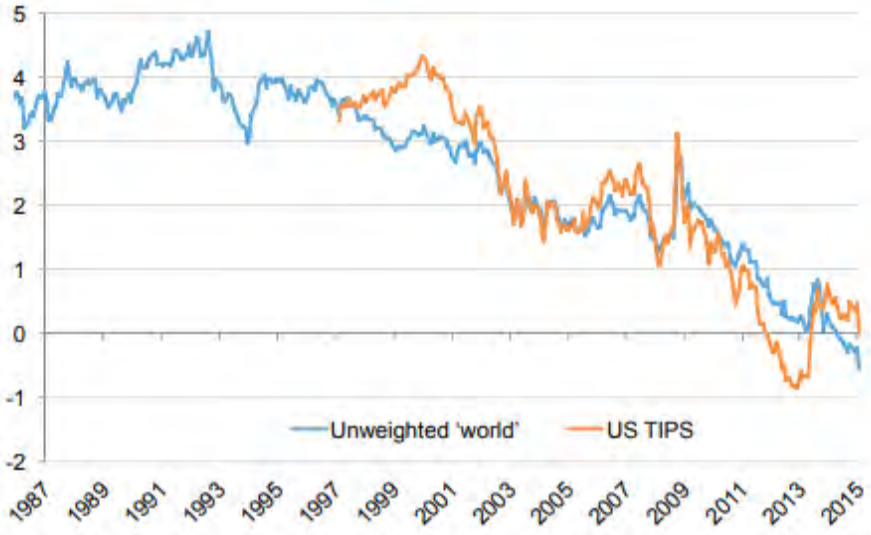
Interest rate risk is one of the important risks in the life insurance industry. With the aging of population and the slowdown of macroeconomic, many countries are entering a low interest rate environment, which brings severe challenges to the development of the life insurance industry. This section firstly reviews the global trend of low interest rate and summarizes the impact of aging on interest rate. Then we introduce the assessments of interest rate risk at domestic and abroad in the life insurance industry, especially the researches on the risk of insurance companies under low interest rate environment. As low interest rate brings a relatively large challenge to the life insurance industry, the experience of relevant insurance industry interest rate risk management is summarized to provide an effective investment management.

5.4.1 Low interest rate tendency under global aging

1. Global low interest tendency

With the global aging, the world's macroeconomic growth rate has slowed down, which has affected the interest payment ability of the capital holders, and thus lower the interest rate. General analysis shows that with the increase of the population aging, the interest rate level shows a downward trend. At the same time, based on previous data, it can be clearly observed that developed economies are facing the risk of decreasing real interest rate.



Notes: 'World' real interest rate is an unbalanced simple average of G7 ex Italy ten-year real yields. Sliced UK indexed gilts were used to proxy world real yields from 1985-1996. From 1997-2006, 'World' rates were calculated using a simple average of spliced US ten-year TIPS and UK IGs. From 2007-2008, 'World' rates were calculated using a simple average of spliced ten-year US, UK, Canada, Japan, and France indexed bonds. From 2008-2015, 'World' rates were calculated using a simple average of spliced 10-year US, UK, Canada, Japan, France, and Germany.

Source: Barclays, Bloomberg mid yields.

Figure 19 Real interest rate movements in US and global market

In many literatures, low interest rate environment has been tested. As shown in Figure 19, both the US market and the global developed markets are faced with a decline in real interest rate. In addition,

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Caballero et al. (2008) observe the global economic imbalance by US data, and obtain the downward trend of real interest rate. Meanwhile, the paper proposes an equilibrium model to explain the reason of low interest rate environment. Maddaloni and Peydró (2011) find low interest environment in Europe and the United States. Rachel and Smith (2015) attempt to explain the phenomenon of low interest rate, the paper finds that in the past three decades, the long-term real interest rate has dropped by 450bps, and the decline in the birth rate can explain this phenomenon to some extent. But the preference of savings and investment is a more important reason of low interest rate. Due to changes in population, people's saving preferences also change, thus affecting real interest rate. In Carvalho (2017), it is found in American society that in the past century, the birth rate of the American social population has declined, and the real interest rate has also declined.

2. Explanation of low interest rate by global aging

For the explanation of the decline in interest rate, global aging is an important factor. Many literatures have argued that population aging and economic growth are negatively correlated by showing empirical results. Bloom et al. (2010) show that under the aging of population, the macroeconomic growth rate will be lowered. The most direct phenomenon is that aging affects the population of labor workers and labor participation rate, thereby reducing macroeconomic growth and affecting real interest rate.

In addition, aging of population will reduce the capital demand for investment and consumer's credit, thus increasing the savings size of pensions and the supply of funds. Since interest rate can be viewed as the measure of price of funds, interest rate will be reduced by the supply and demand forces in the case of oversupply. Based on Chinese data, Li et al (2012) find that under the aging of population, the proportion of savings and investment increases, which will affect the country's economic growth rate and the real interest rate will fall.

Meanwhile, productivity will decline as the population ages, see Lisenkova (2012). By observing the labor market, the paper finds that there is a significant decline in worker's productivity under population aging.

Besides, from the perspective of risk, interest rate is affected by the risk of borrowing. High risk of borrowing will lead to higher interest rate, while low risk of borrowing will result in lower interest rate. At the same time, the risk aversion of the elderly population is prominent, and they are more likely to take stable or low-risk, low-yield activities such as deposits or fund investments. It is also beneficial for financial institutions and capital demanders to obtain funds at low cost. In this respect, aging of the population will also lead to lower interest rate.

Besides aging etc. can lead to the global low interest rate trend, in order to cope with the slowdown of economic development and stimulate economic growth, many central banks have implemented loose monetary policies. For example, since 1991, Japan has repeatedly lowered interest rate. Since the financial crisis in 2007, United States has also lowered down interest rate several times. From the year of 2014, China has also cut interest rate several times. We can see that on one hand, the global

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economic slowdown will lead to a decline in real interest rate. On the other hand, the monetary policy issued in response to the economy has further led to a decline in interest rate.

3. Related empirical analysis

In many previous studies, many scholars analyze the trend of low interest rate under the aging population in foreign markets. The papers often propose an equilibrium economic model, and introduce different economic indicators to describe population changes. By empirical analysis, the impact of population changes on the equilibrium real interest rate is studied. The significance of the relationship between them is also analyzed. In most developed countries, the impact of population ageing on real interest rate can be found.

Ikeda and Saito (2014) study the relationship between population ageing and interest rate trends for Japanese society. In the paper, a general equilibrium model is proposed to validate in Japanese society. Demographic change is characterized by the proportion of the working population. The paper analyzes the impact of demographic change on total factor productivity (TFP). The study finds that in Japanese society, the decline of the proportion of the working population will lead to a decline of real interest rate, which has a significant effect on the long-term trend of interest rate.

Carvalho et al. (2016) point out that population growth rate has two effects on interest rate. On one hand, the increase in capital per person will reduce the productivity of capital, thereby affecting economic trends and further affecting interest rate. On the other hand, the dependency ratio will increase and the speed of economy will also slow down. The paper proposes a relevant life cycle model for developed economies such as Japan, the United States, and Western Europe. Using data from 1990-2014, it is found that the impact of population changes on real interest rate is at least 1.5%. The role of some policies (fiscal policy, monetary policy, and structural reform) on this negative impact is analyzed. However, in Favero et al. (2016), the proportions of the middle population (40-49) and the younger population (20-29) are used to characterize the demographic changes. They act as an important factor in the change of the term structure of the US market. Through empirical studies, it is found that the population changes have a significant effect on inflation, which can affect the evolution of real interest rate.

5.4.2 The impact of low interest rate on Life Insurance Company

1. Features of asset and liability of Life Insurance Company

As a liability-operated enterprise, life insurance companies have unique characteristics of their assets and liabilities. Li (2000) emphasizes the long-term and indebted features of life insurance business. Life insurance business is a liability operation. One of the important issues for the life insurance industry is whether its assets can meet the liabilities of the insurance company that belong to the policy owner.

Interest rate mainly affects the asset and liability structure of life insurance companies at the same time. On one hand, liability structure of life insurance products is determined by the future interest

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rate level. Life insurance company's liabilities mainly come from premium income and exist in different liability reserves. In the assessment of liabilities of life insurance companies, it is necessary to make certain assumptions about the insured's mortality rate and the future discount rate. Choices of future life table and interest rate are important. The liability reserve falls when interest rate increases, and vice versa. In addition, life insurance companies have long-term liabilities with maturities of up to several decades, so their liabilities are easily affected by interest rate. If the central bank cuts down interest rate, the insurance demand will increase, and the surrender rate will also decrease. In addition, the life insurance company's liability reserve will increase, and its liabilities will increase. In theory, when the interest rate is lowered, the insurance company's liabilities will have a significant increase. Coupled with the impact of improvement of mortality, the insurance company's liabilities will also increase.

On the other hand, the insurance company's return of investment is related with the interest rate level. The assets of insurance companies often are invested in deposits, bonds, and stocks. Generally, there is a positive correlation between the rate of return of financial products and interest rate in the market. When the interest rate is low, the insurance company's return from investment will be relatively low, that is, the profit margin is low. So, interest rate can significantly affect the risk level and solvency of life insurance companies. Especially in the latest Solvency II framework, the measurement of the required capital of interest rate risk has great importance on the stability of the pension system. Holsboer (2000) first describes the impact of low interest rate on life insurance companies, indicating that the low interest rate environment also poses a major challenge to the management of pensions. Holsboer (2000) also proposes several feasible solutions. Most of the previous studies have analyzed the structure of the pension market and assessed the solvency of pensions in a low interest rate environment, thus obtaining changes in the annuity market in a low interest rate environment.

2. Global market

Berdin (2016) analyzes the longevity risk and interest rate risk of German pension participants under the framework of Solvency II. The paper obtains the stochastic mortality and interest rate models via historical data. Results show that the interest rate risk is the largest risk of pension participants. However, longevity risk can be reduced by other ways. And it is also found in the article that the phenomenon of low interest rate is reflected in the assessment of assets. Generally, in low interest rate environment, relatively small changes in interest rate will have a big impact on assessment of capital and debt. Therefore in a low interest rate environment, the risk of capital liabilities in Solvency II will be larger, which can have a significant impact on the pension fund. Antolin et al. (2011) find that low interest rate can affect investment opportunities and thus have a significant impact on life insurers. For example, in DB pension plans, liability is determined by the return of investment. Thus, life insurance companies have greater risks in low interest rate environment. In order to reduce the risk of the pension market, Bams (2016) studies the changes of the pension investment strategy since the low interest rate environment. The paper finds that in the low interest rate environment, the proportion of investment in equity decreases, while investment in fixed income assets increases. The results of the

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article show that although pensions cannot make use of future information, they can reasonably adopt investment strategies to reduce the risks brought by low interest rate environment.

Berdin and Gründl (2015) also analyze the challenges faced by life insurance companies in a low interest rate environment. Low interest rate has seriously affected the stability of life insurance. The paper analyzes the changes in the balance sheet of German pension participants under the low interest rate environment. The work analyzes changes of investment return in a stochastic interest rate framework. Based on empirical data, changes in the assets and liabilities of pension participants can be observed. Finally, the paper finds that the low interest rate environment can significantly affect the solvency of pensions, making the life insurance company's ruin probability larger. The same phenomenon is found in Kablau and Wedow (2012). In a low interest rate environment, the return of investment significantly decreases, and the solvency of pensions may deteriorate. Kablau and Wedow (2016) explore the impact of low interest rate environment on German life insurance companies. Based on the life insurance company's balance sheet and different insurance scenarios, it is finally found that low interest rate will bring a reduction in income. Thus the life insurance company's wealth may deteriorate.

The previous work mainly analyzes the impact of interest rate decline on the solvency of insurance companies. It shows that after the interest rate declines, the life insurance industry's solvency and risk level will encounter relatively big challenges. Feng (2005) conducts an in-depth discussion on the bankruptcy of Japan's life insurance industry from 1997 to 2001. Since World War II, due to the rapid economic development, Japanese life insurance companies have also developed rapidly. Especially in 1995, Japan’s life insurance revenue accounted for 41.5% of the global life insurance industry. However, due to the Japanese bubble economy and economic depression, the solvency ratio of Japanese insurance companies has fallen sharply, and the amount of debt has risen, triggering a big bankruptcy wave. Among them, the huge spread of yield is an important reason. Before the Japanese economy collapsed, the life insurance industry sold a large number of products with high yield. After the Japanese economy collapsed, the central bank adopted a policy of ultra-low interest rate, while the economic depression led to the decline of return of other products. Therefore, the life insurance company's yield spread greatly expands, leading to bankruptcy of the company.

3. Chinese market

In Chinese market, the randomness of interest rate is relatively large, and the impact of different interest rate models on pension researches is also significant. Although there is no study in the Chinese market to observe the decline in real interest rate, the recent interest rate cut by the central bank has increased interest risk in the Chinese market. As shown in Figure 20, in Chinese market from year 2011-2015, the central bank cut interest rate frequently, leading to lower bank deposit interest rate. And this indicates that China may also be entering the low interest rate environment. Thus low interest rate will also bring big risk to life insurance companies in China.

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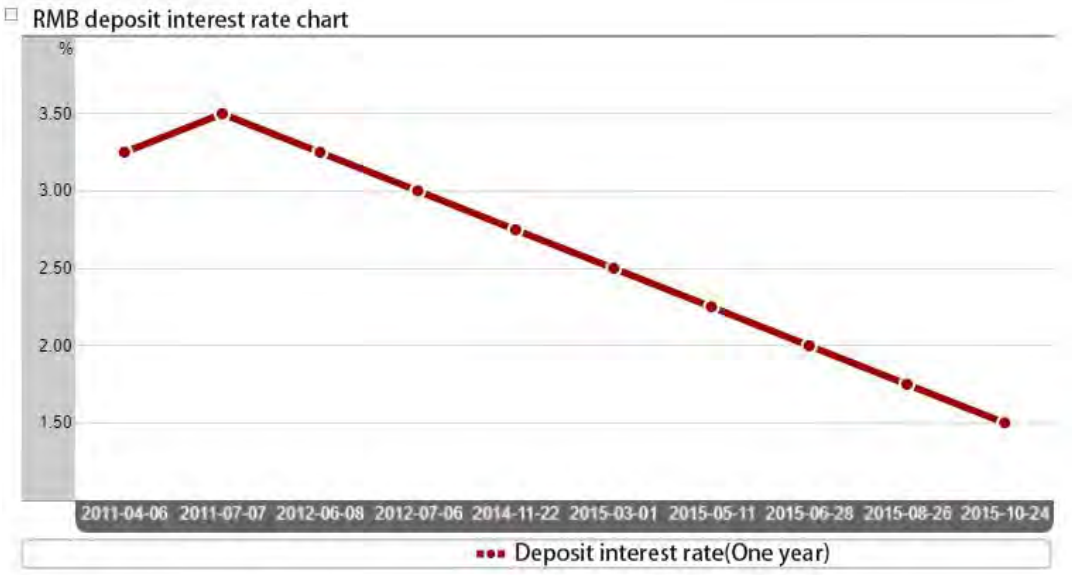

Figure 20 One year interest rate in China from 2011 to 2015

In the study of the interest rate in Chinese market, there are mainly two different ways: static interest rate models and stochastic interest rate models. The static interest rate model estimates the daily term structure by a parametric method, while the stochastic interest rate model uses a stochastic differential equation to fit the interest rate evolution. Pan and Shao (2004) consider the single factor model for analysis in China. The parameters are estimated by maximum likelihood method. The article finds that the CKLS model fits well in Chinese market, and interest rate in the Chinese market also has an obvious mean revision property. More relevant interest rate models are Vasicek model (Zheng et al (2017)), Hull-White model (Song and Shi (2006)), Nelson-Siegel model (Zhang and Liu (2016))), CIR model (Zhang and Lin (2012)) and so on.

Researchers may consider different models of interest rate in the analysis of Chinese market. Due to the importance of the interest rate model in the assessment of life insurance liabilities, researchers often analyze the risk assessment of pensions under different interest rate models. In Zheng et al. (2017), the author calculate the minimum capital requirement of interest rate for the Chinese market. Interest rate is calculated using the Vasicek model. The standard method and Monte Carlo simulation method are also used. The studies show that the results of different calculation methods are quite different. Therefore, when studying the impact of interest rate risk on pensions, on one hand, the choice of interest rate model is more important. On the other hand, the calculation of risk capital and the principles of asset valuation also have an important impact on the outcome. Zhou and Zhang (2014) consider the Smith-Wilson interest rate model based on the European Union Solvency II framework. By calculating and analyzing the reserve for a two-insurance product, S-W interest rate model is found to be superior to the 750-day moving average method used in the past.

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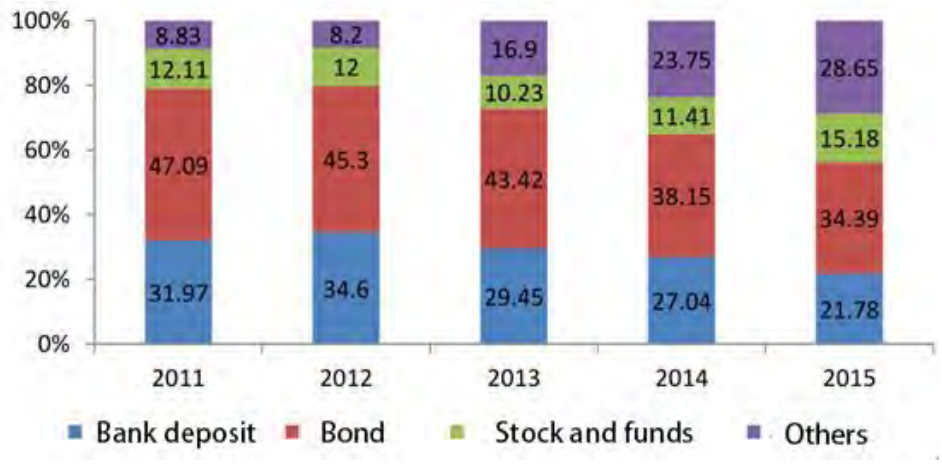

Figure 21 Investment proportions of Chinese insurers

Figure 21 shows that a larger proportion of China's insurer is invested in bank deposits and bonds. However the price fluctuations of these two are closely related to the interest rate level. Therefore, in the risk management of insurance companies, interest rate risk needs to be properly studied. Liu (2003) states that life insurance companies in long-term life insurance have high sensitivity to interest rate. Interest rate risk is the biggest operational risk of life insurance companies. And Liu (2003) proposes several methods to deal with low interest rate environment: expanding investment diversification and optimizing insurer's organizational structure (such as investing based on ALM) and development of bond market.

In Chinese market, with the rapid development of the economy, the life insurance industry has also developed rapidly. At the same time, there is a phenomenon of interest rate loss in China's life insurance industry. Ni (2011) measures and analyzes the size of the interest loss of China's life insurance industry from 1995 to 1999, indicating that the high interest rate life insurance issued in 1995-1999 brings a large risk to Chinese Life Insurance Company. At the same time, due to the long-term feature of life insurance policies, this gap may further expand in the short term. Yang (2017) shows that with the decline of return in China's deposit in recent years, the interest rate loss of these products threatens the operation of Life Insurance Company. This will push some life insurance companies to adopt a radical strategy, which further increases the risk of the life insurance industry and cause instability. Zhu and Fu (2016) state that the central bank's interest rate cuts from 2011 to 2016 bring new opportunities and challenges to China's insurance industry's liability management. Figure 21 also shows that after the interest rate cut, although the investment proportion in bank deposits and bonds decline, but it also has a ratio of more than half. Meanwhile, from 2005 to 2013, the investment return of China's insurance industry is relatively low, and the gap of liability and asset in China is relatively large.

5.4.3 Longevity-Related Annuities

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1. Longevity Insurance Annuities in the United Kingdom

The annuity market in the United Kingdom is the best developed annuity market in the world, and more than half the annuities sold in the world are sold in the UK (Singleton et al. 2010). At one time, longevity insurance annuities, defined as deferred annuities beginning payment at an advanced age, were sold in the United Kingdom, but no life insurance company in the UK offers these annuities to individuals currently (Blake and Turner, 2014). Blake and Turner (2014) point out two reasons for this change. (1) According to Solvency II, without effective hedge against longevity risk, insurers are required to hold adequate capital to cover 99.5% of potential cases of longevity increases. This requirement has raised the cost of providing longevity insurance annuities to the point that the UK's life insurers no longer offer them to individuals, because demand would be insufficient at the prices to be charged to cover the extra reserve costs (Blake and Turner, 2014). (2) Since the beginning of 2013, the pricing of longevity insurance annuities is required to be on a unisex basis. However, for life insurers, the cost difference between genders in providing longevity insurance annuities is much greater than the cost difference in providing immediate annuities at retirement age (Turner and McCarthy, 2013).

2. Longevity Insurance Annuities in the United States

Currently, many life insurance companies in the United States do not offer longevity insurance annuities, which are deferred annuities beginning payment at an advanced age (e.g., 85 years old). Three companies that do offer these annuities are New York Life Insurance Company, Symetra Life Insurance Company and Northwestern Mutual Life Insurance Company (Tergesen, 2012). New York Life is currently the largest provider of this type of annuity in the US. However, among its customers of longevity insurance annuities, only 4% would purchase an annuity which is solely a longevity insurance annuity. Most would choose the annuities providing both annuity payments and death benefits (Turner and McCarthy, 2013).

3. Guaranteed Lifetime Withdrawal Benefit Annuity in Canada

The Guaranteed Lifetime Withdrawal Benefit (GLWB) annuity was introduced to Canada in late 2007 by Manulife Financial (Mitchell et al., 2011). Mitchell et al. (2011) point out that, the initial GLWB product was modeled on the variable annuity, and over time, these products have developed to include riders with features of minimum income stream which purchasers could receive. A GLWB rider gives purchasers the right of partial withdrawals of the account value for lifetime, thus allows them to lock in a minimal income for lifetime (Milevsky and Salisbury, 2006). Therefore, the GWLB annuity can provide its purchasers with some degree of retirement longevity protection without forcing them to surrender upside potential or liquidity (Mitchell et al., 2011).

5.4.4 Interest risk management for insurance company

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Since the existence of interest rate risk in the financial market, it is more important for insurance companies to manage interest rate risk effectively. Considering the management of interest rate risk, some of the literatures manage interest rate risk by the method of risk hedging. In the past years, there are many papers on hedging longevity risk. For example, Cox and Lin (2007) manage longevity risk by combining life insurance products and annuity products. By combining life insurance products and annuity products, the longevity risk can be well hedged. Many related managements of longevity risk are based on Cox and Lin (2007). Later, Huang and Wang (2011) use VaR as a risk measure and predict the mortality rate of Chinese male by APC model. Then they construct the optimal product portfolio to hedge longevity risk. We can see that there are many studies on longevity risk hedging. For more related research, see Jin (2013), Bernard and Boyle (2011) Wong et al. (2017).

However, except the longevity risk, interest rate risk also plays a major role in insurance company's risk management. Along with the global population aging trend, the world's macroeconomic growth rate has slowed down, which has affected the interest payment ability of the capital users, and thus lowered the interest rate. The general analysis shows that as the population ages, the interest rate level shows a downward trend. At the same time, through previous data, it can be clearly observed that developed economies are facing the risk of falling real interest rates. Past literatures mainly assesse interest rate risk of life insurance products based on the asset-liability gap, duration theory and risk value (VaR theory). Studies on hedging interest rate are relatively rare. Generally, researches consider delta hedging or other hedging methods to reduce interest rate risk. For example, Wei and Song (2014) consider natural hedging of life insurance products and annuity products under the framework of stochastic interest rate. However, the paper considers the impact of interest rate risk on annuity products, but does not consider the relevant hedging strategy, especially after natural hedging. Because changes of annuity products and longevity products are the same with interest rate, the addition of longevity products will increase the interest rate risk. Therefore, risk management of interest rate is more important in the insurance company's hedging strategy. Luciano (2012) first considers the management of interest rate risk and longevity risk in annuity products based on the Delta-Gamma method. The work applies stochastic differential equations to present the models of mortality and interest rate, and obtained the optimal ratio of Delta-Gamma hedging for annuity products. Later, Jevtić and Regis (2015) apply Delta hedging investment decision by purchasing bonds in the annuity management. In numerical simulation, the paper finds that interest rate risk is the main risk in annuity products. By Delta hedging, interest rate risk can be efficiently reduced. Although the probability of solvency of annuity products has decreased, other risk levels of annuity products such as coefficient of variation and 0.5% quantile have improved.

More related literatures of interest rate risk management are based on the idea of asset allocation. Since returns of most of the assets in the market, such as deposits, bonds, and stocks, have significant relationship with interest rate. Interest rate risk can be reduced by diversifying investments in different assets. Most papers consider the insurance company's asset-liability framework. For example, based on ALM theory, Gerstner (2008) manage interest rate risk by the allocation of different risk assets. Jin and Huang (2005) use the asset-liability management method to calculate the optimal contribution rate

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and the optimal asset allocation of pension funds in bank deposits, bonds and stocks. The parameters are calibrated based on the actual data of pensions in Liaoning Province to provide an effective reference for pension management

Under stochastic interest rate, Lang (2014) establishes a comprehensive life insurance model and considers several different life insurance products, such as deferred annuity, life insurance, and repayment of the part. The corresponding optimal life insurance model is obtained. For dc pension fund, Zhang and Rong (2012) consider the affine interest rate model and obtain the optimal portfolio of the pension plan by dynamic programming method. The results indicate that under the exponential utility, the manager need to invest more in risky asset near the retirement time. Later, Jia (2014) considers the impact of interest rate and inflation on optimal strategies of pension plans at the same time.

Many literatures have studied the management of fund for insurance company under stochastic interest rate. Most of the works appear in pension management since the invest horizon of pension is relatively long. Boulier et al. (2001) first considers the risk of stochastic interest rate for DC pension fund. They require that the wealth of the pension fund at retirement is above a minimum living guarantee. The paper derives the optimal investment in cash, bond and stock by dynamic programming,. Besides, the paper shows that in the initial time, insurance companies need to borrow money in order to maximize the expected utility at retirement. However Josa-Fombellida and Rincó n-Zapatero (2010) consider the impact of interest rate risk on defined benefit pension plan. Pension manager needs to minimize the actuarial liabilities of the unfinished fund at the time of retirement, i.e. minimizing the final solvency risk. We can see that in order to ensure the solvency of insurance companies at retirement time, most studies have shown that wealth should be invested in risky assets in the initial time. However money should be invested in low risk asset when the retirement time approaches.

6 CONCLUSION AND PROSPECT

This report mainly studies the development of China's Commercial Annuity market and its long-term risk management issues in the context of population aging, slowing economic growth, and lower interest rates. First, we study the current situation of China's pension system and evaluate its adequacy and sustainability. And then analyze the demand for commercial annuity under the multi-tier pension system. Secondly, combining the international experience of the annuity market with the development of the Chinese annuity market, the future development trend of the China's Commercial Annuity market will be analyzed. On this basis, this report analyzes the annuity puzzle problems existing under the voluntary annuity selection, and explores the reasons for the weak supply and demand of commercial annuities, combing the factors affecting the supply and demand of annuity. Thirdly, based on the basic experience of the insurance company's longevity risk measurement and management, a mortality prediction model for Chinese mortality data is constructed to measure longevity risk. At last,

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some suggestions are given to promote the development of commercial annuity market and the risk management of longevity. To summarize the full text, the conclusions are as follows:

1. In the context of population aging, slowing economic growth, and lower interest rates, the basic pension insurance faces challenges in terms of adequacy and sustainability. From the perspective of adequacy, the scale of financial subsidies for basic pension system is increasing. If the financial subsidies are deducted, the annual income and expenditure gap will appear from 2014, indicating that the basic pension system is insufficient. From the perspective of financial sustainability, with the increase of dependency ratio in the system, the cost rate of maintaining a certain level of replacement rate will continue to rise. In the retirement age of 60 and 65-year-old two assumptions, both pay gap will appear and become increasingly large. At the same time, occupational pension as the second pillar have limited coverage and underdevelopment. These challenges have provided sufficient development space for the development of China's Commercial Annuity market, and also set forth the inevitable requirements and urgent needs for its development.

2. From the point of development and current annuity market, annuity products including longevity risk have developed slowly for a long time while new types of insurance such as universal and participating annuity are developing rapidly and occupying the main annuity market. From the perspective of development trend, due to the influence of external environment and the relevant regulations of CBRC on the short and medium term duration, it is gradually clear that annuity products return to the traditional long term and longevity protection trend. With the pilot of individual tax-deferred annuity and other old age services from insurance company, the longevity risk and interest rate risk can change to service consumption, completing the change from cost to income. It’s expected to promote the true development of annuity products, returning to the nature of life annuity.

3. Both supply and demand for commercial annuity market is insufficient. From the perspective of annuity supply, the development of commercial annuity market is plagued by longevity risk, investment risk, credit risk, liquidity risk, business risk and so on. Among them, the longevity risk restricts insurers to develop the pension business to a great extent. From the perspective of annuity demand, the development of commercial annuity market is plagued by bequest motives, adverse selection, the crowding-out effect of government pensions, lack of understanding, tax-favored competing assets and so on. In the quantitative analysis of annuity supply and demand, Scholars have shown that the design of annuity products, the performance of financial markets and the characteristics of individuals (like personal education level, wealth at hand, health status and so on) have a greater impact on a person's willingness to buy an annuity.

4. Mortality prediction is the core issue of longevity risk measurement and management, and has an important impact on the basic pension system, occupational pension and commercial annuity. This report compares five mortality models, finds that the Bayesian hierarchical model has good performance in fitting, prediction, rationality, and robustness, and it performs well in the modeling and prediction of China's aging mortality data. In the longevity risk measurement, a Bayesian hierarchical mortality model is recommended. Judging from the forecast results, the mortality rate in China is

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obviously declining, and the risk of longevity in the future is still outstanding. According to international experience, life insurance companies' strategies for dealing with longevity risks mainly include risk retention, reinsurance, risk securitization and design related annuity products. In addition, the impact of interest rate risk on annuity products should also be considered.

In summary, in the context of population aging, slowing economic growth, and lower interest rates, the basic pension insurance faces challenges in terms of adequacy and sustainability, the development of commercial annuity market is imminent and the only option. From the point of development and current annuity market, annuity products including longevity risk have developed slowly for a long time while new types of insurance such as universal and participating annuity are developing rapidly and occupying the main annuity market. With the trial of individual tax-deferred annuity and the business model of starting from old age services from insurance company, it’s expected to promote the true development of annuity products, returning to the nature of annuity. Both supply and demand for commercial annuity market is not active, and further analyze the factors affecting it, and specifically point out that special attention should be paid to the impact of longevity risk on the annuity supply. On this basis, the report further analyzes the longevity risk problem in China, and gives suggestions for promoting the development of China's commercial annuity market and longevity risk management.

1. The insurance supervision department can strengthen supervision and policy guidance to further promote the development of long-term guaranteed annuity products in the commercial annuity market, and make sure the annuity products return to its essence. With the trial of individual tax-deferred pension, it’s expected to form a new annuity market to promote its industrial upgrading.

2. The government continues to vigorously develop the economy and increase the disposable income of residents. From the quantitative analysis of the supply and demand of commercial annuities, the personal wealth of residents has a greater impact on the demand for commercial annuities; therefore, continuing to vigorously develop the economy is also a major driving force for the development of the annuity market.

3. Governments and insurance companies can increase the publicity of commercial annuities to give people a correct understanding of annuity products. In the analysis of commercial annuity demand, the lack of understanding of annuity products has become a factor influencing annuity demand. Therefore, relevant departments can increase publicity on commercial annuities and their products. Communication channels include television, internet, newspapers, community lectures, campus lectures, etc.

4. The government can reduce the proportion of basic pension insurance contributions, lower the contribution by companies and individuals, therefore, individuals may have more motivation to purchase commercial annuity. At the same time, reducing the proportion of basic pension contributions will help cuts down its benefit and financial gap, and will benefit the financial sustainability.

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5. Drawing on international experience, it is a good choice to gradually implement longevity risk securitization and transfer longevity risk through reinsurance. Longevity risk is the main cause of insufficient supply in the commercial annuity market, moreover, insufficient supply and weak product innovation further affect the demand for commercial annuity. Therefore, how to deal with the longevity risk is the key to promoting the development of China's commercial annuity market. According to international experience, life insurance companies' strategies for dealing with longevity risks mainly include risk retention, reinsurance, risk securitization and design related annuity products. Combined with the development of China's capital market, longevity risk can be attempted to transfer through risk securitization, reinsurance, and design related annuity products such as longevity risk dividend annuity. In order to manage longevity risks, on the one hand, the regulatory authorities can improve the regulatory system. On the other hand, insurance companies can increase the reserves of profession talents. Finally, it can be better if the government gives some tax support and guides people to correctly understand commercial annuity.

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7 Appendix A: Annuity products in China

At present, the types of commercial annuity products in China can be divided into traditional annuity, universal annuity, bonus annuity, as follows.

7.1 Traditional annuity

The examples of Traditional annuity include Sunshine Life Kangzunwuyou Annuity and BOB-CARDIF yuexiangyisheng Annuity. Table 9 shows the details.

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Table 9 Details of traditional annuity

Product name	Sunshine Life Kangzunwuyou Annuity	BOB-CARDIF Yuexiangyisheng Annuity
Purchase age	0-60 years old	30 days to 57years old
Insurance Duration	The date of entry into force of the insurance contract shall run until the policyholder reaches the age of 80	Whole life
Payment methods	1、3、5、10、20 annual contribution	3、6、10 annual contribution
Contract annual rate	Reference to the six-month RMB lending rate of the People's Bank of China	4.03%

Source: insurance clause of Sunshine Life Kangzunwuyou Annuity and BOB-CARDIF yuexiangyisheng Annuity

It can be seen from this table that traditional annuity products have a long insurance period, mainly with the guarantee function, its interest rate is around 4%, and the main way of payment is annual contribution.

7.2 Universal annuity

Universal insurance is a personal insurance product that contains an insurance guarantee function and has at least a certain asset value in an investment account. In addition to providing life protection as traditional life insurance, universal insurance policy value is linked to the investment performance of the insurance fund.

The examples of Universal annuity include Fude Life Wealth Management No. 3 Annuity Qianhai Investment Wealth Management Annuity, Table 10 shows the details.

Table 10 Details of universal annuity

Product name	Fude Life Wealth Management No. 3 Annuity	Qianhai Investment Wealth Management Annuity
Purchase age		28 days to 70 years old
Collection age	5 years after contract entered into force	10 years after contract entered into force
Duration of insurance	Whole life	20 years

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Payment methods	net single premium or additional premium	Can choose monthly, Quarterly, half a year or annually payment
guaranteed annual rate	2.5%in the first five years and 1.75% in the latter year	2.5%

Source: insurance clause of Fude Life Wealth Management No. 3 Annuity Qianhai Investment Wealth Management Annuity

The issuer of universal insurance is required to publish the last month's settlement rate monthly, and their insurance contracts claim an annual guaranteed interest rate of around 2.5 % annually, the return on investment above the guaranteed interest rate is uncertain. The characteristics of universal annuity reflected in the increase in the value of the personal insurance account with the inclusion of insurance premiums and insurance interest in the policy account, and after a fixed year the policyholder can choose to receive the agreed percentage of the value of the policy account and also can convert the personal account value of this contract into annuity insurance in whole or in part. In conclusion, the main characteristics of universal annuity are the guarantee of the minimum interest rate and the diversification of the value.

7.3 Participating annuity

The Participating annuity is a life insurance product which the insurance company assigns to the policyholder in proportion to the surplus of its actual operating result over the price assumption, and its characteristic is that the policyholder enjoys the operating results, and also takes a certain investment risk. The advantages are more inflation-resistant, the disadvantages are premium rate is relatively high, and the dividend uncertainty. Participating annuity is suitable for people with financial needs.

The example of Participating annuity includes China Life fulumantang old age Annuity and Taikang happy lives a old age Annuity, table 11 shows the details.

Table 11 Details of participating annuity

Product name	China Life fulumantang Pension Annuity	Taikang happy lives A Pension Annuity
Purchase age	30days to 64 years old	Not over 65 years old
Payment methods	net single premium or 5,10,20 annual contributions	5,10 annual contributions
Dividend System	In Cash or accumulated interest	accumulated interest

Source: insurance clause of China Life fulumantang Pension Annuity and Taikang happy lives A Pension Annuity

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The Participating annuity decides whether or not to allocate the dividends to the insured according to the actual development of insurance business. Most of its dividends in the form of accumulated interest, that is, the retention of dividends in the company are accumulated; the annual interest rate published by the insurance company, the risk of Participating annuity is greater than traditional annuity and universal annuity because of the non-guaranteed interest rate.

8 Appendix B: Mortality models and longevity risk management

8.1 Mortality Model

Since the second half of the 20th century, the world's population mortality rate has declined overall in the world, and the issue of population aging has become more prominent. The decline in mortality has placed unanticipated financial pressures on pension system arrangements and the financial calculation of pension funds. Mortality prediction is a core issue in population mortality projections, pension and health care costs and debt assessments, and longevity risk measurement and management. It is important for social pension systems, occupational pensions and annuity businesses. In recent decades, research on mortality models has continued to make progress. From describing static models of mortality with age to various dynamic models that include age and time factors, there are dynamic models of age, time, and cohort factors, as well as the Bayesian model of mortality, which contains prior information. This section mainly reviews and summarizes various types of mortality prediction models, and briefly describes the applicable conditions and application effects of the main models.

8.1.1 Static mortality model

The static mortality model is used to describe the pattern of mortality as a function of age. The earliest static mortality model can be traced back to the mortality model proposed by De Moivre (1729).

$$\mu(x) = 1/(\omega - x), (0 \le x \le \omega) \qquad (1)$$

where, ω represents the limit life, and x represents the age, $\mu(x)$ Represents the death force in x-year-old.

The classical and widely used important static mortality models include the Gompertz model, the Makeham model, the Weibull model, and the eight-parameter model proposed by Heligman and Pollard.

The Gompertz model was proposed by Benjamin Gompertz in 1825. The model is as follows:

$$\mu(x) = Bc^x, \quad x \ge 0 \quad , \quad B > 0, c > 1 \qquad (2)$$

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The Gompertz model is suitable for the description of the age-related mortality and is still used to extrapolate the age of high-age mortality.

In 1867, Makeham added an age-independent constant item to the Gompertz model to describe the part of mortality that does not change with age. The model is as follows:

$$\mu(x) = A + Bc^x, \quad x \geq 0, \quad B > 0, c > 1, \quad A > -B \tag{3}$$

In addition, Thiele proposed a mortality model for all ages in 1871 in the following form

$$\mu_x = Ae^{-Bx} + Ce^{-D(x-E)^2} + FG^x \tag{4}$$

where, the first term describes the infant mortality rate as a function of age, the second term is used to describe the increase in mortality due to accidents during young adults, and third to describe the change of mortality in the elderly with age.

In 1951, Weibull gave the power function of the death force,

$$\mu(x) = kx^n, x \geq 0, \quad k > 0, n \geq 1 \tag{5}$$

The above models describe the relationship between mortality and age. In addition to the death force model, many static mortality models directly take the form of mortality or the ratio of mortality to survival. One of the more commonly used is the eight-parameter model proposed by Heligman and Pollard in 1980:

$$q(x) / p(x) = A^{(x+B)^C} + De^{-E(\ln x - \ln F)^2} + GH^x / (1 + GH^x) \tag{6}$$

where q_x is the probability of dying within 1 year for a person aged x exactly, and $p_x = 1 - q_x$, {A, B, C, D, E, F, G, H} are parameters to be obtained by least squares estimate. The Heligman-Pollard (1980) model is an eight-parameter model containing three terms, each representing a distinct component of mortality. The first item reflects a downward trend in childhood mortality; the second item reflects male accidental death rates and female accidents and birth deaths and the third item reflects an upward trend in the mortality rate of old age. The model has achieved good results in describing the age-specific mortality rates in Australia, Germany, the United States, Switzerland, Spain, and the United Kingdom. Table 12 lists several important static mortality models.

Table 12 Static Mortality Model

Author	Models	Parameters
De Moivre（1729）	$\mu(x) = \frac{1}{\omega - x} (0 \leq x \leq \omega)$	x - age，

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		ω - limited life
Gompertz（1825）	$\mu(x) = Bc^x, \quad x \geq 0$	$B > 0, c > 1$
Makeham（1867）	$\mu(x) = A + Bc^x, \quad x \geq 0$	$B > 0, c > 1, \quad A > -B$
Weibull（1951）	$\mu(x) = kx^n, x \geq 0$	$k > 0, n \geq 1$
Thiele (1871)	$\mu_x = Ae^{-Bx} + Ce^{-D(x-E)^2} + FG^x$	$A, B, C > 0$
Heligman, Pollard（1980）	$q(x)/\ p(x) = A^{(x+B)^C} + De^{-E(\ln x - \ln F)^2} + GH^x/(1+GH^x)$	$A, B, C > 0$

The static mortality model only considers the relationship between mortality and age, does not consider the dynamic change of mortality, and generally only applies to the fitting of mortality data, and cannot predict future mortality. At the end of the 20th century, research scholars began to introduce time variables with years or birth cohorts to simultaneously characterize the relationship between mortality and age, calendar year, and birth year. These models are called stochastic mortality models which also called dynamic mortality prediction models.

8.1.2 Dynamic mortality model

The explained variables of the commonly used dynamic mortality model are generally the connection function between the model and the data, and the logarithm of the central mortality rate or the probability of death by logistic transformation is commonly used. The explanatory variables are generally divided into three categories: age effect, time effect and cohort effect, among them, the time effect and the cohort effect will be reflected in the age difference. The general model is formed as follows:

$$\eta_{x,t} = \alpha_x + \sum_{j=1}^{n} \beta_x^j \kappa_t^j + \beta_x^0 \gamma_{t-x} \qquad (7)$$

Where $\eta_{x,t}$ is the connection function between the model and the data, α_x is mortality rates at each age based on static life table, β_x^j is age functions—which ages mortality is changing at—in non-parametric form, κ_t^j is period factors governing trends in time at same age range, β_x^0 is often

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set to 1 for simplicity and robustness, γ_{t-x} is cohort parameters—"lifelong" factors depending upon year of birth.

（1） Lee-Carter Model

It is generally believed that the earliest and most classical dynamic mortality prediction model is the lee-carter model. It was proposed by Lee and Carter(1992), and the model is described as follows:

$$\ln(m_{x,t}) = a_x + b_x k_t + \varepsilon_{x,t} \qquad (8)$$

where $m_{x,t}$ is the central mortality rate at age x in year t, α_x is average (over time) log-mortality at age x, b_x measures the response at age x to change in the overall level of mortality over time, κ_t represents the overall level of mortality in year t, and $\varepsilon_{x,t}$ is the residual.

The predicted value is

$$\ln(m_{x,t}) = \tilde{\alpha}_x + \tilde{b}_x \tilde{\kappa}_t$$

Where,

$$\tilde{\alpha}_x = \alpha_x + m\tilde{b}_x, \tilde{b}_x = b_x / n, \tilde{\kappa}_t = n(\kappa_t - m) .$$

With the current model we use the following constraints:

$$\sum_t \kappa_t = 0, \sum_x b_x = 1 .$$

Lee and Carter used this model to fit the death rate data of the United States from 1900 to 1989 and made a prediction on the death rate of the United States from 1990 to 2065, pointing out that the death rate of the United States population was seriously underestimated. In this study, Lee and Carter found that the model had a large deviation in the mortality prediction of the aged population over 85. Tuljapurkar et al.(2000) used the lee-carter model to simulate and predict the mortality data of seven countries from 1950-1994 (Italy in 1951-1993 and Germany in 1952-1990) in Canada, France, Germany, Italy, Japan, the United Kingdom and the United States, and found that the official mortality forecasts of these countries were underestimated. Life expectancy in the UK, for example, was underestimated by 1.3 years in 2050, and in Japan by eight. Heather Booth and Leonie Tickle (2004) applied the lee-carter model to simulate the life expectancy of people over 50 in Australia from 1964 to 2000, extrapolated to predict the life expectancy of people over 50 in 2001-2041, and found that it was undervalued compared with official estimates. In addition, the Wilmoth(1996) and Sweden(2004)

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respectively used the lee-carter model to predict mortality rates in Japan and Sweden, and obtained similar conclusions.

The Lee-Carter model changes the shortcomings of deterministic models that can only be fitted without extrapolation. Heather Booth and Leonie Tickle (2008) pointed out that the Lee-Carter model has many advantages, such as strong Interpreting of model parameters, strong objectivity of the model, and very simple model form. Therefore, the model is widely used in developed countries.

Cairns et al (2007, 2008a and 2008b) noted several disadvantages of the Lee-Carter model:

It is a 1-factor model, resulting in mortality improvements at all ages being perfectly correlated (trivial correlation structure).

For countries where a cohort effect is observed in the past, the model gives a poor fit to historical data.

The uncertainty in future death rates is proportional to the average improvement rate bx. For high ages this can lead to this uncertainty being too low, since historical improvement rates have often been lower at high ages.

The basic version of the model can result in a lack of smoothness in the estimated age effect b_x.

（2） RH Model

The first model that incorporated the cohort effect was proposed by Renshaw and Haberman (2006):

$$\ln(m_{x,t}) = \alpha_x + \beta_x^{(1)} k_t + \beta_x^{(2)} \gamma_{t-x} + \varepsilon_{x,t} \qquad (9)$$

where, $m_{x,t}$ is central mortality, γ_{t-x} is a random queue effect, depending on the year of birth. With the current model we use the following constraints:

$$\sum_t \kappa_t = 0, \sum_x \beta_x^{(1)} = 1, \sum_{x,t} \gamma_{t-x} = 0, \sum_x \beta_x^{(2)} = 1$$

.

The model is applied in predicting mortality of England and Wales, using mortality data at age of 1961-2003 to estimate model parameters, forecasting the mortality from 2004 to 2025, and found that prediction results had a significant difference with Lee - Carter model. For countries where a cohort effect is observed in the past, this model provides a significant better fit to the historical data.

However, Tabeau et al.(2001) pointed out that the main disadvantage of all cohort models is that they involve heavy data demands. Booth et al. (2006) pointed out that the model with cohort effect may better fit the model, but the prediction may not be more accurate. David Blake et al. (2009) pointed out that the convergence of parameters in the RH model is very slow, and there are problems that the model may not recognize. In practical applications, the model with cohort has certain advantages in

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fitting the mortality data of the population affected by World War II, and few obvious interpretable cohort effects are observed in other cohort applications.

（3） APC Model

Currie (2006) introduces the simpler Age-Period-Cohort (APC) model,

$$\ln \mu_{x,t} = \alpha_x + \kappa_t + \gamma_{t-x} + \varepsilon \qquad (10)$$

This model can be regarded as a simplified version of R-H models. The model does not need smooth conditions and eliminates potential robustness problems. The following constraints were used:

$\sum_t \kappa_t = 0$, $\sum_{x,t} \gamma_{t-x} = 0$.

（4） Plat Model

Plat(2009) proposed a new stochastic mortality model that aims at combining the nice features from existing models, while eliminating the disadvantages. The proposed model for $m_{x,t}$ is:

$$\ln(m_{x,t}) = \alpha_x + \kappa_t^{(1)} + \kappa_t^{(2)}(\overline{x} - x) + \kappa_t^{(3)}(\overline{x} - x)^+ + \gamma_{t-x} + \varepsilon_{x,t} \qquad (11)$$

where $(\overline{x} - x)^+ = \max(\overline{x} - x, 0)$. Identifiability constraints of this model is as follows,

$\sum_t \kappa_t^{(3)} = 0$, $\sum_{x,t} \gamma_{t-x} = 0$, $\sum_{x,t} (t-x)\gamma_{t-x} = 0$.

The factor $\kappa_t^{(1)}$ represents changes in the level of mortality for all ages. The factor $\kappa_t^{(2)}$ allows changes in mortality to vary between ages, to reflect the historical observation that improvement rates can differ for different age classes. Furthermore, historical data seems to indicate that the dynamics of mortality rates at lower ages (up to age 40 / 50) can be (significantly) different at some times. The factor $\kappa_t^{(3)}$ is added to capture these dynamics. The factor γ_{t-x} is capturing the cohort effect, in the same way as the models of Currie (2006) and Cairns et al (2007).

To evaluate whether the proposed model fits historical data well, Plat had fitted the model to three different data sets and compared the fitting results with those of models like Lee-Carter model, R-H model and so on. The three used data sets are:

United States, Males, 1961-2005, ages 20-84

England & Wales, Males, 1961-2005, ages 20-89

The Netherlands, Males, 1951-2005, ages 20-90

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The models compared using the Bayes Information Criterion shows that the Plat model comes out most favorable, closely followed by the R-H model.

（5） CBD model

Cairns, Blake and Dowd(2006) proposed the CBD model. The interpreted variable of the CBD model is the death probability after logistic conversion, that is the logarithmic form of the ratio of the death probability to the survival probability, and the transformed death probability has a linear relationship with the time term and the age term.

The CBD model is as follows:

$$\log itq(x,t) = \ln \frac{q(x,t)}{1-q(x,t)} = \kappa_t^1 + \kappa_t^2 (x - \bar{x}) \tag{12}$$

Where, $q(x,t)$ indicates the probability of death and $\bar{x}$ indicates the average age of the sample. The logistic transformation of the model is more concise. Two time-effect factors are introduced to distinguish the improvement effect of the mortality rate of the high-age population over time, so that the model fits the historical data better. However, the transformed linear relationship of the CBD model generally only applies to the middle age group (Cairns et al., 2006), and the fitting and forecasting effect for all ages is not good. The CBD model contains two-time items that can better capture the changes in mortality over time at different ages. For example, modeling mortality throughout the 20th century, mortality improvement in the first half century is concentrated at the low age stage, the improvement of mortality rate in the latter half century is more advanced in the high age stage. The CBD model can capture the effects of different periods better.

Based on the CBD model, we consider the cohort effect and generate some CBD cohort effect expansion models. For example, the single-factor cohort effect CBD model is as follows:

$$\log itq(x,t) = \kappa_t^1 + \kappa_t^2 (x - \bar{x}) + \gamma_{t-x}.$$

The two-factor CBD cohort effect model is as follows:

$$\log itq(x,t) = \kappa_t^1 + \kappa_t^2 (x - \bar{x}) + \kappa_t^3 ((x - \bar{x})^2 - \sigma_x^2) + \gamma_{t-x}.$$

κ_t^1 should be understood as a logistic transformed mortality trend over time, reflecting the degree of improvement in mortality over time. κ_t^2 can be understood as a "gradient" coefficient, with a gradually decreasing drift term, which reflects the slower improvement of the age-related mortality

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rate than the younger age; κ_t^3 can be understood as a "curvature" coefficient; γ_{t-x} represents cohort effect.

In 2009, the Cairns et al (2009) compared eight stochastic models based on Bayesian information criteria, and compared the numbers of the British, Welsh, and the United States (UK and Welsh for 1968-2003 years in the United States, 1968-2003 years) for the high age group (60-89 years). It shown that, for higher ages, an extension of the Cairns-Blake-Dowd (CBD) model that incorporates a cohort effect fits the England and Wales male data best, while for the U.S. male data, the Renshaw and Haberman (RH) extension to the Lee and Carter model that also allows for a cohort effect provides the best fit.

（6）P-splines model

P-splines model (Currie, Durban, and Eilers 2004; Currie 2006)

$$\log m(t,x) = \sum_{i,j} \theta_{ij} B_{ij}(t,x) \qquad (13)$$

where, $B_{ij}(t,x)$ denotes a basis function with a regular spatial node; θ_{ij} denotes the parameter to be estimated. The model is succinct and the surface is smooth within the confidence interval. However, using spline method will lead to over-fitting of the function.

Currie et al.(2004) showed how the method of P-splines can be extended to the smoothing and forecasting of two-dimensional mortality tables. They use a penalized generalized linear model with Poisson errors and show how to construct regression and penalty matrices appropriate for two-dimension modelling. An important feature of the method is that forecasting is a natural consequence of the smoothing process.

（7）Bayesian Hierarchical Model

Chunn, Raftery, and Gerland (2010) proposed a Bayesian hierarchical model (BHM), the model is given by

$$l_{c,t+1} = l_{c,t} + g(l_{c,t} \mid \theta^{(c)}) + \varepsilon_{c,t+1} \qquad (14)$$

where,

$$\mathrm{g}\left(l_{c,t}|\theta^{(c)}\right) = \frac{k^c}{1+\exp\left(-\frac{A_1}{\Delta_2^c}\left(l_{c,t}-\Delta_1^c-A_2\Delta_2^c\right)\right)} + \frac{z^c-k^c}{1+\exp(-\frac{A_1}{\Delta_4^c}(l_{c,t}-\sum_{i=1}^{3}\Delta_i^c-A_2\Delta_4^c))}$$

$$\theta^c = (\Delta_1^c, \Delta_2^c, \Delta_3^c, \Delta_4^c, k^c, z^c)$$

$$\Delta_i^c|\sigma_{\Delta_i} \sim \mathrm{Normal}_{[0,100]}\left(\Delta_i, \sigma_{\Delta_i}^2\right), \ \ i = 1, \ldots, 4$$

$$k^c|\sigma_k \sim \mathrm{Normal}_{[0,10]}(k, \sigma_k^2)$$

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$$z^c|\sigma_z \sim \text{Normal}_{[0,1.15]}(z, \sigma_z^2)$$

The Bayesian hierarchical model contains 13 parameters, each of which has a prior distribution. The Markov Chain Monte Carlo method can be used to estimate the parameters of the posterior distribution of life expectancy in each country.

In the 2012 World Population Prospects, the Bayesian hierarchical model was adopted by the United Nations Population Division. Raftery AE, Chunn JL, and Gerland P (2013) used life expectancy data from 1950 to 1995 in various countries into the Bayesian hierarchical model to predict the life expectancy of each country from 1996 to 2005, cross-checked with actual data. Think of the model as giving an accurate prediction interval. This model takes the life expectancy time series as the research object, and it is a random walk model with non-constant drift. Among them, the drift term is a nonlinear function of current life expectancy, which can reflect the growth rate of life expectancy in different countries at different life levels. The model does not have strict requirements for data quality and is applicable to countries with different data quality.

（8） Bayesian Hierarchical Poisson-Gamma model

Bryant et al. (2013) pointed out that Bayesian hierarchical Poisson-Gamma model can obtain accurate fitting and prediction results, it can apply data from different sources, and the model is as follows:

$$d \sim Poisson(\gamma \cdot e),$$

$$\gamma \sim N(\beta^0 + \beta^{age} + \beta^{time}, \sigma^2)$$

Where,

$$\beta^{age} \sim \text{Random walk with drift},$$
$$\beta^0 \sim N(\mu_1, \sigma_1^2),$$
$$\beta^{time} \sim N(\mu_2, \sigma_2^2)$$

The posterior simulation is carried out using Markov chain Monte Carlo methods. Bryant et al. (2013) illustrate the methods using data over the period 1996-2011 for six regions within New Zealand.

The Poisson gamma model is used to describe the distribution of the number of deaths and risk exposure, and the number of deaths and exposures in the community is estimated with Bayesian hierarchy model under a variety of data sources.

（9） Progress of Recent Dynamic Mortality Models

In addition to traditional models, some scholars use machine learning methods to model mortality. Hainaut (2018) summarized the solution method of the Lee-Carter model and its extended model, concluded that principal component analysis (PCA) can extract lower-dimensional linear structures in large multivariate data sets, but the mortality data has a nonlinear characteristic that PCA cannot

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detect and extract. Referring to the nonlinear principal component analysis (NLPCA) method proposed by Kramer (1991) in the chemical engineering literature based on neural network, Hainaut proposes to use neural network method to fit and predict mortality to detect and reproduce the Lee-Carter model. The nonlinearity observed during the logarithmic mortality evolution. Before this, there were a few research papers using neural networks to predict mortality, and in the existing research, neural network methods were replaced by econometric models or linear regression. Puddu and Menotti (2009) used multi-layer neural networks to predict coronary mortality in seven countries. Abdulkarim and Garko (2015) used a particle swarm algorithm to fit a feed-forward neural network to predict maternal mortality in an area in Nigeria. It is not applicable to actuarial applications because previous studies did not use neural networks to predict and simulate the complete term structure of mortality. Hainaut's (2018) neural network method uses a three-layer network structure of the input layer-hidden layer-output layer, using hyperbolic sine and sigmoid function and linear function as activation function, fitting and forecasting in two steps. First, the 3-layer neural network is used to summarize the logarithmic mortality information carried by the latent variables. Then, these latent variables are predicted by a random walk model, and the term structure of log mortality is reconstructed by inverse transformation. The neural network analysis method fits the mortality data from 1946 to 2000 in France, the United Kingdom, and the United States, uses the data from 2001 to 2014 to perform prediction verification, and predicts life expectancy. The results show that compared with the Lee-Carter model whether the cohort effect is included, the neural network method has excellent ability of fitting and prediction, and the prediction of long-term life expectancy is more realistic, but the number of neurons must be carefully selected to avoid over-fitting. Table 13 lists commonly used dynamic mortality models and their constraints.

Table 13 Dynamic Mortality Model

Model	Model form	constraints
LC (1992)	$\ln(m_{x,t}) = \alpha_x + \beta_x \kappa_t + \varepsilon_{x,t}$	$\sum_x \beta_x = 1$, $\sum_t \kappa_t = 0$
RH (2006)	$\ln(m_{x,t}) = \alpha_x + \beta_x^{(1)} \kappa_t + \beta_x^{(2)} \gamma_{t-x} + \varepsilon_{x,t}$	$\sum_x \beta_x^{(1)} = 1$, $\sum_t \kappa_t = 0$, $\sum_x \beta_x^{(2)} = 1$, $\sum_{x,t} \gamma_{t-x} = 0$
APC (2006)	$\ln \mu_{x,t} = \alpha_x + \kappa_t + \gamma_{t-x} + \delta.$	$\sum_t \kappa_t = 0$ $\sum_{x,t} \gamma_{t-x} = 0$
CBD (2006)	$\text{logit}(q_{x,t}) = \kappa_t^{(1)} + \kappa_t^{(2)}(x - \bar{x}) + \varepsilon_{x,t}$	Not have
P-Spline (2004)	$\log m(t,x) = \sum_{i,j} \theta_{ij} B_{ij}(t,x).$	Not have

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Plat (2009)	$\ln(m_{x,t}) = \alpha_x + \kappa_t^{(1)} + \kappa_t^{(2)}(\bar{x} - x) + \kappa_t^{(3)}(\bar{x} - x)^+ + \gamma_{t-x} + \varepsilon_{x,t}$	$\sum_t \kappa_t^{(3)} = 0$, $\sum_{x,t} \gamma_{t-x} = 0$, $\sum_{x,t} (t-x)\gamma_{t-x} = 0$
BHM (2010)	$l_{c,t+1} = l_{c,t} + g(l_{c,t} \mid \theta^{(c)}) + \varepsilon_{c,t+1}$	$\theta^c = (\Delta_1^c, \Delta_2^c, \Delta_3^c, \Delta_4^c, k^c, z^c)$ $\Delta_i^c \mid \sigma_{\Delta_i} \sim \text{Normal}_{[0,100]}(\Delta_i, \sigma_{\Delta_i}^2)$, $i =$ $k^c \mid \sigma_k \sim \text{Normal}_{[0,10]}(k, \sigma_k^2)$ $z^c \mid \sigma_z \sim \text{Normal}_{[0,1.15]}(z, \sigma_z^2)$
Bayes-hi (2013)	$d \sim Poisson(\gamma \cdot e)$, $\gamma \sim N(\beta^0 + \beta^{age} + \beta^{time}, \sigma^2)$	$\beta^{age} \sim$ Random walk with drift $\beta^0 \sim N(\mu_1, \sigma_1^2)$, $\beta^{time} \sim N(\mu_2, \sigma_2^2)$

8.1.3 Criteria for stochastic mortality models

It is important to consider whether a specific stochastic mortality model is a good model or not. Therefore, Cairns et al (2008a) defined several criteria against which a model can be assessed:

- Mortality rates should be positive.
- The model should be consistent with historical data.
- Long-term dynamics under the model should be biologically reasonable.
- Parameter estimates should be robust relative to the period of data and range of ages employed.
- Model forecasts should be robust relative to the period of data and range of ages employed.
- Forecast levels of uncertainty and central trajectories should be plausible and consistent with historical trends and variability in mortality data.
- The model should be straightforward to implement using analytical methods or fast numerical algorithms.
- The model should be relatively parsimonious.
- It should be possible to use the model to generate sample paths and calculate prediction intervals.

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- The structure of the model should make it possible to incorporate parameter uncertainty in simulations.
- At least for some countries, the model should incorporate a stochastic cohort effect.
- The model should have a non-trivial correlation structure.

Plat (2009) thought an important additional criterion is that the model is applicable for a full age range. Some models are designed for higher ages only (say 60 years or older). However, the portfolios of insurers and pension funds usually exist of policyholders from age 20 and older. One would want to model the mortality rates and their dependencies for the whole portfolio consistently, therefore the model should be applicable for the whole age ranges.

8.2 Longevity risk management

In recent years, with the development of economy and the improvement of health service, the mortality of the global population has been improved continuously and human life expectancy has been increasing.

Concerning longevity risk management, overall, there are four main approaches: Retention, reinsurance, securitization, and longevity-related annuities.

8.2.1 Longevity Risk Retention

Life insurance companies and pension funds can manage longevity risk as part of their own business risk when they expect investment returns to cover the long-term risk of loss (Blake D, 2008). In this case, the company needs to choose a suitable asset-liability management method to ensure that the assets can cover the debt. At present, the main longevity risk retention methods used by insurance companies include raising the premium of annuity insurance to cover the longevity risk, holding sufficient reserves, limiting the age of annuity purchases and the duration of the payment, deferring the initial payment age of an annuity, and the natural hedging of longevity risks.

Private sectors (e.g., insurance companies) can hedge specific longevity risk via risk pooling (Blake D, 2008). As the mortality rate improves, life insurance products will have a death benefit, because the death benefit will be postponed; and the annuity product will have a dead time difference, because the life payment period will be extended (Cox & Lin, 2007). Milevsky and Promislow (2001) verify the opposite impact of mortality changes on life insurance and annuities separately. Wang, Yang, and Pan (2003) analyzed the specific effects of mortality changes and based on empirical data on mortality in Taiwan, proposed a mortality immunization model to hedge longevity risks. Cox and Lin (2007) put forward and empirically support the idea of natural hedging, which utilizes the interaction of life insurance and annuities to a change in mortality to hedge against longevity risk. Huang, Liu and Tang (2007) apply the mortality immunization theory to optimize the product mix of life insurers and discuss the mode of asset/liability management in life insurance industry under the condition of mortality immunization.

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Ralph Stevens et al. (2010) point out that, many defined benefit pension funds offer a joint and survivor annuity, which has a natural hedging effect. A joint and survivor annuity is the combination of old-age annuity insurance, which consists of a single life annuity for the participant, and partner annuity insurance, which consists of a survivor annuity for the partner in the condition that the partner outlives the participant (Ralph Stevens et al., 2010).

8.2.2 Reinsurance

Life insurers and pension funds can manage longevity risk through reinsurance. Linfoot (2010) analyzes longevity risk financing from a reinsurance perspective, pointing out that reinsurance arrangements can help insurance companies to meet regulatory requirements on capital, and to improve investment diversification. However, potential disadvantages of this approach include high reinsurance costs and credit risk. Daniel Bauer (2006) also pointed out that because the longevity risk is systematically non-dispersible, the demand for reinsurance for longevity risk is relatively limited. However, Richards and Jones (2004) pointed out that the quantitative measures of insurance companies and pension managers for the continuous improvement of long-life risk reinsurance demand and longevity risk can enhance the reinsurer's willingness to this business.

8.2.3 Longevity risk securitization

Life insurance companies and pension funds can securitize part of their business or use mortality-linked derivatives to manage their longevity risk. The traditional method of risk management for longevity has such problems as insufficient liquidity, insufficient market capacity and low transparency of transactions and so on. Therefore, longevity risk securitization, the low-cost and effective method, has attracted the attention of many scholars and institutions. The existing methods of longevity risk securitization mainly include the followings:

(1) Longevity Bonds

The future coupon payment for longevity bonds depends on a mortality index. Blake and Burrows (2001) first proposed a method of hedging longevity risk by issuing longevity bonds and transferring longevity risk to investors in the capital market. Blake et al. (2006) have an in-depth discussion on the main characteristics of longevity bonds (LBs), the factors to be considered in designing the LBs and how LBs can be used as a risk management tool for hedging longevity risk, it also proposed various forms of LBs such as Longevity Zeros (LZs), Classic Longevity Bonds, Principal-at-Risk LBs, Inverse LBs and Collateralized Longevity Obligations (CLOs).

(2) Longevity Swaps

A longevity swap is an agreement to exchange one or more cash flows in the future based on the outcome of at least one (random) survivor or mortality index. Lin and Cox (2005) first explore the theory of longevity swap. They note that since changes in mortality experience have opposite effects on pensions and assurance business, these two parties should be able to hedge each other’s risks. Dowd et al. (2006) discuss the possible uses of survivor swaps (another name for longevity swaps) as

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instruments for managing, hedging, and trading mortality-dependent risks and proposed the concept of vanilla survivor swaps (VSS), which involves one fixed leg and one floating leg. The fixed leg of the VSS involves preset payments that decline over time in line with the survivor index anticipated at time 0. And the floating leg of the VSS depends on the realized value of the survivor index at time t. The use of a longevity swap is simply to shift the longevity risk, pension plans still carry investment risks associated with asset portfolios. Sweeting (2007) consider basis risk when pricing longevity swaps and found that if the age being hedged is at least as high as the reference age used by the speculator, then a hedge is possible: the basis risk is lower than the risk premium required.

(3) Q-Forward

Coughlan et al. (2007) first propose the concept of "q-forward" and described an example with a 10-year q-forward written on the one-year death rate q65 for males age x = 65 in England & Wales. A q-forward is an agreement between two parties to exchange at a future date (the maturity of the contract) an amount proportional to the realized mortality rate of a given population (or subpopulation), in return for an amount proportional to a fixed mortality rate that has been mutually agreed at inception (usually the realized mortality rate published at a specified future date by J.P. Morgan, in the Life Metrics system). In other words, a q-forward is a zero-coupon swap that exchanges fixed mortality for realized mortality at maturity. Cox et al. (2010) discuss the q-forward contract based on extreme mortality risk. Biffis and Blake (2009) suggest that other, more complex life-insurance-related derivatives can be created on a q-based basis, helping to significantly increase the liquidity of longevity risk markets.

(4) Longevity Futures and Options

Longevity futures are developed from financial futures and are usually based on tradeable assets such as longevity bonds issued, mortality indices, etc. The difference between longevity options and futures is that futures are usually standardized contracts, while options have a more flexible form. Blake et al. (2006) discuss mortality/longevity futures and options.

8.2.4 Longevity-Related Annuities

With the goal of longevity risk management, scholars have discussed a series of annuity product designs.

(1) Group Self-Annuitization (GSA)

Piggott et al. (2005) put forward an approach to the management of uncertain future longevity, which is called group self-annuitization (GSA). GSA is designed with the purpose of pooling idiosyncratic risk with individuals bearing systematic risk. Piggott et al. (2005) determine specifications of the benefit payment cash flows emerging in a GSA plan, assuming actuarial fairness, and provide adjustment formula for payout cash flows under a series of assumptions. Valdez et al. (2006) addressed adverse selection and demand issues for GSAs. Using Extreme Value Theory, Qiao Chao and Sherris (2011) calculate the distribution of survival probability and the annuity price. Based on this, they measured

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the risk pooling efficiency of GSA, and quantify the impact of the pool size on future benefit payments for GSA members.

(2) Mortality-Indexed Annuities (MIA)

Richter and Weber (2009) design Mortality-Indexed Annuities (MIA), which is a sort of indexed variable annuity product. In the operation of MIA, insurers can avoid cumulative losses through effectively sharing systematic longevity risk with policyholders, and policyholders can also gain in comparison with a comparable conventional annuity product (Richter and Weber, 2009).3) Longevity-Indexed Life Annuities (LILA)

Michel Denuit et al. (2011) design another sort of indexed variable annuity product, Longevity-Indexed Life Annuities (LILA). According to their design, the annuity payments and the transfer of systemic longevity risk are both linked with a longevity index, and there are upper and lower limits for the transfer proportion (Michel Denuit et al., 2011). The annuitants of LILA bear only the non-diversifiable risk that the future mortality trend deviates from that of the reference prediction, so LILA can be a substitute for reinsurance and securitization of longevity risk in the management of longevity risk (Michel Denuit et al., 2011).

(4) Advanced-Life Delayed Annuities (ALDA)

Milevsky (2005) design Advanced-Life Delayed Annuities (ALDA), a variant of a deferred annuity contract which is paid by installments, linked to consumer price inflation, while locking in longevity insurance. For ALDA, the payments of annuity benefits will start from an advanced age (e.g., 80 years old), and the annuitants of ALDA can buy the product at a lower price than a traditional annuity. Therefore, ALDA can manage longevity risk while lowering the price of annuities. Gong Guan and Webb (2010) evaluates Milevsky's proposal of ALDA. Using numerical optimization, Gong Guan and Webb (2010) show that ALDA can provide a large proportion of the longevity insurance provided by an immediate annuity, at much lower cost.

(5) Ruin-Contingent Life Annuity (RCLA)

Motivated by the proposal of ALDA, Huang et al. (2013) design a type of annuity called a Ruin-Contingent Life Annuity (RCLA), which is a separate version of the option embedded inside a variable annuity but without the buyer having to transfer investments to the insurer. For an annuitant of RCLA, the payoff is a dollar of income per year for life, deferred until a certain wealth process hits zero (Huang et al., 2013). Using numerical methods, Huang et al. (2013) price and provide hedging guidance on RCLA under a series of realistic parameters.

(6) Longevity-Indexed Deferred Annuities (LIDA)

Based upon the payment modes of GSA and LILA, Zhang and Wang (2014) designed Longevity-Indexed Deferred Annuities (LIDA) and quantified the insurance value of LIDA from both longevity risk transfer aspect and longevity risk coverage aspect. Only the lower limit is set for annuity payments of LIDA, so annuitants of LIDA can buy the product at a lower price than immediate annuities and LILA (Zhang and

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Wang, 2014). Zhang and Wang (2014) show that ALDA can provide a partial transfer of systemic longevity risk from annuity providers to policyholders.

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