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SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

**TRANSFER AND HEDGING OF LONGEVITY RISK**

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## AUTORSHIP STATEMENT

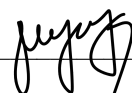
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# TABLE OF CONTENTS

|          |                                                                           |           |
|----------|---------------------------------------------------------------------------|-----------|
| <b>1</b> | <b>INTRODUCTION.....</b>                                                  | <b>1</b>  |
| <b>2</b> | <b>GENERAL ASPECTS OF LONGEVITY RISK .....</b>                            | <b>4</b>  |
| 2.1      | Increasing life expectancy and mortality improvements .....               | 5         |
| 2.2      | Longevity risk and the need for transferring and hedging .....            | 9         |
| 2.3      | Primary bearers of longevity risk and its implications .....              | 14        |
| 2.3.1    | Individuals .....                                                         | 14        |
| 2.3.2    | Governments.....                                                          | 15        |
| 2.3.3    | Pension funds and annuity providers (insurance companies).....            | 18        |
| <b>3</b> | <b>LONGEVITY RISK TRANSFER MARKETS .....</b>                              | <b>21</b> |
| 3.1      | Development, size, and potential of longevity risk transfer markets ..... | 22        |
| 3.2      | Participants in longevity risk transfer markets .....                     | 28        |
| 3.3      | History of longevity risk transfer transactions .....                     | 30        |
| <b>4</b> | <b>LONGEVITY RISK TRANSFER MECHANISMS .....</b>                           | <b>32</b> |
| 4.1      | Insurance-based solutions .....                                           | 33        |
| 4.1.1    | Buy-ins .....                                                             | 34        |
| 4.1.2    | Buy-outs .....                                                            | 36        |
| 4.1.3    | Longevity swaps .....                                                     | 37        |
| 4.1.4    | Pricing of bulk annuities.....                                            | 40        |
| 4.1.5    | Pricing of longevity swaps .....                                          | 41        |
| 4.1.6    | Asset-Intensive Reinsurance .....                                         | 42        |
| 4.2      | Capital market-based solutions .....                                      | 43        |
| 4.2.1    | Longevity Bonds .....                                                     | 44        |
| 4.2.2    | Government-issued longevity bonds .....                                   | 45        |
| 4.2.3    | q-Forwards.....                                                           | 46        |
| 4.2.4    | Tail-risk protection .....                                                | 47        |
| 4.2.5    | Superfund transactions .....                                              | 48        |
| 4.2.6    | Reinsurance sidecars.....                                                 | 50        |
| <b>5</b> | <b>EFFECTIVENESS OF INSURANCE-BASED SOLUTIONS.....</b>                    | <b>51</b> |
| 5.1      | Modelling approach and model description .....                            | 51        |
| 5.2      | Scenarios' framework and inputs .....                                     | 53        |

|                           |           |
|---------------------------|-----------|
| <b>5.3 Results.....</b>   | <b>54</b> |
| <b>6 CONCLUSION .....</b> | <b>58</b> |
| <b>REFERENCES.....</b>    | <b>60</b> |
| <b>APPENDICES .....</b>   | <b>66</b> |

## LIST OF FIGURES

|                                                                                            |    |
|--------------------------------------------------------------------------------------------|----|
| Figure 1: Probabilistic projections of life expectancy at birth in developed regions ..... | 6  |
| Figure 2: Life expectancy at age 60 and 65 by sex, OECD average, 1960-2050 .....           | 7  |
| Figure 3: Potential medical advances could significantly impact life expectancy.....       | 9  |
| Figure 4: The underlying risks that constitute longevity risk.....                         | 12 |
| Figure 5: Variability in life expectancy.....                                              | 12 |
| Figure 6: Evolution of population pyramids from 1950 to 2018 and projections.....          | 16 |
| Figure 7: Pension spending and economic replacement rate .....                             | 17 |
| Figure 8: European pensions market share .....                                             | 19 |
| Figure 9: Breakdown DC/DB/Hybrid schemes in EU Countries.....                              | 19 |
| Figure 10: Current and future retirement ages in different countries.....                  | 20 |
| Figure 11: Split between DC and DB plans per country.....                                  | 25 |
| Figure 12: Overview of LRT activities .....                                                | 33 |
| Figure 13: Structure of Pension Buy-In Transactions .....                                  | 35 |
| Figure 14: Structure of Pension Buy-Out Transactions .....                                 | 36 |
| Figure 15: Structure of longevity Swap Transactions.....                                   | 38 |
| Figure 16: Cash flow exchanges in a longevity swap (fixed and floating leg) .....          | 40 |
| Figure 17: Comparison between longevity swaps and funded reinsurance .....                 | 43 |
| Figure 18: Structure of Longevity Bond Transaction .....                                   | 45 |
| Figure 19: Exchange flows in a q-forward at the maturity of the contract .....             | 47 |
| Figure 20: Payoff profile in tail-risk protection .....                                    | 49 |
| Figure 21: Overview of a pension superfund .....                                           | 51 |
| Figure 22: Overview of a sidecar structure .....                                           | 51 |
| Figure 23: Historical mortality improvements in males and females since 1983 .....         | 53 |
| Figure 24: NPV of pension liabilities response to stress test .....                        | 56 |
| Figure 25: Net payoff of a longevity swap.....                                             | 57 |

## LIST OF TABLES

|                                                                                           |    |
|-------------------------------------------------------------------------------------------|----|
| Table 1: Possible drivers of future mortality improvements.....                           | 8  |
| Table 2: Current and future retirement ages in the EU and other countries.....            | 21 |
| Table 3: Characteristics of longevity risk transfer markets and rating per countries..... | 24 |

|                                                                                    |    |
|------------------------------------------------------------------------------------|----|
| Table 4: Top 22 pension markets by asset size .....                                | 26 |
| Table 5: Comparison of the risks transferred in bulk annuities and swaps .....     | 38 |
| Table 6: Differences between indemnity-based and index-based longevity swaps ..... | 39 |
| Table 7: Stress testing.....                                                       | 56 |

## LIST OF APPENDICES

|                                                                             |    |
|-----------------------------------------------------------------------------|----|
| Appendix 1: Povzetek vsebine (Summary in Slovene language).....             | 1  |
| Appendix 2: Survival Probabilities .....                                    | 3  |
| Appendix 3: Liabilities' valuation (Base scenario).....                     | 5  |
| Appendix 4: Liabilities' valuation (Scenario A).....                        | 7  |
| Appendix 5: Liabilities' valuation (Scenario B) .....                       | 9  |
| Appendix 6: NPV of Longevity Swap's payoff (Floating Leg LTR of 2%) .....   | 11 |
| Appendix 7: NPV of Longevity Swap's payoff (Floating Leg LTR of 0.5%) ..... | 13 |

## LIST OF ABBREVIATIONS

|              |                                                        |
|--------------|--------------------------------------------------------|
| <b>BIS</b>   | Bank of International Settlements                      |
| <b>CRO</b>   | Chief Risk Officer                                     |
| <b>CMI</b>   | Continuous Mortality Investigation                     |
| <b>DB</b>    | Defined Benefit                                        |
| <b>DC</b>    | Defined Contribution                                   |
| <b>EU</b>    | European Union                                         |
| <b>EIB</b>   | European Investment Bank                               |
| <b>EIOPA</b> | European Insurance and Occupational Pensions Authority |
| <b>GDP</b>   | Gross Domestic Product                                 |
| <b>ILS</b>   | Insurance-Linked Securities                            |
| <b>IMF</b>   | International Monetary Fund                            |
| <b>LRT</b>   | Longevity Risk Transfer                                |
| <b>LTR</b>   | Long Term Rate                                         |
| <b>LM</b>    | Life Market                                            |
| <b>NPV</b>   | Net Present Value                                      |
| <b>OECD</b>  | Organization for Economic Co-operation and Development |
| <b>ONS</b>   | Office of National Statistics                          |
| <b>PPF</b>   | Pension Protection Fund                                |
| <b>PRA</b>   | Prudential Regulation Authority                        |
| <b>PRT</b>   | Pension Risk Transfer                                  |
| <b>PV</b>    | Present Value                                          |
| <b>SPV</b>   | Special Purpose Vehicle                                |
| <b>UK</b>    | United Kingdom                                         |
| <b>US</b>    | United States                                          |
| <b>WHO</b>   | World Health Organization                              |



# 1 INTRODUCTION

Life expectancy has been steadily increasing, resulting in an expected lifespan of over 80 years in developed countries (WHO, 2020). This increasing lifespan has appeared very gradually due to the improvements made in our society, such as medical achievements, sanitation, housing, and education. On the one hand, these improvements have considerably reduced mortality and subsequently increased human life duration. On the other hand, they have brought to our attention new types of financial risks that have been gaining interest over the last two decades. The risk that the lifespans will continue to increase is one of the most significant financial risks of today. Providers of long-term insurance products are searching for ways to mitigate the longevity risk posed by rising lifespans.

Many definitions of longevity risk come from different authors. De Waegenare et al. (2010, p.1) define it as the uncertainty in future changes in mortality rates, and Bravo & Diaz-Giménez (2014, p.8) define it as the risk that future outcomes in mortality and life expectancy turn out to be systematically different from expectations. According to the CRO Forum (2010, p.1), longevity risk appears when individuals live longer than expected.

However, the question is why longer lives and reduced mortality are seen as a risk when it is something positive. On the individual level, the risk appears when individuals who live longer lack sufficient income to cover all their needs. Our society's aging population will need more financial resources than what has been forecast by governments, employers, or private pension providers. Governments and private pension providers are the ones who are most affected given the vast quantities of longevity risk coming from the big groups or collectives of pensioners and insureds.

For individuals, longevity risk means the inability to maintain the same lifestyle during the retirement period due to their savings' insufficiency. The shortage of funds leads to poverty in the later stages of retirement (OECD, 2014). On the other hand, there are governments for whom longevity risk translates into the length and the volume of public pensions they have to pay to the retirees. A study made by the OECD (2019) shows that government spending on pensions in developed countries has increased sharply due to longer lifespans.

Besides individuals and governments, pension funds and annuity providers are also on the top of the list of direct bearers of collective<sup>1</sup> longevity risk. According to OECD (2014), this risk appears when the actual lifespan is higher than what has been considered in the funds' provisions, leading to underfunded pension obligations. The IMF (2012) has estimated that the increase of the lifespan for one year translates into approximately a 4 percent increase in the defined benefit pension fund liabilities' present value. Nowadays, defined benefit plans

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<sup>1</sup>[https://www.ecb.europa.eu/pub/financial-stability/fsr/focus/2005/pdf/ecb~cd50ffadc4.fsrbox200512\\_16.pdf?086a06eadf01568a5929f41b19c84384](https://www.ecb.europa.eu/pub/financial-stability/fsr/focus/2005/pdf/ecb~cd50ffadc4.fsrbox200512_16.pdf?086a06eadf01568a5929f41b19c84384)

are increasingly disappearing and are not on offer due to the high risk of increasing longevity and the low-interest rates environment. But there is still a sufficient number of existing ones to pose a serious threat to financial stability in the future if insurance companies and governments take no measures. Thus, the need for transferring longevity risk has appeared with ever-increasing interest from vulnerable pension funds and annuity providers due to their fixed obligations with pensioners and annuitants. There are countries where these types of plans do not exist. Others, such as the United Kingdom (from now on: UK), the Netherlands, United States (from now on: US), and Canada have a high portion of defined benefit plans in their pension portfolios. These countries have a significant stake of pension and life assets in their national Gross Domestic Product (from now on: GDP). Consequently, in the past few years, the highest volumes of longevity de-risking transactions have been performed among/in the mentioned countries.

The longevity risk transfer market officially started approximately 20 years ago, but it has been gaining more interest in the last years. The market we know today includes both insurance-based as well as capital market-based solutions. Although the former is currently more developed and widely used than the latter, both are useful mechanisms to consider. So far, quite a few longevity risk transfer transactions have taken place, with the vast majority of them taking place in the UK, the Netherlands, the US, and Canada (Kessler, 2019, p.1). However, among all, the UK is undoubtedly seen as the global leader of de-risking strategies and transactions. It owns the most developed longevity (or pensions) risk transfer market, resulting from its highly developed life and pension insurance market. In terms of the development of life and pension market and longevity risk transfer transactions, the Netherlands follows closely, leading the European and even the global markets.

The volume of longevity risk transfer markets increases every year, given the high demand for longevity risk transfer from the different stakeholders. In 2024, longevity risk transactions have reached their highs again, with an approximate turnover of over \$100 billion distributed between the two most active markets (the UK and the US) and focusing only on insurance-based solutions.

This thesis will provide historical figures of longevity risk transfer transactions since the beginning of the market, distinguishing between the instruments used in each transaction. Some of the most used methods or tools for transferring longevity risk are pension buy-outs and buy-ins and traditional insurance longevity swaps, solutions considered as insurance-based, followed by capital market-based solutions or longevity derivatives as bonds or forward contracts which are used for hedging longevity risk rather than to transfer it. Longevity swaps hedge longevity risk specifically. Buy-in or buy-out transactions, on the other hand, also hedge investment or inflation risk. By comparing longevity swaps to other financial instruments, Rodríguez-Reyes (2017) concluded that they were the simplest to construct and had the lowest implementation cost. However, OECD (2014, p. 177) claims the same about forwards.

Consequently, in this thesis, I will compare the available instruments to find their characteristics and a straightforward mechanism to be used in different needs and situations of the hedger. Longevity and mortality bonds are also traded on the market and were the first to be issued for transferring longevity risk. In this sense, Blake et al. (2006, p. 6-15) include an analysis of the mortality and longevity bonds issued by 2006. However, these bonds have not been very successful, therefore I will only briefly mention those.

The literature on longevity risk transfer from the last two decades is extensive given the market's need to manage longevity risk and the longevity transfer markets' potential. Blake et al. (2006) offered an analysis of the different instruments to manage the previously mentioned stakeholders' exposure to longevity risk. Many of these instruments were hypothetical back in 2006. The markets implemented some of them but not the others.

Furthermore, more recent research is an update to the previously mentioned work. Blake et al. (2018, p. 68-69) discuss the longevity risk transfer market's development since 2006. They expose some challenges to consider to continue developing the longevity risk transfer market, such as equalizing stakeholders' preferences regarding different instruments and likely regulators' measures. However, this has still not been tackled in practice, as longevity derivatives are not widely traded, and the momentum is focused on insurance-based transactions between pension funds, insurers and reinsurers.

The vast literature on the topic indicates that longevity risk instruments and transfer markets are a lively research topic. It is increasingly clear that the potential of these markets is high.

This thesis aims to understand better the importance of longevity risk and its transfer in times of increasing lifespans. It will provide a comprehensive overview of the current longevity risk transfer market, including theoretical description of the majority of the existing instruments and mechanisms. I will investigate the implications and pricing of the insurance-based instruments. To do this, I will provide a comprehensive summary of the typical bearers of longevity risk and their potential role in the longevity risk transfer markets. Furthermore, I will offer a comprehensive analysis of the characteristics of possible longevity transfer mechanisms, and provide a comparison between them, clearly distinguishing between their advantages and disadvantages to find the most straightforward and most efficient way of longevity risk transfer. Consequently, I would like to establish which of the available instruments are the simplest to use and have the most significant potential. I want this research to serve as a useful and structured contribution on the topic addressing the needs of potential investors and anyone interested in longevity risk and offer some advice for the development of longevity risk transfer markets.

I will base this master thesis on theoretical research through an extensive literature review and recompilation of data from different sources. I will examine the trends regarding longevity, the financial aspects of longevity risk, and how it affects various players, the historical approaches, and the possible transfer mechanisms and instruments to capital

markets. The emphasis will be on the existing transferring mechanisms, their use, and characteristics, and their presence on the current longevity risk transfer markets. Finally, I will estimate the impact of longevity risk in a hypothetical pension scheme and analyse the effectiveness of a longevity swap as an insurance-based instrument in longevity risk transfer.

In the first part of the thesis, I will describe the increasing trend in the aging of populations, increased longevity, reduced mortality, and how this change affects the different players, thus explaining the need for risk transfer. In the second part, I will describe the evolution of the longevity risk transfer markets worldwide, their characteristics and current status. Next, I will dive deeper in the existing mechanisms and instruments for transferring longevity risk differentiating between insurance-based and capital markets-based solutions. In this part, I will focus on their main characteristics, pricing, and their presence in the longevity risk transfer market. Finally, I will employ the CMI\_2023 model (CMI, 2024) to estimate the longevity risk impact on a hypothetical pension scheme and analyze the impact of employing a longevity risk transfer instrument for the sake of longevity risk transfer. In conclusion, I will provide an executive summary of the main findings obtained in this thesis.

## **2 GENERAL ASPECTS OF LONGEVITY RISK**

Longevity risk has attracted significant interest in the past two decades, motivated by the continued demographic trend of increasing life expectancy and improving mortality. Although life expectancy and mortality are two opposite sides of the same coin representing human life, the two are very tightly connected demographic indicators (Edwards, 2020). According to Edwards (2020), the most straightforward connection between them can be seen in the factors influencing them.

Life expectancy can be calculated by taking into account, in the first place, an individual's mortality. This is only possible if we know the different mortality rates for future years, a phenomenon widely known as mortality improvements. But, unlike calculating mortality, the calculation of mortality improvements is somewhat complex and subjective. As a result, the possibility of a substantial misestimation of mortality improvements and life expectancy leads to longevity risk.

Considering the trend of increasing life expectancy and continuous mortality improvements at an unpredictable pace, longevity risk will continue to pose threats in the future. The risk already has significant economic consequences in today's economic and social systems, with pensions listed as one of the most affected areas. When we say pensions, we refer not only to public pension systems (governments) and individuals but also to the private pension sector, comprised of pension funds, insurers, and annuity providers. As direct bearers, the latter are searching for ways to mitigate the longevity risk posed by rising lifespans by using different longevity transfer mechanisms.

In summary, the present chapter aims to discuss the historical evolution of life expectancy, explore the main characteristics of longevity risk, as well as to list the most affected players.

## **2.1 Increasing life expectancy and mortality improvements**

OECD (2019) defines life expectancy as the average number of years people of a particular age could expect to live. When talking about life expectancy, it is helpful to distinguish between two basic concepts:

- a) life expectancy at birth refers to a newborn's expected number of years of life at a certain point in time.
- b) life expectancy at a given age refers to the number of years of life for a person who has already reached a certain age.

Life expectancy at birth has gradually increased during the last century. In 1950, global life expectancy at birth was below 48 years, but this figure has been increasing ever since, with estimations for 2025 being almost 30 years higher compared to the 1950s. When differentiating between global figures and the figures for more developed regions, this demographic indicator for the latter increases even more. As shown in Figure 1, life expectancy at birth is much higher in more developed regions (blue curve) compared to world average figures (red curve). In many developed countries, life expectancy at birth surpassed 80 years in 2019 (OECD, 2021).

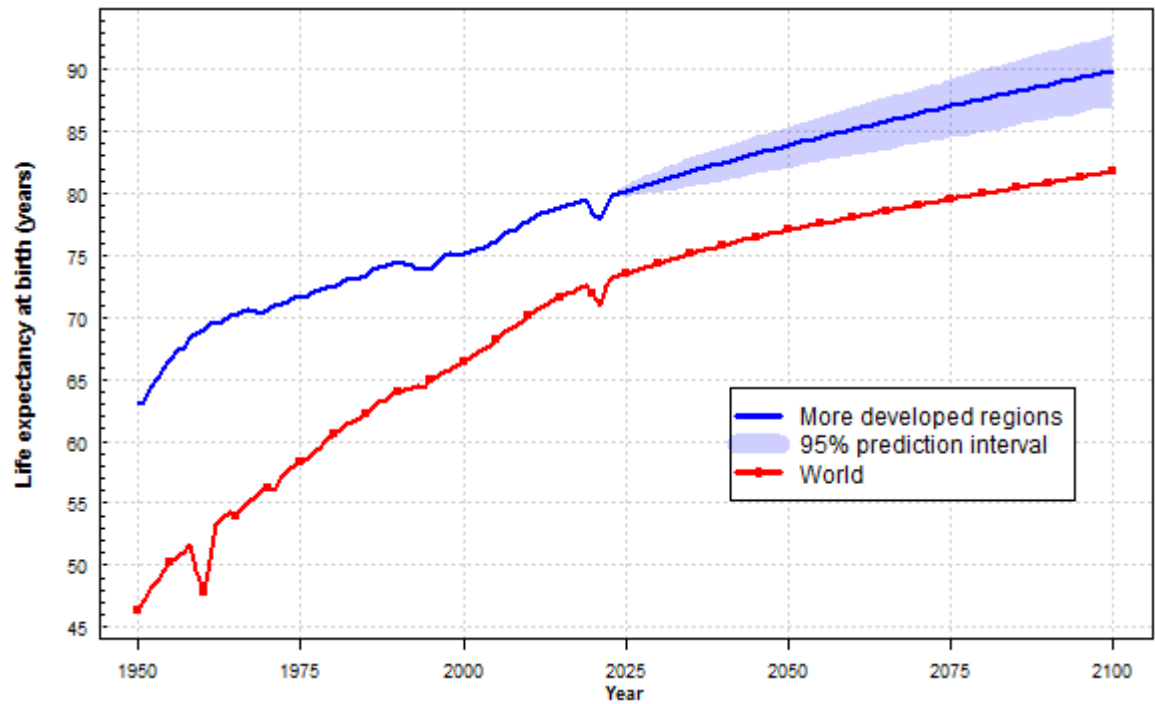
Moreover, it is predicted that by the end of the 21st century, life expectancy at birth could reach 90 years in more developed regions. According to estimations, some countries, such as Japan, are very close to reaching this figure much earlier, considering that Japanese females born in 2019 had an estimated life expectancy at birth of almost 89 years. Switzerland also ranks high compared to Japan, with a life expectancy of 84 years (WHO, 2020).

On the other hand, there is also the concept of life expectancy at a given age, which is the most important demographic indicator when talking about longevity risk. Specifically, life expectancy at older ages is what's being estimated in terms of pensions and annuities and the risk borne by individuals, pension funds, annuity providers and social security systems (Antolin & Blommestein, 2007). For example, pension providers want to know how long a pensioner will live after reaching retirement age – the age of eligibility for mandatory pension benefits (OECD, 2011, p.19). Like life expectancy at birth, this indicator has been increasing consistently. This is represented in Figure 2, from where we can see, that just a few decades ago, people lived fewer years after retirement than today. For instance, on average, a person aged 65 in the 1960s enjoyed less than 15 years in retirement. Nowadays, a person aged 65 is predicted to live, on average, approximately 18 more years (OECD, 2011). When analyzing all these figures, one must bear in mind that they are average numbers, with some people dying before and others after the estimated life expectancy. In

Figure 2, we can also see the comparison between life expectancy at 60 years and 65 years for men and women between 1960 and 2050 for OECD countries.

When talking about life expectancy or mortality nowadays, especially after the recent pandemic caused by COVID-19, we must not forget to consider its implications. Namely, it has had an essential impact on increased mortality and life expectancy worldwide, with the extent and nature of this impact varying widely by region, country and demographic factors. According to the ONS (2023), it could be said that it has altered the trend of increasing life expectancy rather than slowing it down (for example, compared to 2019, mortality in England and Wales rose by 13.9 percent in 2020, 9.2 percent in 2021, and 6.2 percent in 2022, however, 2023 is getting closer to figures before the pandemic). Moreover, there is the phenomenon of “Long-term COVID”, characterized by prolonged health complications following COVID-19 infection, that poses a challenge to quantifying its direct impact on mortality rates. Some institutions, such as the U.S. Center for Disease Control and Prevention (CDC), acknowledge the presence of long-term adverse effects stemming from COVID-19, which contribute to excess mortality (CDC, 2025).

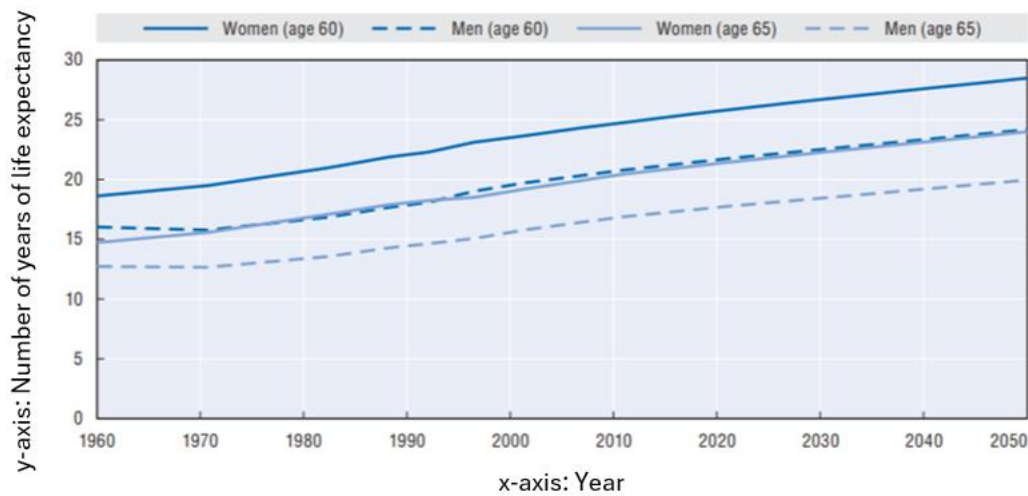
Figure 1: Probabilistic projections of life expectancy at birth in developed regions



Source: United Nations (2024).

However, accurately attributing mortality to long-term COVID is complex due to the diversity of symptoms and the lack of uniform clinical guidelines. According to Milliman (2023) an offsetting effect on overall mortality improvement is possible, given that COVID-19 has disproportionately affected individuals with preexisting conditions, who typically have higher base mortality.

Figure 2: Life expectancy at age 60 and 65 by sex, OECD average, 1960-2050



Source: OECD (2011).

Nevertheless, longer and healthier lives are among the most significant achievements of the world. According to the OECD (2021), improvements in life expectancy at birth have been reached due to the combination of different factors such as education, health, sanitation, better living standards and improved lifestyle, among others. Also, given the scientific development in fields such as medicine, the length of human life is much more predictable nowadays than a few decades earlier. As a confirmation, the OECD (2011, p. 27) has determined that at the beginning of the previous century, total life expectancy increased due to lower mortality at younger ages. In contrast, life expectancy grew in the second half of the century due to the lower mortality risk at retirement age (OECD, 2011, p. 27).

When considering longevity or life expectancy, we need mortality data, which can be used to estimate life expectancy (Institute and Faculty of Actuaries, 2015). However, mortality is only an input, and to calculate a person's life expectancy, it is necessary to talk about mortality improvements. Calculating mortality improvements involves analyzing changes in mortality rates over time to predict future trends. For actuarial needs, these two demographic indicators are connected in life tables. Life tables summarize the mortality, survivorship and life expectancy of specific populations by age, and they show the age-specific life expectancies, given the mortality rates at that age (Antolin & Blommestein, 2007, p.5). By providing a comprehensive view of mortality and survival within a population, life tables enable a nuanced analysis of past and present trends, which, when projected into the future, offer valuable forecasts for longevity, ensuring that empirical data and realistic assumptions about mortality trends are considered. According to Antolin & Blommestein (2007, p.6), improvements in mortality rates and life expectancy have been underestimated in the past, showing that projections of life expectancy in 2005 were below the actual outcomes. Additionally, the author reports that future life expectancy increases are expected to be generated by mortality improvements in old age (65 or more). However, projections show

that future mortality and life expectancy will improve slower, though this slows down the gains in longevity reached so far.

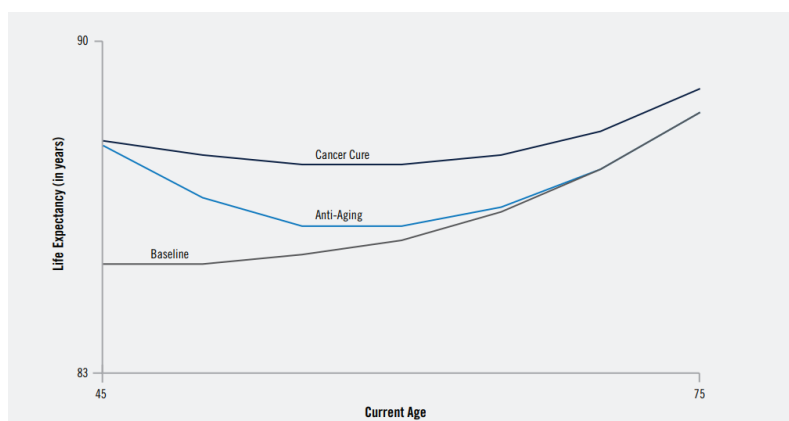
Blake (2018, p. 1-2) also presents two opposite views on the future of life expectancy improvements: the pessimistic and optimistic. The former suggests that factors such as global warming or obesity will negatively affect life expectancy, reducing the years we live. On the contrary, the latter points out that further scientific developments, especially in regenerative medicine and technological innovation, would increase the limit of human life. For example, Prudential Financial Inc. (2017) states that a purely theoretical scenario of releasing a general cure for all cancer types or an anti-ageing technology can enormously impact longevity improvements. The former would show its effects and impact more on the middle-aged population, whereas the latter would affect the younger population to apply this potential anti-ageing technology. Namely, this is represented visually on Figure 3, where we can see that there would be a different effect in life expectancy in function of the current age under the theoretical scenario tackled by Prudential Financial Inc. (2017). Additionally, Table 1 lists the possible driver of future mortality improvements grouped into different areas such as environmental, healthcare, economic and social, or behavioral among others (Swiss Re, 2018).

*Table 1: Possible drivers of future mortality improvements*

| <b>Area</b>                    | <b>Possible drivers</b>                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Environment                    | Climate change, air, water and land pollution, war/terrorism and crime rate                                                                                                                                                                                                                                                                                               |
| Healthcare                     | Availability, access, quality/effectiveness and usage of healthcare                                                                                                                                                                                                                                                                                                       |
| Economic and social inequality | Socio-economic factors (e.g., education, occupation, income), inequality within and across countries                                                                                                                                                                                                                                                                      |
| Behaviour                      | Activities of daily living such as drug, tobacco (incl. e-cigarettes/vaping), alcohol use/addictions, diet/nutrition, avocations, physical activity, stress, sleeping pattern                                                                                                                                                                                             |
| Medical advances               | New treatments (precision medicine: e.g., CRISPR, immunotherapy), improved prevention (e.g., genetic testing), early detection (e.g., liquid biopsy), regenerative medicine, stem cells, 3-D organ printing                                                                                                                                                               |
| Technological advances         | New types of and/or more accurate data (e.g., electronic health records, wearables and (ingestible) biosensors), new statistical/analytical methods (e.g., artificial intelligence in healthcare but also underwriting mortality risks of insureds), nano-technology, internet of things, robotics and automation (e.g., self-driving cars that reduce accidental deaths) |
| Ageing                         | Anti-ageing (drugs), ambient assisted living arrangements (e.g., supportive home environments that integrate sensors, actuators, alarms etc.), improved mental, physical and social care                                                                                                                                                                                  |
| Catastrophes                   | Natural catastrophes, man-made disasters, epidemics/pandemics (e.g., antibiotic-resistant infections)                                                                                                                                                                                                                                                                     |

*Source: Swiss Re (2018).*

*Figure 3: Potential medical advances could significantly impact life expectancy*



*Source: Prudential Financial Inc. (2017).*

## **2.2 Longevity risk and the need for transferring and hedging**

According to the IMF (2012, p. 131), financial stability is at risk as a consequence of longevity risk since, on the one hand, it affects the fiscal stability of countries given the increasing governments' exposure to longevity and on the other hand, it undermines pension and annuity providers' solvency. Longevity risk can be defined as the risk that the lifespans will continue to increase more than expected or provisioned for (OECD, 2014, p. 14). According to De Waegenare et al. (2010, p. 152), longevity risk is the uncertainty regarding future mortality developments. Furthermore, the IMF (2012, p. 125) defines it as “the risk that actual life spans of individuals or whole populations will exceed expectations”. Longevity risk may also be defined as the financial consequences of people living longer than expected (IMF, 2012). Additionally, Pieschacón Velasco (2014, p. 13) suggests that longevity risk could be directly compared to catastrophic risk. Considering all the abovementioned factors, longevity risk is the risk produced by misestimating life expectancy and mortality improvements.

The fact that people spend more time in retirement affects not only individuals who need more financial resources to support their longer lives but also pension plans, annuity providers, and social security schemes, given that with the increase in lifespans, the pension obligations of these institutions also increase (Kessler, 2019).

Many studies help quantify the financial impact of longevity risk. The IMF (2012, p.124), for example, has estimated that our society's cumulative expense during an increased lifespan of only three years could reach between 25 and 50 percent of GDP (in emerging and advanced economies, respectively). Furthermore, the study shows that in terms of the solvency of private sector pension plans in the United States, the three-year longer lifespans would lead to a 9 percent increase in these institutions' liabilities (IMF, 2012, p.124). Additionally, Blake et al. (2018) summarize Michaelson & Mulholland's (2014)

quantification of longevity risk as a 4 to 5 percent increase in pension liabilities with each year of additional underestimated life expectancy.

According to Blake (2018) longevity risk is driven by three underlying risks:

- a) modelling risk: it refers to the uncertainty associated with the accuracy of models used to predict how long people will live (for example, incorrect modelling of the probability distribution). This type of risk arises from various factors, including the complexity of modelling human mortality as described above, the assumptions made within the models and the quality and limitations of the data used. Modelling risk acknowledges that different models may produce different projections of future life expectancies, leading to potential inaccuracies in estimating longevity-related liabilities for pension funds and insurance companies.

As indicated and employed by many authors, it can be summarized that longevity modelling is vital for longevity risk estimation, and it can be performed by employing various methodologies that can be broadly categorized as follows (IMF, 2012):

- Process-based (or cause-of-death models, according to Blake (2018)): These models aim to understand and quantify the underlying factors or processes that influence death rates. The models in this group are characterized by the use of biomedical assumptions and socio-economic data for forecasting death and longevity rates. The approach of these models is complex, requiring a deep understanding of the relationship between the numerous influencing factors and longevity. This translates in the present challenge of accurately predicting mortality rates.
- Explanatory and Causal: These models forecast mortality using external variables such as macroeconomic factors and socio-economic indicators, which can be correlated with mortality improvements (for example, GDP growth has a directional correlation with mortality improvements, and the differences in mortality rates due to lifestyle factors can account for most of the mortality differences between different groups) (Blake, 2018).
- Extrapolative Methods: Unlike process-based models, extrapolative methods rely only on historical mortality data to predict future trend, assuming the continuation of historical mortality rates or applying statistical techniques to produce smoothed trends or sophisticated models (these can be cohort-specific). Such models include the well-known Lee-Carter model, which has been applied as the standard model for forecasting longevity so far (it has shown success in several countries but not as effective in others due to unique cohort effects). Here, we can also list the Continuous Mortality Investigation (CMI) models. These models can be deterministic, projecting mortality trends directly or stochastic, allowing for random deviations from historical trends.

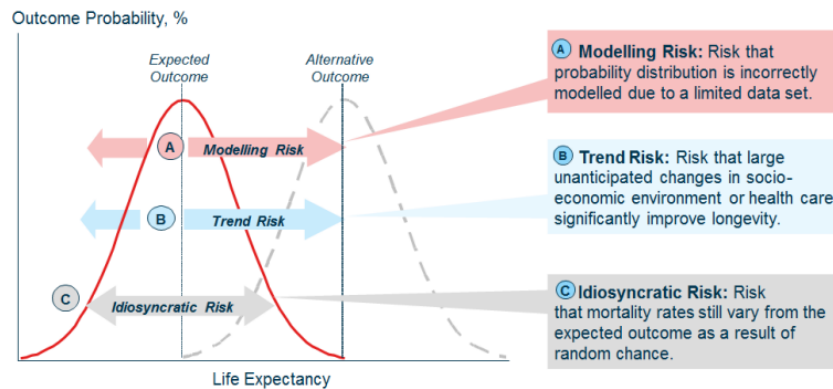
Naturally, each method has its own set of strengths and challenges. Process-based models, for example, offer a causal understanding of mortality factors, but they are complex, limiting their predictive power. Extrapolative methods, on the other hand, are more straightforward but may need more flexibility to account for future changes in mortality trends. Additionally, cohort analysis adds depth by considering generational effects but can be complicated by data limitations and the need to make assumptions about future cohort behaviours.

- b) idiosyncratic risk: this risk arises from individual-specific factors that can affect an individual's lifespan and longevity outcomes. Unlike systematic or aggregate risks, which affect a broad population or group, idiosyncratic risk refers to each person's specific factors that influence their life expectancy, for example, genetics, lifestyle choices, socio-economic status, occupation, access to healthcare, or environmental conditions. These factors can vary significantly among individuals and lead to differences in mortality rates and longevity outcomes within a population.

Blake (2018) illustrates this concept showing the expected distribution of deaths for males aged 65 and 85. For instance, for a male aged 65, the projected life expectancy is 86.6 years, with the most probable age at death being around 90 years. However, Figure 5 illustrates that approximately 25 percent of individuals will die before reaching 86.6 years (suggesting idiosyncratic risk, or the individual variation in lifespan) and another 25 percent will live beyond that age. Moreover, there is about a 1 in 1000 chance for an individual to live to double the life expectancy, meaning up to or beyond 130 years. This demonstrates the extreme tail risk associated with individual variation. For comparison, for a male aged 85, the life expectancy is 91.6 years, with the most likely age at death being 86 years. According to Figure 5, 1 in 3 individuals will reach age 93, and 5 percent will reach age 100 (Blake, 2018).

- c) trend risk: it refers to the uncertainty associated with the future direction and magnitude of changes in life expectancy trends. This type of risk acknowledges that historical patterns of mortality improvements may not continue as expected in the future. Factors such as medical technology advances, lifestyle habits, socio-economic developments and environmental factors can influence longevity trends (see Table 1) (Swiss Re, 2018).

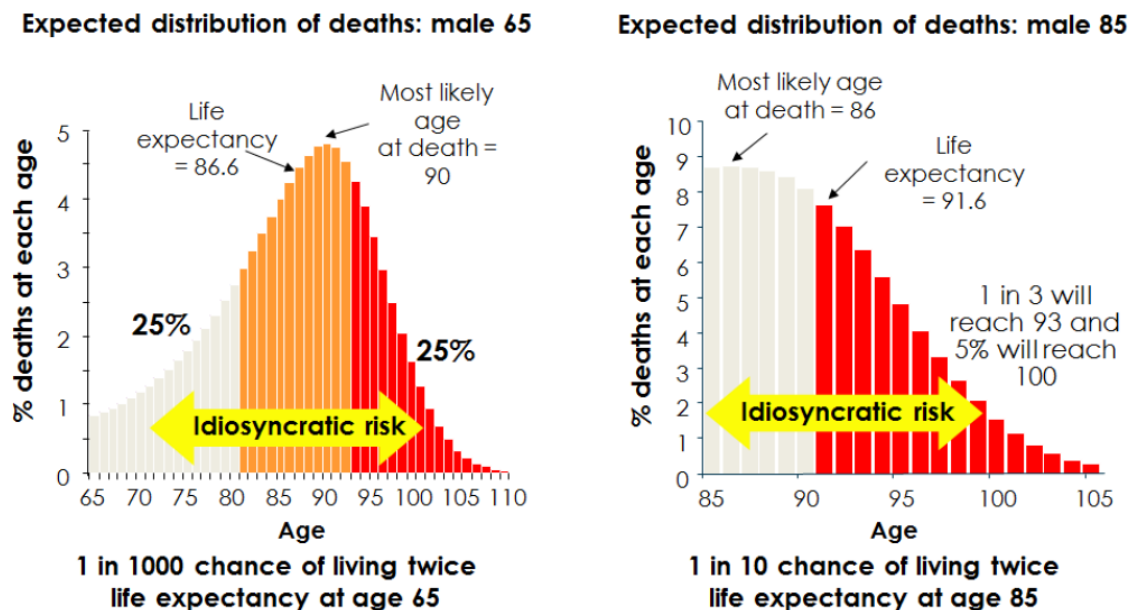
Figure 4: The underlying risks that constitute longevity risk



Source: Blake (2018).

Blake (2018) states modelling and idiosyncratic risk comprise the so-called “specific longevity risk”. However, modelling and idiosyncratic risks can be diversified when dealing with large populations. For example, the impact of modelling risk can be mitigated by using different modelling approaches, incorporating various data sources, and validating models against historical data from various demographic groups for accuracy. Similarly, as to idiosyncratic risks, while individual characteristics and circumstances may lead to varying longevity outcomes for each person, its effect can be mitigated when considering a large and diverse population that diversifies the idiosyncratic risk. Figure 4 represents the risk types underlying longevity risk and how those can affect the life expectancy distribution (Blake, 2018).

Figure 5: Variability in life expectancy



Source: Blake (2018).

Trend risk, on the other hand, is seen as a systematic longevity risk with slow development and cumulative nature (which is the main difference from investment risk). It has been stated by various authors that the underestimation of trend risk can have important financial impact. For instance, according to Coughlan (2014), even a modest deviation in expected mortality improvements (for example a 1 percent deviation in the annual decline of mortality rates) can have substantial impact on the costs incurred by pension and annuity providers. These providers base their obligations on long-term expectations of life expectancy, and even small underestimations can accumulate significantly over time (cumulative values have a huge impact). This effect is especially pronounced for younger individuals. For example, a 45-year-old plan member could see their projected life expectancy increase by 2.7 years, which corresponds to a 7 percent increase in the cost of funding a fixed pension, or almost 11 percent if the pension is inflation-linked. In comparison, the same shift in assumptions would raise the life expectancy of a 65-year-old retiree (pensioner) by about 1 year, resulting in a 3 percent cost increase for fixed pensions and a 5 percent for those that are inflation-linked. There is an evident contrast in cost impact between pre-retirees and current retirees which must be taken into consideration when accounting for trend risk (Blake, 2018). Also, measures for risk management should be undertaken as soon as possible. The IMF (2012, p.124), for example, has suggested an approach that consists of three components and involves the following methods:

- maintain fiscal sustainability by implementing measures to deal with longevity risk exposure of governments;
- motivate risk-sharing between the three affected parties (governments, private pension providers, and individuals) by implementing pension regulations reforms and promote individual saving for retirement;
- longevity risk transfer on capital markets.

Prudential Financial Inc. (2015) gives a supporting statement to this approach, which states that longevity risk cannot be mitigated only by employing a particular investment strategy, meaning that the impact should be mitigated by collaboration between all affected players. In terms of pension funds and annuity providers, the OECD (2014, p.50-63) has performed a study that shows that the provisioning of pension funds and annuity providers based on mortality tables used at the moment of the study in selected countries could lead to shortfalls in meeting these entities' obligations, due to mortality tables not performing according to the projections in life expectancy and mortality improvements. Furthermore, Whitehouse (2007, p.11) states that growing life expectancy and the threat of longevity risk have financial and political implications. This is due to the vital role of pension systems and the reforms that should take place to account for longer lives.

## **2.3 Primary bearers of longevity risk and its implications**

Another distinction of longevity risk we can make, is between individual and aggregate longevity risk (MacMinn et al., 2006). The latter can also be defined as systemic risk, according to Pieschacón Velasco (2014).

According to ECB (2005), individual longevity risk can be easily shared and diversified by participating in private annuity markets. In contrast, collective longevity risk is much more severe and can not be simply shared given its volume and complexity. As the name itself suggests, individual longevity risk is the one that is borne by individuals as the incapability to continue with the same lifestyle or run out of financial resources in retirement. However, individuals can react quickly and start saving for retirement early in their working lives. Furthermore, they can share this risk with insurance companies (annuity providers) or pension funds.

Pension funds and annuity providers are next on the list of longevity risk bearers because they accept the risk shared by individuals or corporate schemes. Their pension portfolios reach substantial quantities and, thus, the severity of the longevity risk they bear. Additionally, if not provisioned accordingly, the risk is even higher.

Governments are responsible for public pension systems. Public pension systems or governmental social security schemes have existed for quite a long time now; however, with the changes in demographic factors, their sustainability is becoming questionable. Moreover, governments bear the risk of longevity as a result of providing public pensions and as a lender of last resort responsible for financial stability. Thus, the government's role is very important in managing and dealing with longevity risk.

Given all these facts, and with the objective of more efficient longevity risk management, the IMF (2012) has recommended sharing longevity risk between these three primary bearers.

### **2.3.1 Individuals**

Individuals often underestimate their life expectancy, leading to insufficient retirement savings. For example, a male aged 65 has an average life expectancy of 87, but there is a 25 percent probability that he lives to 94 and a 10 percent chance of reaching 99 years (Institute and Faculty of Actuaries, 2015). Longer lives come with a higher cost and a need for more retirement income, which individuals must bear and take care of. Part of this cost is already externalized through the contributions that individuals make to the social security system pension schemes during their working life, however, with the emerging problem of longevity and reducing mortality and fertility, state pensions may not be enough for the increasingly ageing population. The latter can be seen from the evolution of the population pyramids, presented in Figure 6. Public pension systems are, therefore, highly endangered, which is

why governments are shifting the longevity risk they bear to individuals through the implementation of reforms in pension systems, such as increasing retirement ages, introducing reduction coefficients and sustainability factors, or transforming the pension systems to notional defined contribution (the case of Sweden) among others.

Individuals face an individual or “idiosyncratic” longevity risk that may cause them to outlive their financial resources, sometimes referred to as “retirement ruin” (Milevsky, 2006). On a more straightforward note, longevity risk for individuals can be seen as the inability to maintain the same lifestyle during the longer-lasting retirement period and live longer than what has been planned in terms of their savings, which can even lead to poverty in the later stages of retirement (OECD, 2014). Although, as discussed previously, it is challenging to estimate how long an individual will live, people must consider longevity risk to avoid suffering from income shortage once they retire.

On an individual level, the risk can be mitigated with proper individual financial management, meaning that apart from generating “old-school” savings, individuals should externalize the “longevity cost”. The externalization of this cost would be seen in contracting life annuities and contributing to any individual pension plans or defined contribution schemes provided by employers. Defined benefit schemes still exist. However, many employers are changing their retirement savings schemes to defined contribution plans, reducing the employers' responsibility for any retirement income insufficiency and shifting the risk to the individual (American Academy of Actuaries, 2016). Thus, the mentioned changes make the importance of longevity risk consideration for individuals even higher.

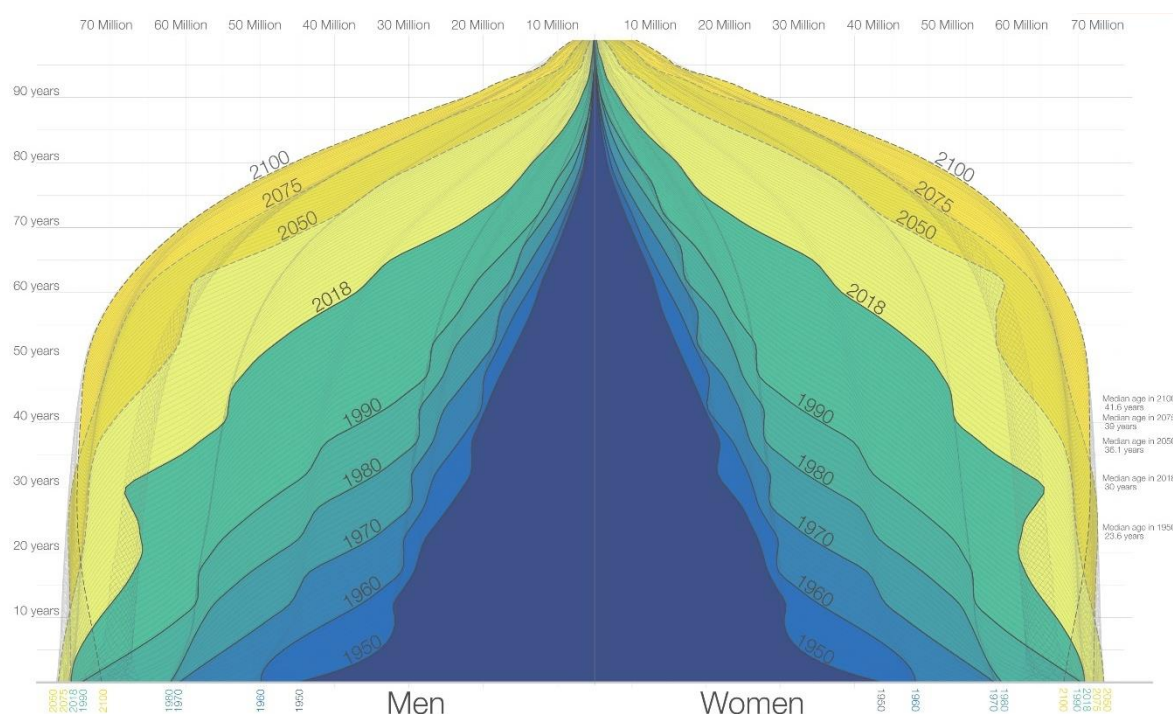
Additionally, as suggested by the Actuaries Institute Australia, Institute and Faculty of Actuaries, and the American Academy of Actuaries (2015, p. 2), it is essential not only for individuals to generate savings for retirement through different savings methods but also, how are they going to spend these savings once they retire. Many employers increasingly take the responsibility of raising awareness and providing financial education for their employees, highlighting the importance of adequately saving for retirement. This effort is highly recognized and valued by employees, that is considered as another employee benefit provided by the company. The Actuaries Institute Australia, Institute and Faculty of Actuaries, and the American Academy of Actuaries (2015, p. 2) also highlight the importance to contract the proper insurance or annuities by providing sufficient information regarding estimation, planning and expectation compared to the possible reality.

### 2.3.2 Governments

Next in line as direct longevity risk bearers are governments. These institutions, as opposed to individuals, bear the aggregate longevity risk, whose impact can be huge and leave important financial consequences. According to the IMF (2012, p. 131), longevity risk for these stakeholders comes from three sources: public pension plans, social security schemes, and the government's role as a lender of last resort for individuals and financial institutions.

Firstly, the longevity risk for governments is reflected in the length and amount of public pensions they pay retirees. This impact will increase in the future, considering the reduced birthrate in most developed countries worldwide, meaning fewer people will enter the active workforce. Consequently, fewer people will pay social security contributions to finance the longer-lasting pensions, increasing the stake and liability of governments. The demographic pattern of increasing life expectancy and reduced fertility and mortality has gradually changed the structure of the so-far known population pyramids (Fundación MAPFRE, 2017). Also, as visible from Figure 6, population pyramids are on their way to becoming inverted by the end of this century (yellow colour; year 2100), with most of the population being mature and stable, with low fertility and mortality rates. This means that the older population is surpassing the number of the younger population.

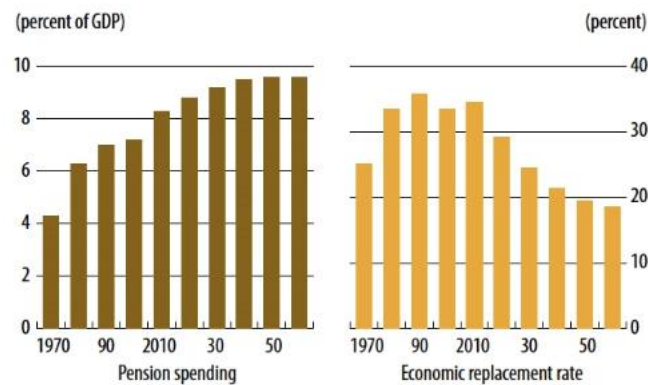
*Figure 6: Evolution of population pyramids from 1950 to 2018 and projections*



*Source: Roser (2017).*

To support this, a study by the OECD (2019) shows that longer lifespans in developed countries have increased government spending on pensions. For example, in advanced economies, an average of 4 percent of the GDP was spent on pensions back in 1970, while this figure has increased to 9 percent in 2015 due to ageing population (IMF, 2017). According to the IMF (2017), another very important indicator that witnesses the need of reforms in the pension systems is the economic replacement rate, or the public pension expenditure per elderly person as a percentage of the income per capita. This indicator has been steady at 35 percent since 1980 but, there are projections that it will decline to less than 20 percent by 2060 as visible from Figure 7 (IMF, 2017). Figure 7 represents the pension spending as a percentage of the GDP since year 1970, as well as the economic replacement rate as a percentage.

Figure 7: Pension spending and economic replacement rate



Source: IMF (2017).

Public pension plans have been in place since the end of the 1800s, and in some countries, they have stayed intact for almost a century. However, considering the demographic changes during the same period, public pension systems should have also evolved accordingly. For example, back in 1919 in Spain, only 10 percent of the retirees survived to reach the retirement age of 65. This retirement age was still in place in 2010, when 90 percent of the population reached the retirement age (Pieschacón Velasco, 2014, p. 15). As visible from Table 2, there are still many countries that maintain the retirement age at 65, but there are also some that have increased it. They are expected to follow this pattern shortly (changes typically have been scheduled between 2020 and 2030) (Eläketurvakeskus - Finnish Centre for Pensions, 2021). Additionally, Figure 10 helps to graphically represent the movements in the retirement ages per country in the European Union.

The burden of public pension systems is important. Therefore, they are highly endangered, which is why governments are shifting the longevity risk they bear to individuals through the implementation of reforms in pension systems, such as increasing retirement ages, introducing reduction coefficients and sustainability factors, or transforming the pension systems to notional defined contribution (the case of Sweden) among others. Now, people live longer but have longer working lives, which justifies these reforms. Some other reforms can be seen in incentivizing individual saving for retirement by increasing tax exemption limits for contributions to employer retirement savings products (case of Spain), auto-enrollment programmes (New Zealand and UK), or mandatory pension plans in countries where this has not been implemented earlier (OECD, 2020, pp. 20-25).

Secondly, social security is also mentioned as a source of risk because, once people are left without income in the retirement period, they will request social security help through subsidies. Finally, governments also bear more aggregate risk from another source: having the lender of last resort role for individuals and financial institutions since they are expected to step in if the latter face solvency issues (IMF, p. 131, 2012).

### 2.3.3 Pension funds and annuity providers (insurance companies)

On the top of the list of direct bearers of aggregate longevity risk, there are pension funds and annuity providers (for example, life insurance companies). According to the Thinking Ahead Institute (2025, p.7), retirement savings in pension funds, pension insurance contracts and other vehicles at the end of 2023 exceeded \$58 trillion in the 22 biggest pension markets in the world. Outside these 22 markets, the Thinking Ahead Institute (2025, p.5) estimates that there is an additional \$3 to \$5 trillion of pension assets. This figure is reported to be the highest so far. Most of these assets were held in pension funds. The concentration of the assets in retirement savings plans was in the US, Canada, the UK, Netherlands and Japan accounting for over 82 percent of all pension assets (Thinking Ahead Institute, 2025, p.21).

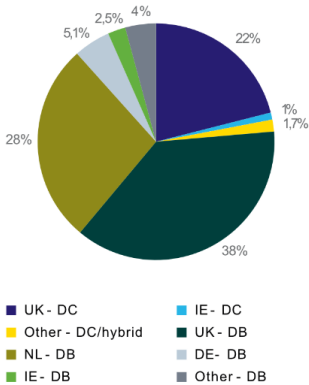
De Nederlandsche Bank (2015, p.8) sees the exposure to longevity risk for these players reflected through the higher amounts of pay-outs than what has been provisioned for due to longevity increases. Pension funds with defined benefit schemes offering annuities are more vulnerable to longevity risk than those offering lump sum payments. On the other hand, for defined contribution schemes or insurance companies (life insurers) that offer death benefits (as opposed to life annuities), the individual bears the longevity risk. When concentrating on defined benefit plans (as these still have a large stake in the OECD countries), the proportion of pension assets held by them has decreased to less than 50 percent of all pension assets (OECD, 2021, p.38).

Despite the lower proportion of pension assets in defined benefit (DB) plans (approximately \$27 trillion), their prominence is still high. The IMF (2012) has estimated that the increase of the lifespan for one year, can be seen in approximately 4 percent increase in the defined benefit pension fund liabilities' present value. In financial terms, this means that the impact of longevity risk is very significant and, if not treated and reflected correctly in balance sheets, may lead to endangered financial health. Taking the example from Prudential Financial Inc. (2017), if we suppose a life expectancy increase of 4.5 years during the following 20-30 years, and we take a pension plan composed of 50 percent active participants and 50 percent retirees, we can estimate a gradual increase of 15 percent to 20 percent in the value of the liabilities. Although defined benefit plans are increasingly disappearing nowadays, institutions with such plans still want to fulfil their obligations in case of rising life expectancies (Massachusetts Mutual Life Insurance Company, 2018). If not managed, longevity risk can negatively affect the plan's risk profile and reduce the funded status. Prudential Financial Inc. (2017) suggests an approach that consists of three elements, among which are the implementation of a framework for correct measurement and analysis of the longevity risk impact, mitigation through investment and protection actions, and engagement in longevity risk transfer transactions to reduce the volatility in the balance sheet.

Thus, the need for transferring longevity risk has appeared with ever-increasing interest from vulnerable pension funds and annuity providers due to their fixed obligations to pensioners

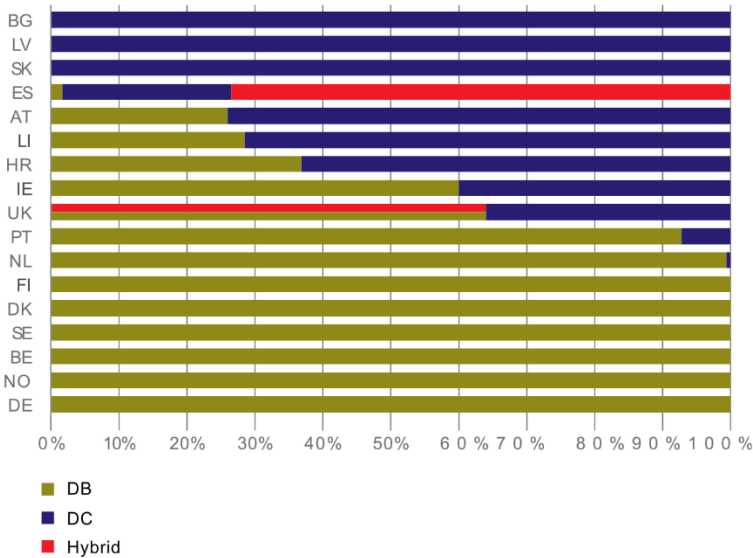
and annuitants. There are countries where these types of plans do not exist, and others, such as the UK, the Netherlands, the US and Canada, with a high portion of defined benefit plans in their pension portfolios. These countries have a significant stake in pension and life assets in their national GDP. Consequently, in the past few years, the highest volumes of longevity de-risking transactions have been performed among/in the mentioned countries. More details on this topic will be covered in the following chapter.

Figure 8: European pensions market share



Source: De Nederlandsche Bank (2015, p 15).

Figure 9: Breakdown DC/DB/Hybrid schemes in EU Countries

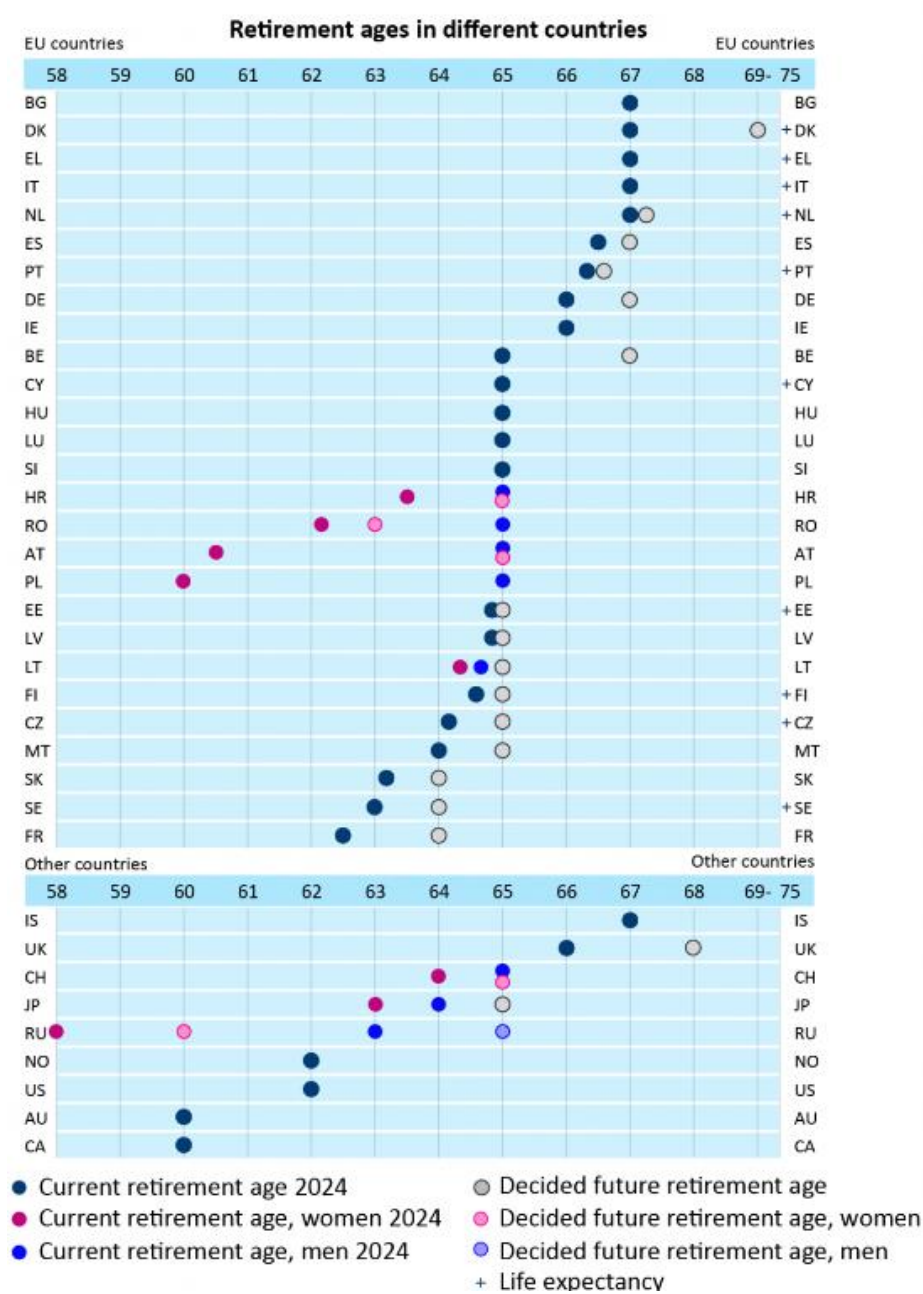


Source: De Nederlandsche Bank (2015, p 16).

Figures 8 and 9, for example, show the European market’s structure in terms of pension plans’ type: whether its defined benefit or defined contribution scheme. It is important to differentiate between defined benefit and defined contribution plans, as both types differ in who bears the longevity exposure. Namely, defined benefit (DB) plans guarantee a specific retirement benefit based on a formula considering service length, salary history, and age,

with the employer bearing all longevity and investment risk, whereas defined contribution (DC) plans define contribution amounts into individual accounts, not final benefits. Here, the retiree bears both investment and longevity risk, as payouts fluctuate depending on investment returns and lifespan.

Figure 10: Current and future retirement ages in different countries



Source: Eläketurvakeskus - Finnish Centre for Pensions (2024).

Table 2: Current and future retirement ages in the EU and other countries

| Country             | Current general retirement age (2024) for Men/Women | Future retirement age for Men/Women |
|---------------------|-----------------------------------------------------|-------------------------------------|
| Austria (AT)        | 65 / 60 y 6 mos                                     | 65 (2033)                           |
| Belgium (BE)        | 65                                                  | 67 (2030)                           |
| Bulgaria (BG)       | 67                                                  | –                                   |
| Croatia (HR)        | 65 / 63 yrs 6 mos                                   | 65                                  |
| Cyprus (CY)         | 65                                                  | –                                   |
| Czech (CZ)          | 64 yrs 2 mos                                        | 65 (2030)                           |
| Denmark (DK)        | 67; 67*                                             | 69 (2035)                           |
| Estonia (EE)        | 64 yrs 9 mos                                        | 65 (2026); 65 (2027)                |
| Finland (FI)        | 64 yrs 6 mos–69 yrs; 65*                            | 65 (2027); 65(2030)                 |
| France (FR)         | 62 yrs 6 mos                                        | 64 (2032)                           |
| Germany (DE)        | 66                                                  | 67 (2031)                           |
| Greece (EL)         | 67                                                  | –                                   |
| Ireland (IR)        | 66-70                                               | –                                   |
| Italy (IT)          | 67                                                  | –                                   |
| Latvia (LV)         | 64 yrs 9 mos                                        | 65 (2025)                           |
| Lithuania (LT)      | 64 yrs 8 mos / 64 yrs 4 mos                         | 65 (2026)                           |
| Malta (MT)          | 64                                                  | 65 (2027)                           |
| Netherlands (NL)    | 67                                                  | 67 yrs 3 mos (2028)                 |
| Portugal (PT)       | 66 yrs 4 mos                                        | 66 yrs 7 mos (2025)                 |
| Romania (RO)        | 65 / 62                                             | – /63 (2030)                        |
| Slovakia (SK)       | 63 yrs 2 mos                                        | 64 (2030)                           |
| Slovenia (SI)       | 65                                                  | –                                   |
| Spain (ES)          | 66 yrs 6 mos                                        | 67 (2027)                           |
| Sweden (SE)         | 63–69; 66*                                          | 67 (2026)                           |
| Australia           | 60;67                                               | –                                   |
| Canada (CA)         | 60-70; 65-70                                        | –                                   |
| United Kingdom (UK) | 66                                                  | 68 (2046)                           |
| Iceland (IS)        | 67                                                  |                                     |
| Japan (JP)          | 64 / 63; 65                                         | 65 (2025) / 65 (2030);              |
| Norway (NO)         | 62–75; 67                                           | –                                   |
| Russia (RU)         | 63 / 58                                             | 65 (2028); 60 (2028)                |
| Switzerland (CH)    | 65 / 64                                             | – /65 (2028)                        |
| USA (US)            | 62 – 70                                             | –                                   |

Source: Eläketurvakeskus - Finnish Centre for Pensions (2024).

### 3 LONGEVITY RISK TRANSFER MARKETS

Longevity risk transfer markets have arisen to address the growing need to manage the longevity risk exposure of different stakeholders. According to De Nederlandsche Bank N.V. (2015, p.7), longevity risk transfer consists of using financial instruments to transfer longevity risk to third parties through different types of transactions constituted by the activities taken on the longevity risk transfer markets. When discussing financial

instruments, it is vital that we think not only about securities but also about insurance policies or reinsurance contracts. Here, we can refer to the categorization of the established mechanisms into two groups: insurance-based and capital market-based solutions for longevity risk transfer. Insurance-based solutions are those where an insurer or reinsurer provides the hedge, whereas capital market-based solutions aim to spread longevity risk across a broader pool of investors through capital markets. For the sake of simplicity, the particularities of each category and the specific instruments are more thoroughly explained in the fourth chapter. In contrast, in the present chapter, I will dive into the level of development of longevity risk transfer markets, their main characteristics, and their stakeholders while describing the most relevant historical transactions and characteristics.

### **3.1 Development, size, and potential of longevity risk transfer markets**

In terms of the emergence of longevity risk transfer markets, it is widely considered by various authors that they are relatively young, mainly as a consequence of the little attention given to longevity risk only until the beginning of this century when the awareness of the importance of managing this risk became global. According to Blake et al. (2018, p. 1), the official longevity risk transfer market started in 2006 in the UK with the first buy-out (an insurance-based solution) by Paternoster and the first longevity swap (a capital market-based solution) by Swiss Re in 2007. This marked the transition to the second stage of market development as per Sandor's paradigm, referenced by Kessler (2019, p.1), who, after 13 years of their officialization back in 2019, positioned longevity risk transfer markets in the second stage of market development when a commodity is being standardized. Almost 20 years later, most of these markets are still developing. The stages of market development that Kessler (2019, p.1) refers to can be summarized as follows:

- I. An occurrence of a structural change in the economy.
- II. Standardization of a commodity.
- III. Creation of evidence of ownership of the commodity to start trading.
- IV. Development of informal markets.
- V. Development of formal markets.
- VI. Establishment of hedging mechanisms or future markets.
- VII. Start of bilateral transactions.

The stages outlined by Kessler (2019) align with some of the key milestones in the longevity risk transfer markets, applying a wider view to both insurance-based and capital market-based solutions.

For example, looking at the origins of longevity risk transfer markets, we could say that the first stage started with the structural change motivated by the global demographic shift and increased life expectancy, a phenomenon that raised international awareness of longevity risk importance and the necessity to shift from defined benefit (DB) to defined contribution (DC) schemes. Here, we could also include the regulatory pressures as an additional

motivating factor that led the affected stakeholders to search for innovative ways to manage increased longevity risk. For instance, Solvency II in the EU and the Pension Protection Act in the US heightened funding requirements, which motivated employers to offload pension liabilities.

The second stage can be related to the development of standardized products or contracts that facilitate easier trading as well as valuation. A financial commodity is being defined and standardized at this phase, lacking complete formalization. Kessler (2019) identified that longevity risk transfer markets are positioned here and haven't progressed to further stages. While the truth is that longevity swaps and bulk annuities (buy-in and buy-out transactions) can be very standardized, most of the known deals are largely bespoke. A buy-in is an insurance policy purchased by typically a pension scheme to cover liabilities while retaining responsibility for benefit payments, whereas a buy-out involves a full transfer of both assets and liabilities to an insurer, who then assumes direct responsibility for pension payments to the members. A longevity swap on the other hand, is an insurance-based risk transfer agreement in which a pension scheme exchanges fixed payments for variable payments linked to actual survival rates, thereby transferring longevity risk to an insurer or reinsurer. These mechanisms will be discussed in greater detail in Chapter 4. Unlike markets for equities or bonds, longevity risk transfer contracts are not easily interchangeable or widely traded. The same goes for the pricing and the corresponding risk assumptions used: they are not fully standardized as different stakeholders use different mortality models, longevity projections, and discount rates. There is little variety in the players involved in these transactions, as a limited number of institutions understand and engage in these transactions. In the UK and Netherlands, for example, the longevity risk transfer market is concentrated among a few insurers and reinsurers as mainly insurance-based mechanisms are used. Capital market investors have generally not engaged in longevity risk transfer, which is one of the main limitations of the market advancing into further stages of development.

Although the longevity risk transfer market has the potential to become a global market and has been developing very quickly and consistently, it has so far developed to some later stages only in a few regions (such as the UK, the Netherlands, US, and Canada) and only partially. When we say this, we refer to insurance-based mechanisms and the mentioned regions that developed active longevity risk transfer markets.

Regarding stage three for example, we can say that bulk annuities and longevity swaps have reached it, with evidence of ownership generated through contractual obligations in insurance policies and reinsurance agreements, transferring pension liabilities from sponsors to insurers or reinsurers. On the other hand, although some capital market-based solutions have “seen the light” but failed or have not gained traction, recognized tradable ownership as such has also been established so far (the release of longevity bonds, q-forwards, or survivor swaps).

Continuing to stage four, where an informal market emergence takes place through transactions between a limited number of participants, it can be said that insurance-based transactions have reached this phase, but not in the literal sense of the meaning of the word “informal”. It is true that the market is informal, as transactions are private, opaque and dominated by only a few players (as mentioned before), however, transactions require formal negotiations and regulatory compliance, with the need to be highly structured. According to my view, what maintains markets in this phase is the absence of continuous liquidity and broad investor participation, as well as greater transparency from the players in terms of making pricing benchmarks publicly available and undergoing a standardized reporting for underlying transactions.

These limitations are one of the main reasons why the market has not reached stage five. Therefore, there are three more stages left to overcome in order to reach full development.

As seen, there are differences in the stage of development of longevity risk transfer markets according to the type of instruments and Sandor’s paradigm, but it is also worth mentioning that not all longevity risk transfer markets are at the same stage. Some countries’ markets are more developed than others, and the grade of development is closely related to some known characteristics, which also witness what could be a potentially interested market in longevity de-risking. These are summarized in Table 3 (Institute and Faculty of Actuaries, 2016). The table represents the four countries with the most potential for longevity de-risking (and an active longevity risk transfer market), and how they rate in each of these characteristics.

In connection with the first two characteristics in terms of size and volume of pension markets and the existence of large pension funds, we can make reference to Blake et al. (2018, p.3) who summarizes the estimated longevity risk exposure of the private sector, putting special attention to where the risk concentration is highest.

*Table 3: Characteristics of longevity risk transfer markets and rating per countries*

| <b>Characteristic</b>                                | <b>Market</b> |                    |           |               |
|------------------------------------------------------|---------------|--------------------|-----------|---------------|
|                                                      | <b>UK</b>     | <b>Netherlands</b> | <b>US</b> | <b>Canada</b> |
| a) Existence of a large pension market               | ***           | **                 | ***       | **            |
| b) Existence of large DB pension funds               | ***           | **                 | ***       | **            |
| c) Evident longevity risk and mortality improvements | ***           | ***                | ***       | ***           |
| d) Drivers to de-risk                                | ***           | ***                |           | *             |
| e) Adequate data available                           | ***           | **                 | **        | **            |

*Source: Pigott & Walker (2016).*

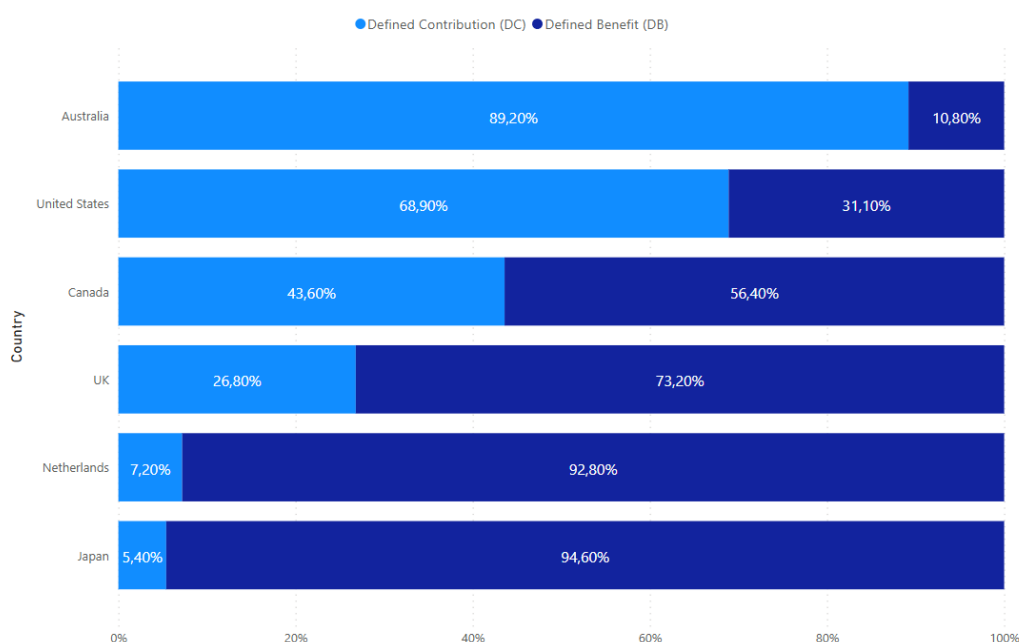
They conclude that among all countries with high longevity risk exposure (where we can list the US, the UK, Australia, Canada, the Netherlands, Japan, Switzerland, South Africa, France, South America, Germany, and Hong Kong), only four of them (the UK, the Netherlands, the US, and Canada) have developed longevity risk transfer markets. It is no

surprise that these four countries are the ones listed, as they also have some of the largest defined benefit pension markets in the world (Kiff, 2022).

The US, Canada, Australia, Japan, the UK, and the Netherlands are in the range of \$1 to \$38 trillion in assets held in funded and private pension plans as visible from Table 4. Specifically, there is a recent study by the Thinking Ahead Institute (2025) in which the top 22 pension markets have been analyzed, and a ranking per total estimated assets held in the market has been provided. This is represented in Table 4. The report states that the US is the largest market by far, with a share of 64.9 percent of pension assets, followed by Japan and Canada with 5.64 percent and 5.58 percent, respectively. The UK is in the fourth place with 5.36 percent, followed by Australia and Netherlands with 4.5 percent and 2.98 percent, respectively (Thinking Ahead Institute, 2025).

However, 97 percent of all transactions on longevity risk transfer markets are made only in the UK and the Netherlands, the two countries showing historically the highest activity in the LRT markets. The US and Canada closely follow, and it is only a matter of time when Japan joins the group. Australia is probably not listed among these, as one of the most developed longevity risk transfer markets yet, due to the low share of defined benefit plans in the total of the pension assets it manages (10.8%). Figure 11 shows the pension markets (per country) with the distribution of pension assets in defined benefits (DB) plans or defined contribution (DC) plans. Therefore, so far, it is clear that the first two characteristics have a lot to do with the development of a longevity risk transfer market. However, there are some other characteristics that we must also keep in mind.

*Figure 11: Split between DC and DB plans per country*



*Source: Thinking Ahead Institute (2025).*

Firstly, the existence of an evident longevity risk and trend, clearly visible by the existence of positive mortality improvements. Namely, the market must have a demonstrable and sustained increase in life expectancy in order to justify the existence of longevity risk transfer transactions. We can delve deeper into this characteristic by assessing the historical mortality improvements, the projected future mortality improvements, and the differences between expected and actual mortality. For example, when we look at the different countries or markets mentioned in the Thinking Ahead Institute (2025) report and represented in Table 4, we can say that all of them have experienced significant mortality improvements during the 20<sup>th</sup> century, however, in the UK and US there has been a slowdown over the past decade (partly due to the COVID-19 pandemics which is still driving excess mortality, among other factors), while the Netherlands and Canada continue to exhibit steady positive trends (Murphy & Grundy, 2022).

*Table 4: Top 22 pension markets by asset size*

| <b>Market / Country</b> | <b>Total Estimated Assets 2024 (\$ billion)</b> |
|-------------------------|-------------------------------------------------|
| US                      | 37,992                                          |
| Japan                   | 3,300                                           |
| Canada                  | 3,267                                           |
| UK                      | 3,139                                           |
| Australia               | 2,639                                           |
| Netherlands             | 1,747                                           |
| Switzerland             | 1,433                                           |
| South Korea             | 1,098                                           |
| Germany                 | 556                                             |
| China                   | 480                                             |
| Mexico                  | 342                                             |
| Malaysia                | 326                                             |
| Finland                 | 299                                             |
| India                   | 270                                             |
| Italy                   | 258                                             |
| South Africa            | 257                                             |
| Brazil                  | 232                                             |
| Hong Kong               | 224                                             |
| Chile                   | 198                                             |
| France                  | 166                                             |
| Ireland                 | 149                                             |
| Spain                   | 142                                             |
| <b>TOTAL</b>            | <b>58,511</b>                                   |

*Source: Thinking Ahead Institute (2025).*

In terms of the existence of drivers to de-risk, we can differentiate between financial, regulatory and strategic incentives that can be acting as motivators to transfer longevity risk. For example, the UK and Netherlands have strong regulatory motivators, while the US and Canada are more driven by financial and market-based considerations. Among the key financial drivers we can list the struggles of some pension funds with underfunding (or

scheme funding deficit), which in the UK it was estimated at £150 billion in 2023, according to the Pension Protection Fund (2023). Also, it is important to include here, the raising life expectancies that directly affect the pension fund liabilities.

The regulatory frameworks in the European countries are one of the main factors that drive longevity risk transfer among UK or Dutch pension funds and insurers. Namely, the strong regulatory environment actively encourages longevity risk transfer as a normative expectation. In the US, on the other hand, regulation plays an important role, but it is on the reactive side, allowing corporate strategies to take the lead. This also explains why the UK has a more mature and active longevity risk transfer market. However, in both markets, there are funding standards for pension schemes and premiums or levies that pension schemes must pay in case of being underfunded.

Lastly, in terms for a longevity risk transfer transaction to become a reality, there must be adequate data sources in order to price longevity risk accurately, and hence make a better risk assessment for effective hedging. Also, market participants require robust data to assess the sustainability of transactions and be provided with benchmarks in order to analyze the market. From the countries listed in Table 4, we can say that the UK leads the way with very high data quality and granularity, whereas Netherlands, Canada, and the US are closely following with plenty of data availability, but with less standardization across industries. For example, the Continuous Mortality Investigation (CMI) model is one of the most widely used mortality projection models in the UK, used by pension schemes and insurance companies assessing longevity risk. It is maintained by the Institute and Faculty of Actuaries.

In general, and considering all the above mentioned, it's a fact that the international pension de-risking activities have significantly expanded since 2006, reaching over \$260 billion in pension liabilities transferred up to 2015 according to Prudential Financial Inc. (2015), and \$600 billion up to 2024, pushing boundaries each year and breaking records with the volume of the deals (Aon, 2024). Reported longevity risk transactions's volume recorded in the last 15 years has been increasing each year, as the markets developed, reaching an all-time record in 2024 through bulk annuities and longevity swaps, in addition to superfund transactions. Most of the deals were performed in the UK and US markets (WTW, 2025).

There is a clear increasing trend of entering in pension de-risking activities which underscores the growing awareness of the importance of financial stability and risk management in the current global pension landscape. Each deal and transaction is unique, with different resource levels, strategic goals and success measures but, all aim to reduce the risk born by pension providers. Effective pension risk transfer strategies can minimize risks around plan contributions, improve the consistency of financial results, realize corporate finance benefits, and enhance retirement security. Lastly, but not less important, companies that proactively manage their pension obligations accordingly, can be seen with an advantage over those that do not (Prudential, 2015).

This substantial growth reflects the increasing trend among companies to transfer pension liabilities to insurers and reinsurers (less likely capital market investors), aiming generally to mitigate financial risks associated with defined benefit pension plans. When we talk about markets on a standalone basis for instance, in 2024 alone, the US pension buyout transaction volume almost reached \$50 billion, a 14 percent increase from the same period in 2023. The UK market performed similarly reaching almost £50 billion of transactions' value at the end of 2024 between buy-ins and buy-outs and longevity swaps (Hymans Robertson LLP, 2025).

### **3.2 Participants in longevity risk transfer markets**

This chapter aims to explore the diverse classes of stakeholders in the longevity risk transfer market making up the longevity ecosystem, shedding light on their roles and interests. There is a difference between participants in case of insurance-based and capital market-based transactions. However, they are interconnected, with emerging dynamics shaping their roles. Therefore, I will enumerate and describe the main participants in both, without differentiating the market type, based generally on the insights provided by Blake et al. (2018, p.4-8) as follows:

- a) pension funds and plan sponsors: as Blake et al. (2018, p.4-8) explains, these players can be defined as the primary stakeholders in the longevity risk transfer markets, as these are the primary entities exposed to longevity risk. Thus their need to manage the risk associated with increased life expectancy of their members and therefore engage in longevity risk transfers to stabilize their financial liabilities. The last point can be considered as their main interest, which can also be seen in reducing financial uncertainty and ensuring long-term sustainability, achieving more predictable cash flows and improving funding ratios with the main objective to improve the financial health of their balance sheet and secure the pensions of their members.
- b) life insurance companies: these stakeholders have a double role as they can act as hedgers in their role of annuity providers, or as risk takers and intermediaries of longevity risk transfer transactions. Blake et al. (2018, p. 4-8) see their interests in the need to balance their risk portfolios and generate profits through premium income and investment return.
- c) reinsurance companies: reinsurers take on longevity risk from primary insurers, providing an additional layer of risk management and capital relief. Therefore, according to Blake et al (2018) they would classify as receivers or risk takers. Nowadays, these stakeholders are becoming increasingly dominant as risk absorbers, given the high involvement of those in buy-in and buy-out transactions, especially in Europe (UK and the Netherlands), influencing pricing power and market liquidity. It is important to mention that reinsurers may offset the longevity risk they take with the mortality risk they usually underwrite, this situation acting as a natural hedge (Barrieu et al., 2010). However, regulatory constraints exist that often prevent reinsurers from directly taking longevity risk from pension funds. This is why the relationship between these two

stakeholders is not direct (as an insurer must be involved) (Carey Olsen (Guernsey) LLP, 2018).

- d) regulators and policymakers: these stakeholders have a very important role in the longevity risk transfer chain which according to Blake et al. (2018, p.7) can be seen from the aspects of enhancing the financial stability by promoting efficient markets and establishing order (for example, through protection against system risks by regulatory capital requirements and thus protecting pensioners), and by ensuring fair deals for customers (in terms of prices of annuity products). Therefore, we can say that these stakeholders act as facilitators who are balancing market growth with solvency oversight.
- e) investors and financial institutions: Blake et al. (2018, p.6) list hedge funds, private equity investors, sovereign wealth funds, life settlement investors, insurance-linked securities investors as specialist investors whether they are of short or long-term nature. Some of them (insurance-linked securities investors, or life settlement investors) could act as buyers or as sellers of longevity protection, making their role bidirectional. Others, such as hedge funds and private equity investors can be viewed as buyers of longevity risk, motivated by its potential as a diversification strategy due to its low correlation with traditional asset classes.
- f) market intermediaries: here, we could talk about different subgroups of stakeholders. For example, actuarial firms, consultants and brokers act as market intermediaries that structure and manage some transactions for smaller pension schemes, or even insurers, that may lack the resources or the expertise to manage those transactions directly. Furthermore, they are contributors of market expertise (see point g). Thus, their role could be distinguished as facilitators.
- g) governments: governments may have multiple roles in the longevity risk transfer markets as they could be classified as direct or as indirect participants. The former role can arise if they issue longevity bonds for hedging purposes as proposed by Blake (2014) to assist financial institutions that want to hedge their exposition to longevity risk. Additionally, it could be said that they can participate in the market indirectly by promoting and facilitating the functioning of these markets. Also, as described in chapter 2.3.2 of this thesis, governments themselves hold longevity risk through state pensions, former public sector employee pensions and by the public healthcare system.
- h) research institutions and academics: the role of research institutions and academics can be seen in their contribution to the general and broader understanding of longevity risk through research and development of new models and theories. Through research they also provide valuable insights and data to market participants, which may lead to further collaboration in different transactions in which the findings can be applied. These would also enrich the literature and contribute to a higher security of participants regarding certain models and theories.

Blake et al (2018) also mention pharmaceutical companies as possible participants in a capital market for longevity risk transfer, as issuers of longevity bonds (debt with which they could finance their research) given that they would benefit from a longevity increase

(people living longer will spend more money on pharmaceutical products). However, so far, there has been no success with pharmaceutical companies entering the market. This may be due to a lack of expertise required for this type of financing to take place. Therefore, I mention these stakeholders as “possible” stakeholders more than a group of established stakeholders already present on the market.

### **3.3 History of longevity risk transfer transactions**

To understand the longevity risk transfer market’s functioning, one must take a look at the history of transactions undertaken. For this reason, it is useful to refer to Blake et al (2018) who delve into the evolution and development of the longevity risk transfer market, providing a timeline of key milestones and events. The UK is considered as the birthplace of the longevity risk transfer market. In terms of life insurance providers, the UK market quickly evolved from a point where there were only two main market players (Prudential and L&G), and whose business was based on many small deals, transacting annually approximately £2 billion, to a market with many players in 2006. The numerous new players (Paternoster, Pension Insurance Corporation (PIC), Synesis, Lucida, Rothesay Life, among others) entered the industry, motivated by the the important size of the UK market (that was estimated at £2.7 trillion on a buy-out basis) (Blake et al., 2018). This situation gave rise to the first longevity risk transfer transactions taking place at the end of 2006 and beginning of 2007, and were executed by Paternoster in the form of a buy-out and a pensioner buy-in transaction respectively (Blake at al., 2018). Continuing on the side of insurance-based solutions, the first longevity swap transaction took place in 2007, with Swiss Re pioneering in the longevity risk transfer markets as a provider of longevity swaps to the UK life insurance company Friends’ Provident as a longevity risk hedger. Annuity contracts written by the insurer in the period 2001-2006 with a size of £1.7 billion were transferred (Blake at al., 2018).

Between 2007 and 2008 indices like LifeMetrics and Xpect Age as well as Cohort indices were introduced with the aim to serve as a trading benchmark for longevity-linked instruments. As a result, longevity swaps based on Deutsche Börse’s Xpect Cohort Indices also emerged in the market in 2009 (Blake at al., 2018). Later on, these indices resulted useful but have so far not been sufficiently exploited. Some players such as Club Vita and Longitude Exchange however, are working on index data with the objective for it to act as a motivation for starting a so called commoditised or capital risk transfer longevity market (Pickett, 2022).

During history, the capital market’s involvement began with JP Morgan’s q-forward contract with Lucida in 2008, followed by the first capital market longevity swap by Canada Life, fully transferring longevity risk to investors, including hedge funds and ILS funds. Swiss Re also launched a longevity-spread bond in 2010 to hedge its own exposure in mortality and longevity risk. Although the first longevity bond was announced in 2004 with a potential

size of £540 million, finally it was not issued due to the very low demand. The issuer was the European Investment Bank, the structurer was BNP Paribas, and Partner Re was the longevity risk reinsurer (Blake et al., 2018). Longevity Experience Option (LEO) was announced in 2013 by Deutsche Bank, which was structured as 10 year out-of-the-money bull call option spread on 10-year forward survival rates. A bull call option spread is a derivative strategy that involves buying a call option at a lower strike price while simultaneously selling another call option at a higher strike price, both with the same expiration. This structure limits both the potential gains and losses, making it suitable for hedging scenarios with capped upside (Hull, 2018). These instruments allow the sharing the longevity risk between pension funds, insurers and investors. For example, a pension fund can buy the option spread gaining (limited profits) if survival rates are higher than the forward rates.

Credit Suisse executed a bespoke longevity swap in 2011 with ITV. Furthermore, JP Morgan executed the first longevity swap for non-pensioners in 2011, targeting valuation risk (given that it tackles active and deferred members of the pension plan, its target was longevity risk before retirement). However, these deals can be considered as insurance-based mechanisms, instead of capital market transactions (Blake et al., 2018).

Between 2009 and 2011, buy-in and buy-out transactions spreaded outside the UK, to Canada and the Netherlands. Also, international longevity reinsurance transactions started in 2011, and the first life book reinsurance swap after the Global Financial Crisis occurred. In 2012, Deutsche Bank executed a substantial index-based longevity swap with a 20-year term for Aegon in the Netherlands, with the main effect in reducing regulatory capital requirements. The effect on actual transfer of longevity risk was minor due to the fact that the swap began out of the money. Also in 2012, in June, General Motors Co. made headlines with a pension risk transfer of \$26 billion of pension obligations to Prudential in the US. This deal represents the largest pension and longevity risk transfer on a global level. Classified as a partial buy-out transaction, it involved the purchase of a group annuity contract for General Motors Co.'s retirees who retired before the 1<sup>st</sup> of December 2011, and declined a lump sum offer in 2012 (Blake et al., 2018).

There has been also plenty of space for innovation. Thus, innovative structures like the pension captive model were introduced in 2011, offering cost-effective solutions. In this structure, a plan can immerse into a buy-in transaction with an insurance company, who later reinsures the buy-in with a captive insurer. Additionally, pension consultants and technology companies started working on adopting technology to streamline processes and cut costs in terms of actuarial valuations and de-risking services, as well as to construct and improve databases for pension risk transfers. In the period of 2013 to 2016, the UK also witnessed the execution of so-called “medically underwritten bulk annuity” transfers in which, as the name itself says, the members have to share medical and lifestyle information so their life expectancy was better assessed by the plan. This can be very useful for plan members who held managerial positions and consequently, represent the largest risk group (Blake et al., 2018).

Consultants and advisors continued offering longevity solutions, for example risk modelling platform called Numerix introduced the “life asset class”, meaning that they immersed in valuation of longevity risk. Also, consultants worked on issuing financial strength statements of different longevity insurers to increase transparency and information in the case of insurance-based transactions, or pricing solutions for buy-ins and buy-outs (Blake et al., 2018).

Buy-ins, buy-outs and longevity insurance prevailed on the market afterwards and up to today, with the market transactions beating records each year, and reaching approximately £50 billion both in the US and the UK, exceeding 130 transactions per year in both markets. New players have also been attracted to enter the market such as Royal London, Utmost or Blumont as longevity insurers. Also, there have been an increasing number of big deals for schemes with over £1 billion (WTW, 2025).

## **4 LONGEVITY RISK TRANSFER MECHANISMS**

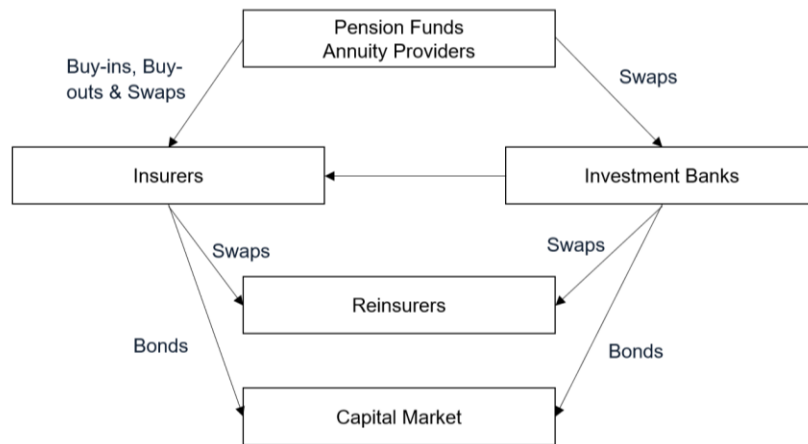
The fourth chapter of this thesis explores the concrete mechanisms for transferring and hedging longevity risk from pension funds/schemes and annuity providers. As discussed in previous chapters, a wide range of instruments have been proposed in the literature to manage this risk. Many have been also tried out and been launched during the years, however not all have gained traction in practice. In order to gain structure, many of these tools can be grouped based on the nature of the counterparty involved.

Thus, this chapter presents a structured analysis of the two main categories of longevity risk transfer mechanisms: insurance-based mechanisms on one hand, such as buy-ins, buy-outs, insurance-based longevity swaps (hereafter: longevity swaps) and other reinsurance structures, that rely on the well-established infrastructure, capacity and expertise of the insurance industry to manage risk, and capital market-based instruments on the other hand, including longevity bonds, q-forwards, tail-risk protection, and most recently, superfund transactions and sidecars, which aim to spread longevity risk across a broader pool of investors through capital markets. These relations and groups are represented in Figure 12, where it is visible that there are different mechanisms used among different participants in the longevity risk transfer markets. Each of these mechanisms is examined in more details, considering their design, practical application and exploring some of the unique characteristics.

The insurance-based solutions for longevity risk transfer are constituting the so-called Pension Risk Transfer Market (or PRTM) as it is today, whereas when we add the capital market solutions (as hedging solutions which are still not sufficiently exploited) we would be speaking about a joint Life Market (or LM) as defined by Blake (2018). Also, as the main goal of both type of mechanisms (insurance-based and capital market-based) is essentially the same, I will interuse the terms risk hedge and risk transfer throughout this chapter. Both

insurance-based and capital market-based longevity risk transfer mechanisms are designed to hedge the longevity risk arising during the decumulation phase, which is the period when pension benefits or annuities are being paid to retirees. These instruments protect pension funds and insurers from the financial impact of beneficiaries living longer than what was estimated with the actuarial assumptions.

*Figure 12: Overview of LRT activities*



*Source: De Nederlandsche Bank N.V. (2015, p.10).*

#### 4.1 Insurance-based solutions

As the name suggests, insurance-based solutions are those where an insurer or reinsurer provides the hedge. These solutions are also known as bulk annuities.

According to Blake et al. (2018) the insurance-based solutions have been more popular than the capital market solutions, given that they seem more straightforward to final users (taking into account that they are considered insurance or reinsurance contracts) and mainly because they remove the total amount of longevity risk as opposed to the capital market solutions. These solutions also have some drawbacks that can be primarily seen in their price, as they are more expensive than the capital market solutions due to their bespoke nature. There are certainly some other factors that add complexity, but they will be explored separately for each mechanism in the corresponding subchapters.

Insurance-based solutions have been popular not only through pension schemes with the need to offload their longevity risk exposure, but also to the insurers and reinsurers that provide these instruments and have a lot of knowledge and expertise on the risk. For example, according to the Pensions and Lifetime Savings Association (2023), one of the main reasons for risk providers to pursue these transactions is the opportunity to diversify their mainly mortality based portfolio exposure. Naturally, insurers and reinsurers mainly offer death benefits. Moreover, insurers and reinsurers possess a long-standing expertise in actuarial science, risk assessment and modelling, which makes them adequate risk takers.

According to Milliman (2020) one of the advantages of insurance-based longevity risk transfer mechanisms is pro rata basis risk transfer. This is one of the main principles of reinsurance meaning that all pension liabilities are proportionally transferred to the insurer or reinsurer, who then takes the responsibility for its payment according to the proportion set. This way, the residual exposure is removed from the pension scheme eliminating basis risk. Basis risk is a common concern in capital markets-based hedging solutions because of possible mismatch between the characteristics of the scheme's population and the reference index used. Another advantage of insurance-based solutions lies in the reduced collateral requirements. Unlike capital market solutions, insurance-based transactions typically involve lower counterparty risk, reducing the liquidity burden on pension schemes. This is because they are not required to maintain large collateral buffers or adjust frequently for market fluctuations.

Reinsurance plays one of the main roles in these transfers as it is one of the most used mechanisms that life insurance companies use as a capital management tool but it is also widely used as a tool for longevity risk transfer, the reinsurer being the third party that assumes the risk. According to Barriga Lucas (2018), reinsurance solutions for longevity risk transfer can be of two types: high-risk and low-risk transfer. In the group of high-risk transfer we can group the bulk annuities and longevity swaps transactions. The other type of reinsurance tool is the so-called low-risk transfer, its main objective being economic capital management through a Stop-Loss reinsurance structure. According to Barriga Lucas (2018), this tool, also known as a longevity shock absorber (or longevity index-based hedges), provides an improvement of the cedant's capital position through the transfer of tail risk in between the range defined in the stress scenario. It is called an economic capital management tool because of its main objective to reduce the Solvency II capital requirement for biometric risk resulting from the Solvency II Standard Formula.

#### 4.1.1 Buy-ins

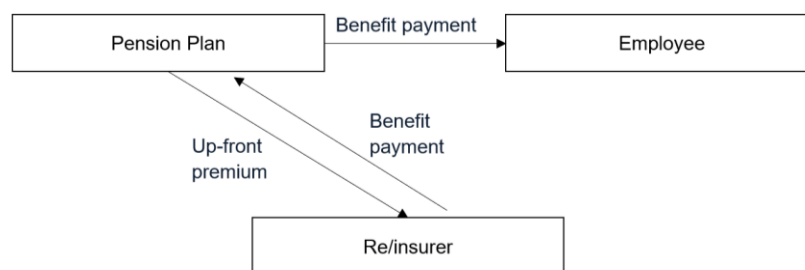
First in the line of insurance-based transactions are buy-ins as one of the most common longevity risk transfer solutions due to their nature as simple insurance transactions. In this type of transaction, the main parties involved are an insurance and/or reinsurance company and a pension sponsor (or a pension fund), where the latter pays an up-front premium to the former in exchange for the reception of periodic payments that match the pensions payments that the sponsor has to make to the individual members of the pension fund as long as they are alive (BIS, 2013, p.5). Figure 13 represents the parties involved as well as the structure of this mechanism. This transaction results in an insurance policy where the policyholder is the pension sponsor. This contract is also called a "bulk purchase annuity contract" or a "bulk annuity policy" (CRO Forum, 2010, p.14).

In a buy-in, the pension sponsor continues to be responsible (the holder) for the pension liabilities subject to the buy-in. The sponsor also holds the policy (contract) as part of its

assets in its balance sheet. This means that while the longevity risk has been transferred to an insurance company through the buy-in, the pension sponsor still has the obligation to make pension payments directly to the pensioners as long as the plan members live after receiving the payments from the insurance company (De Nederlandsche Bank N.V., 2015, p. 10). The scheme continues to operate as usual, receiving contributions and making payments to its members.

According to BIS (2013, p.1), a buy-in transaction is considered a partial risk transfer mechanism because although longevity, investment, inflation, and interest rate risks are transferred to the insurer, the pension plan remains legally responsible for paying benefits to plan members. Here, in terms of counterparty risk, as the pension plan is dependent on the insurer to make the payments, this risk remains present.

*Figure 13: Structure of Pension Buy-In Transactions*



*Source: IMF (2012, p.142).*

Inside the group of buy-ins, we can differentiate between partial and full coverage buy-ins according to the portion of liabilities insured by the pension scheme. In a partial buy-in, the scheme purchases an insurance policy that covers only a segment of its liabilities (usually these are benefits to current retirees or a subset of deferred members). This form of a buy-in a transaction allows pension schemes to reduce risk in stages by transferring longevity, investment and other risks for the insured segment. This helps schemes involved to manage their funding levels and contribution requirements gradually, before committing to larger scale de-risking transactions.

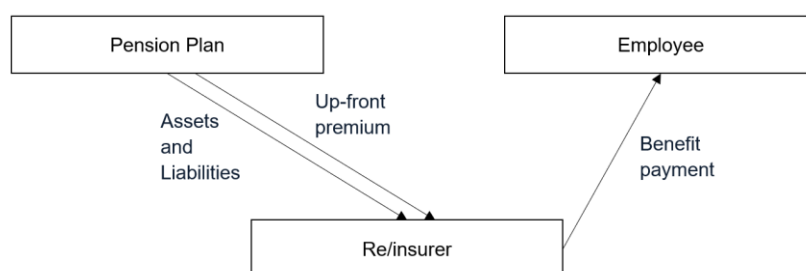
A full coverage buy-in, by contrast, involves the purchase of an insurance policy that covers the entire range of a pension scheme's liabilities, including both current and future pension payments to all members (retirees and deferreds). This form of buy-in is usually a transitional step to a buy-out, where the insurer or reinsurer takes over the direct responsibility for paying the pensions to members, and the scheme winds up. The main objective of a full coverage buy-in is to transfer longevity, investment and other risks, while maintaining administrative control until a full buy-out is executed.

#### 4.1.2 Buy-outs

Buy-outs are the second most commonly used form of longevity risk transaction (Prudential Financial, Inc, 2015, p.3). They are comprehensive solutions in which an insurer assumes all asset and liability risks associated with a pension scheme's liabilities, including longevity, investment and inflation risks. Buy-outs are also known as group or bulk annuity transfers and are often part of a pension termination process (Blake et al. 2018).

Here as well, the parties involved are the insurance and/or reinsurance company and the pension sponsor, pension fund or insurer who pays an up-front, single premium to the former and at the same time, transfers all its assets and liabilities. As opposed to a buy-in transaction, in a buy-out, the only responsible for the pension liabilities is the insurance or reinsurance company who takes on the risk and makes the benefit payments to the plan members as long as they live, after having received an up-front premium paid by the pension scheme. Consequently, the re/insurer has the buy-out annuity contract as an asset as well as a liability in its balance sheet (De Nederlandsche Bank N.V., 2015, p. 10).

*Figure 14: Structure of Pension Buy-Out Transactions*



*Source: IMF (2012, p.142).*

The structure of a buy-out transaction can be seen in Figure 14, where it is also visible that since the employment of this transaction, the pension sponsor or insurance company that transfers the risk, is “out of the equation”, and the relationship is maintained between the plan members or insureds and the re/insurer who has taken on the risk. According to BIS (2013, p.1) this is a full risk transfer given that not only longevity but also investment and inflation risk are transferred to the insurer, and there are no liabilities retained by the scheme.

Similar to buy-ins, we can distinguish between full and partial buy-outs, depending on the extent of liabilities and risks transferred to the insurer. Clearly, a full buy-out transfers all liabilities and risks for the entire scheme, typically leading to its winding-up. In contrast, a partial buy-out involves transferring liabilities and risks associated with only a portion of the members, such as retirees or deferreds, allowing the scheme to continue operating as usual for the remaining members not included in the insured segment.

The advantages of buy-out transactions can be summarized as follows:

- pension liabilities are fully removed from the company's balance sheet. In cases where companies lack immediate funds to pay the single premium, they can secure a loan to cover the deficit. This transforms unpredictable pension liabilities into a fixed financial obligation in form of a loan.
- the company gets protection from volatility in the profit and loss account caused by fluctuations in pension liabilities due to accounting standards.
- the transaction eliminates various costs associated with maintaining a pension plan (in the UK for example, where these transactions are most common we can make reference to the levies paid to the Pension Protection Fund (PPF), and administrative fees in general).
- pensioners or annuitants, on the other hand, gain security as a buy-out ensures pensions are fully backed by an established and reputable reinsurer (or insurer), offering peace of mind regarding future pension payments. However, there remains some exposure to the credit risk of the insuring company.

Regarding the main disadvantages according to Blake et al. (2018) we can list the following two:

- the transaction is irreversible meaning that it is not possible to renegotiate the terms of the transaction in case market conditions change and take advantage of lower prices (for example, if long-term interest rates increase after the buy-out, a higher discount rate would reduce the cost of liabilities, potentially lowering buy-out premiums in the future).
- the credit risk of the provider of the buy-out remains as there is a risk of insolvency of the insurer, which could jeopardize pension payments. However, in countries where such transactions occur, strong regulatory oversight of the insurance sector makes this risk very low.

#### 4.1.3 Longevity swaps

In a longevity swap, a pension scheme agrees to swap its pension payment liabilities with the insurer or reinsurer based on a predetermined schedule. The pension scheme pays a fixed stream of cash flows (or so-called, fixed leg, based on expected liabilities) to the counterparty, and in return, the counterparty pays a variable stream of cash flows (so-called, floating leg) that reflects the actual longevity experience of the pensioners. If the lives do not live as long as expected the insurer/reinsurer profits from the experience as well as the receipt of a price for the transaction. Longevity swap is a simple structure that is represented in Figure 15 as an exchange of cash flows between the parties involved (employee, pension plan, insurer/reinsurer). Furthermore, Figure 16 visually represents the quantity and distribution of cash flows exchanged in a longevity swap transaction.

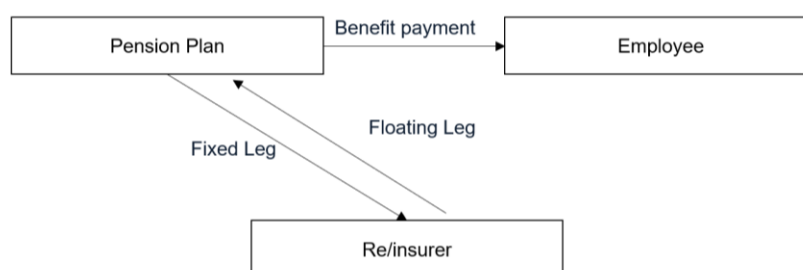
The actual payments made to pensioners remain the responsibility of the pension scheme, but the swap allows the scheme to convert unknown longevity risk into a predictable liability. Here, the primary goal is to hedge against longevity risk without transferring the pension assets or liabilities off the pension scheme's balance sheet. Thus, the re/insurer takes the longevity risk, but not the investment or inflation risk. Precisely the isolation of longevity risk from other risks, is seen as an advantage of longevity swaps compared to buy-ins or buy-outs (BIS, 2013). In order to summarize the types of risks transferred through buy-ins, buy-outs and longevity swaps, I compare them in Table 5 as shown below.

*Table 5: Comparison of the risks transferred in bulk annuities and swaps*

| Risk Type                           | Risk Transfer Mechanism |         |                |
|-------------------------------------|-------------------------|---------|----------------|
|                                     | Buy-in                  | Buy-out | Longevity Swap |
| Longevity Risk                      | x                       | x       | x              |
| Investment Risk                     | x                       | x       |                |
| Interest Rate Risk                  | x                       | x       |                |
| Inflation Risk                      | x                       | x       |                |
| Counterparty risk                   |                         | x       |                |
| Operational and Administrative Risk |                         | x       |                |
| Regulatory and Compliance Risk      |                         | x       |                |

*Source: Own work*

*Figure 15: Structure of longevity Swap Transactions*



*Source: BIS (2013).*

Longevity swaps are suitable for those pension schemes that need to hedge against longevity risk but want to maintain their investment flexibility. Some of the key advantages of this mechanism include the following:

- minimal impact on liquidity and asset allocation: unlike in bulk annuity transactions, pension schemes that engage in longevity swaps do not need to liquidate or set aside large amounts of assets. This allows schemes to maintain their existing investment strategies. Therefore, this mechanism is not out of reach for schemes with high portion of illiquid assets.
- unfunded structure: this allows the scheme to pursue higher investment returns, while maintaining effective hedging of rates and inflation exposure.

- structural flexibility: according to Aon Solutions Ltd. (2025) swaps provide flexibility in terms of structure change, potentially being able to restructure the swap into annuity products if there is need in the future.
- pricing risk mitigation: as the swap does not require full risk transfer, isolating longevity risk transfer only, it reduces the market pricing volatility related to investment or inflation risk (WTW, 2025)

It is interesting to note that pension schemes often use longevity swaps alongside liability-driven investment strategies (such as interest rate and inflation hedges) to construct a bespoke buy-ins. This approach allows schemes to hedge key risks individually while retaining control over their investment portfolio.

It is important to differentiate between the two currently known categories of longevity swaps:

- indemnity-based swaps, whose payments are based on actual mortality experience of the pension scheme, and
- index-based swaps, whose payments depend on an underlying, publicly available, mortality index (Song et al., 2023).

*Table 6: Differences between indemnity-based and index-based longevity swaps*

|                               | <b>Indemnity</b>       | <b>Index-based</b> |
|-------------------------------|------------------------|--------------------|
| <b>Longevity Risk Removal</b> | Full                   | Partial            |
| <b>Term</b>                   | “Last person standing” | Limited            |
| <b>Legals</b>                 | Bespoke                | Standardisable     |
| <b>Execution</b>              | Complex                | Quick, Simple      |

*Source: Club Vita (2019).*

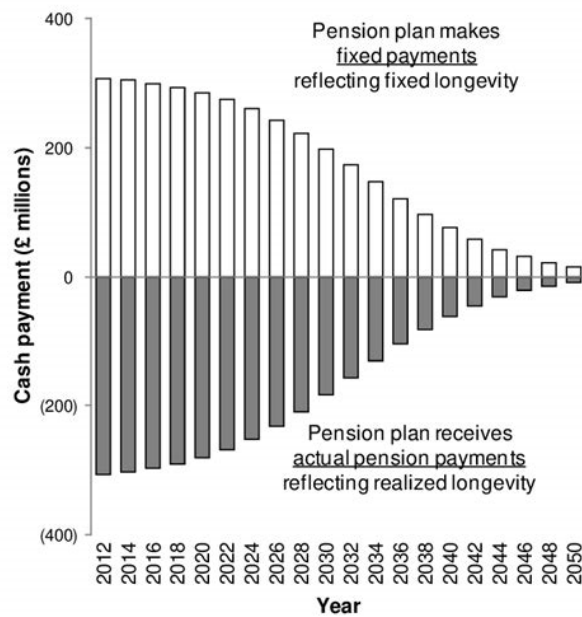
Indemnity longevity swaps are also known as high-risk transfers which are normally instrumentalized through a quota-share treaty structure between an insurer and reinsurer that gets triggered if there is “unfavorable deviation in the longevity assumptions” (Barriga Lucas, 2018) .

Index-based longevity swaps offer a cost-effective (compared to buy-ins or buy-outs or indemnity longevity swaps) and standardized solution for hedging longevity risk by linking payments to a reference population's mortality experience. According to Song et al. (2023), the attractiveness of these swaps can be seen in their high standardization which reduces the need for extensive due diligence.

It is important to note that these swaps are particularly suitable for large pension schemes and insurers seeking capital relief without transferring investment or inflation risks. However, for smaller schemes or those with skewed socio-economic profiles, their effectiveness is limited by basis risk, which arises from differences between the reference

population and the scheme's actual mortality experience. Smaller schemes that need cost-effective de-risking but cannot afford the higher premiums of buy-ins or buy-outs may still find these swaps valuable. Furthermore, the scalability and liquidity offered by global capital markets enhance the growth potential of index-based swaps, especially as traditional reinsurance capacity faces constraints (Club Vita, 2019). Table 6 summarizes these characteristics or differences between the two types of longevity swaps in terms of the quantity of risk removed, term, legal and execution nature (Club Vita, 2019).

Figure 16: Cash flow exchanges in a longevity swap (fixed and floating leg)



Source: Coughlan et al. (2007a); Blake (2018).

#### 4.1.4 Pricing of bulk annuities

The pricing of longevity risk transfer mechanisms, such as buy-ins and buy-outs is a complex process that requires insurers to assess the present and future liabilities of pension schemes, while accounting for various risks and market conditions. In both cases, the premium charged by the insurer reflects the present value of expected future pension payments, adjusted for risk margins, expenses and profit considerations. The simplified vision of the key components of this pricing model can be expressed by the following formula:

$$\text{Premium} = \text{PV of Liabilities} + \text{Risk Margin} + \text{Expenses} + \text{Profit Margin} \quad (1)$$

Firstly, the present value of expected future benefit payments must be determined. This requires projecting pension cash flows based on age, gender and benefit amounts of the members, as well as longevity assumptions (here, a very important role is given to retirement ages, as well as to mortality rates through the use of the adequate mortality or life expectancy

tables) and other features of the pension payments (for example indexed to inflation or fixed payments). Then, the projected future benefit payments are discounted to present value using a discount rate that reflects expected investment returns (normally government, or investment-grade corporate bonds are the base for the discount rate set by insurers). Furthermore, the risk margin accounts for the uncertainties in the assumptions underlying the pricing model and the capital requirements in place. Also, the expenses cover the administrative and operational cost related to managing the subject liabilities.

The profit margin also constitutes the premium, and it is usually set according to the level of competition on the market, the hedger's risk appetite as well as the characteristics of the particular pension scheme (for example, the quality of its data, or its demographic characteristics). It is worth mentioning that these two factors involve an important stake of negotiations between the parties.

#### 4.1.5 Pricing of longevity swaps

Naturally, the goal of the pricing of a longevity swap transaction is to determine the fixed leg that the pension scheme will pay, in exchange for the floating leg that the insurer or reinsurer will pay based on the actual mortality experience. As opposed to bulk annuities, longevity swaps only reflect the longevity risk transfer seen in the fixed leg payment, therefore, the pricing focuses on projected mortality experience and the present value of expected liabilities.

As described by Insight Investment (2022) the pricing of the swaps comprises two primary components:

- Best estimate cash flow projection which represents the swap provider's assessment of the total future pension payments to be made to the scheme members over their lifetimes. To develop this projection, the provider (who is typically a reinsurer) evaluates member details (in terms of age, gender and other demographic factors) current pension amounts and benefits structure. This is then combined with the baseline mortality, as well as future improvements of mortality (how much longer will people live). The baseline mortality or the mortality experience data appropriate for the individuals may be taken into account through different models, such as socio-economic mortality models or scheme-specific mortality analysis models (applicable in case of large schemes with sufficient historical experience to derive mortality rates). Furthermore, the mortality improvements assumptions are very important to be accounted for correctly, given the long-term nature of a longevity swap deal. These should be projected forward with statistical methods. However, there is basis risk included here that should be also quantified in order to be included in the pricing.
- Longevity risk fee or risk margin: this component is the compensation for assuming the risk and is added to the best estimate cash flow projection. Reinsurers normally present

this as a percentage of the best estimate cash flow projection. The fee calculated at this step should allow the reinsurer to cover the expenses of writing the deal (current expenses), the expected lifetime expense of administering the deal (future expenses), charge in respect of the capital the reinsurer needs to hold against the risk (cost of capital), and last, include sufficient profit for the reinsurer.

#### 4.1.6 Asset-Intensive Reinsurance

Recently, especially on the UK and US markets, asset-intensive reinsurance has been introduced as an innovative solution to complement the usual insurance-based transactions (buy-ins or buy-outs) and as an additional tool to manage not only longevity risk (Cheng, 2024). This is due to the fact that the main difference of asset-intensive reinsurance when compared to buy-ins and buy outs, is that it is used as a way to extend longevity reinsurance with asset performance risk. As its own name suggests, the structures representing asset-intensive reinsurance are particularly prevalent in asset-intensive products like annuities or universal life insurance as stated by Skadden (2025). At the current phase of development of these solutions, the terms asset-intensive reinsurance and funded reinsurance are often used interchangeably in the context of longevity risk transfer, and I will also do this in the context of this thesis.

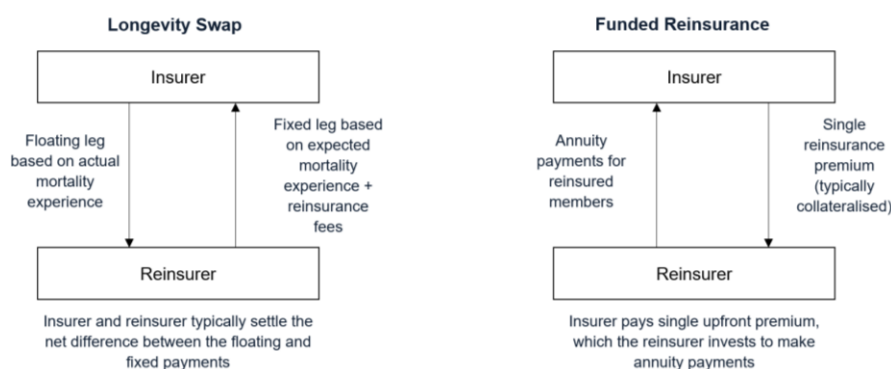
In asset-intensive reinsurance transactions, the insurer (who acts as a cedent) transfers liability reserves as well as the assets supporting these reserves to the reinsurer through a reinsurance contract, and in return, the reinsurer receives a significant net positive cash inflows as single premium, defined as present value of the fixed leg, typically paid at the inception of the transaction. In return, the reinsurer takes over liabilities associated with the premium received (claims) and takes full responsibility for the management and performance of the asset portfolio (Blake & Li, 2024, p.64). There are highly predictable liability cash flows as starting point for defining an asset strategy that needs to ensure appropriate asset-liability matching to service liability cash flows. The transaction is successful if the reinsurer is able to generate returns exceeding the liabilities' cost. Also, the benefits are that the solution offers risk reduction, capital relief and access to broader universe of investable assets. However, there are also risks related to recapture, concentration and increased complexity (Skadden, 2025). Recapture risk for example, appears when due to different reasons (regulatory compliance, or investment strategy) the cedent has the necessity to recover the assets transferred. The risk consists in a financial loss for the cedant (Skadden, 2025).

As already mentioned, this structure is also known under the term funded reinsurance, and simplifying the definition, we can practically say that it is a longevity swap with an added component of asset performance risk transfer as also visible from Figure 17 that represents the comparison of the structure between a longevity swap and funded reinsurance transaction. Given the capital intensity of asset performance risk as a result of a buy-out

transaction, insurers consider reinsuring it. That way it can be converted into asset-intensive reinsurance. This way, much larger buy-out transactions are to be expected in the near future. Additionally, these transactions are also characterized by high exposure to counterparty risk, therefore, they are collateralized with the objective to offer protection against reinsurer's default (Cheng, 2024).

It is worth mentioning that the growing use of funded reinsurance as a longevity risk transfer mechanism has attracted significant regulatory attention as regulators in these markets have expressed concerns about the increasing concentration of offshore counterparty exposure, especially in Bermuda, also highlighting risks related to correlated investment strategies and the illiquidity of collateral assets in recapture scenarios (Hogan Lovells, 2024). Consequently, in 2024 the UK regulator (UK Prudential Regulation Authority, or PRA), has enhanced the requirements for parties engaging in funded reinsurance such as mandatory self-assessments by the risk takers, detailed counterparty limits, as well as defined stress testing frameworks. Given that due to the high development of the UK longevity risk transfer market, the UK regulator is seen as a reference, other jurisdictions and regulators have followed its example, with the NAIC (the US authority) proposing new cash flow testing rules in the US and the European Insurance and Occupational Pensions Authority (EIOPA) announcing new guidelines for 2025. The objective of the regulator's close watch of these transaction is only a proof of the importance of these deals, as they pose high systemic risk which, as mentioned, is expected to be mitigated through strengthened governance by the parties involved, transparent reporting, and robust recapture (Hogan Lovells, 2024).

*Figure 17: Comparison between longevity swaps and funded reinsurance*



*Source: Cheng (2024).*

## 4.2 Capital market-based solutions

The other group of solutions are capital market-based solutions. These have not been as popular as insurance-based solutions, mostly due to the fact that they are mainly index-based, compared to the customized insurance-based solutions. Through the years, there have certainly been some exceptions of capital market-based solutions that have been fully customized, but they are just a minority (Blake et al. 2018, p.11). Also, Blake (2018) points

out as very important, the fact that longevity-linked assets are not correlated with equities and bonds in relation to the positive effect they have in diversifying portfolios, insisting that longevity linked assets can positively contribute to all parties included. In this sense the benefits of capital market-based solutions are straightforward and their effect on the reduction of the systemic risk posed by the longevity risk accumulation in the insurance and reinsurance industry is very positive, but due to the higher complexity and less possibilities for customization, as well as limited knowledge by capital markets participants, they have not been fully exploited so far. Thus, in the present chapter, I will summarize the main solutions and their characteristics.

#### 4.2.1 Longevity Bonds

Longevity bonds have been one of the first financial instruments with payouts linked to the life expectancy of the tackled group since the beginning of longevity risk transfer markets. Their payouts depend on the actual life expectancy of the group (predefined cohort). These groups are defined according to age or other chosen demographic factors. In terms of structure, longevity bonds are very much alike to traditional debt securities, but with a twist – payments vary depending on how many people in the group are still alive (survival rates). This is also why, longevity bonds are known by the name “survival bonds”. As noted by Leppisaari (2008), this link between payouts and survival rates makes longevity bonds an appealing option for hedging. If the cohort lives longer than anticipated, the bond issuer ends up making larger payments, shifting that risk to the investors.

It is interesting to mention that in the literature, we can also find referral, not only to survival but also to mortality bonds. These two contradictory names appear due to the fact that longevity bonds can be of two types: principal-at-risk or coupon-based. The former are used to hedge against mortality risk, whereas the latter link the payments to the survival rate of a cohort (De Nederlandsche Bank N.V., 2015, p. 10).

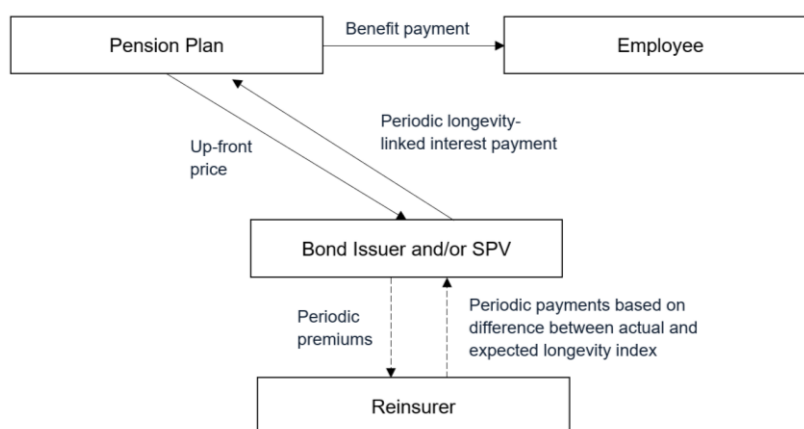
Some of the main advantages of a longevity bond is their standardized structure, which results in lower price of the longevity hedge, given the low transaction costs and simplified administration process as well as the effort invested in the portfolio analysis. Also, given their nature, the hedge through longevity bonds reduces the counterparty default risk, as it can be spread across various counterparties (Milliman, 2023, p.16). The latter, is also one of the main differences with insurance-based mechanisms.

One of the main challenges with longevity bonds, is that investors must make a significant upfront payment to purchase them. Thus the exposure to credit risk appears, in terms of the inability of the issuer to meet its payment obligation over time. However, this risk can be mitigated if the bonds are issued by financially robust institutions such as governments or highly rated international organizations, or through a special purpose vehicle (SPV) that invests the proceeds in secure, liquid assets capable of covering the bond’s future payments. As illustrated in Figure 18, some issuers can mitigate some of the longevity risk by entering

into a reinsurance agreement or a longevity swap contract, further securing the bond's payout commitments (IMF, 2012).

Despite various attempts to introduce longevity bonds as a mechanism for longevity risk hedge, they have not reached success so far. As mentioned earlier in Chapter 3, there have been some unsuccessful attempts in practice, due to limited appetite from investors. One example of this instrument's failure is the BNP Paribas–EIB longevity bond, highlighted by Damen (2006). This bond aimed to shift systematic longevity risk to the capital markets using index-linked coupon payments. However, finally it never launched mostly due to concerns around basis risk, structural complexity, and the little knowledge existing on the market in this type of product. Still, the concept of longevity bonds continues to hold considerable promise taking into account their potential to bring long-term stability to pension and annuity portfolios. However, time and resources should be dedicated to increasing the awareness and knowledge of longevity risk.

*Figure 18: Structure of Longevity Bond Transaction*



*Source: IMF (2012, p.143).*

#### 4.2.2 Government-issued longevity bonds

As mentioned in the first chapter of this thesis, governments are one of the bearers of longevity risk, but they could also have an important role in the longevity risk transfer markets, as issuers of longevity bonds. Namely, longevity bonds issued by the government could offer hedging of the systematic longevity risk given their unique position to manage and share intergenerational risk through pools across time and population cohorts (something that private institutions cannot replicate). Sharing intergenerational risk refers to the mechanism by which the longevity risk is distributed not only among current pensioners, but across the broader society, including future taxpayers.

When a government issues a longevity bond, it effectively absorbs systematic longevity risk by committing to higher coupon payments if survival rates exceed expectations. Pension

funds and insurers, who are naturally exposed to longevity risk through their long-term liabilities, purchase these bonds to hedge against this exposure. However, the government does not hedge its own position, instead, any excess payments due to higher longevity are funded through public finances (financed also by future generations of taxpayers). As Blake (2018, p. 24) points out, governments are the only players capable of issuing longevity bonds at scale, especially when it comes to covering extreme tail risks (such as pensioners living well beyond 90 or 95 years).

Furthermore, apart from risk management and longevity risk transfer, government-issued longevity bonds could play a critical role in developing reliable longevity indices based on large-scale demographic data creating robust survival and mortality datasets (Blake et al., 2014). All these points would play in favor of the interest of the government to ensure that an efficient annuity market exists, and to motivate the capital market formation for longevity risk transfer (Blake, 2018, p.24).

However, Brown & Orszag (2006) suggest that while government-issued longevity bonds could play a significant role in enhancing the private annuity market by mitigating aggregate mortality risk and providing an efficient risk management by distributing risk across generations, we must take into account that there are challenges in terms of political and economic factors that could make this type of longevity risk hedging a less preferential option compared to others.

#### 4.2.3 q-Forwards

q-forwards are financial derivatives that specifically hedge longevity risk. According to Blake (2018, p.14), q-forwards are considered one of the most straightforward tools for transferring longevity risk, due to their simple structure and transparent payout process mechanism. A q-forward is a derivative contract based on a predefined future mortality index or on the survival rates of a particular cohort defined in advance. The pension plan or annuity provider acts as a buyer of longevity risk protection, and the investment bank or capital market investors provide the hedge and act as sellers of longevity risk protection. Figure 19 visually represents the simplicity of the structure.

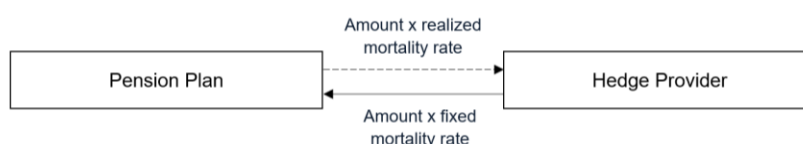
As the nature of all instruments mentioned so far, the payout of a q-forward is also based on the difference between a predetermined mortality rate and the actual observed mortality rate at a specified future date. If people live longer, actual mortality is lower than expected, and the seller compensates the buyer, therefore protecting it from the higher than expected longevity. Blake et al. (2018, p.15) also define the q-forward as a swap between fixed and actual mortality rates at the maturity. This simplifies the cash flow exchange without involving the transfer of the principal, also reviewed by Cairns et al. (2008).

q-forwards also rely on publicly available mortality indices, a characteristic that on one hand, adds transparency and makes it easier to benchmark across different transactions, but on

another hand, complicates the development of these instruments, given that indices are still not well developed. It is important to note that the first feature would help reduce basis risk, depending on how closely the pension scheme's population matches the demographic characteristics of the index used. As Coughlan (2014) points out, q-forwards are particularly useful for managing systematic longevity risk, especially when detailed, scheme-specific mortality data is lacking. The latter would be also one of the key factors to make q-forwards an effective hedging instrument.

The first capital market transaction in the longevity risk transfer markets was known to be a q-forward transaction back in 2008 (Coughlan, 2014). However, while q-forwards provide a structured and standardized method for longevity risk hedging, basis risk remains a critical limitation especially for small schemes or tail risks. Although early initiatives such as LifeMetrics argued that carefully constructed mortality indices could minimize basis risk, empirical experience highlighted by Cairns et al. (2014) shows that real pension scheme populations often exhibit material deviations from standardized indices. Nevertheless, with the growing sophistication of mortality data and modelling, q-forwards remain a promising tool for capital-efficient longevity risk hedging (Cairns et al., 2014). Namely, Li & Zhou (2017) list q-forwards among the so-called “off-the-rack” or standardized solutions as a cheaper alternative to the bespoke solutions.

*Figure 19: Exchange flows in a q-forward at the maturity of the contract*



*Source: Coughlan et al. (2007b, Figure 1); Blake (2018).*

#### 4.2.4 Tail-risk protection

Tail-risk protection refers to hedging strategies or financial instruments designed to safeguard against extreme outcomes or rare events in longevity trends, such as significantly higher than expected increases in life expectancy (which is what is known as remote or tail risk). As Blake (2018, p.16) has summarized, a commonly tail-risk protection strategy is done through out-of-the-money hedges that trigger payouts in the case of an occurrence of predefined extreme longevity scenarios (thresholds). This is structured as a longevity bull call spread which involves buying a call option on a longevity index at a lower strike rate (moderate expected increase in longevity) while simultaneously selling a call option at a higher strike rate (an extreme longevity scenario) as shown in Figure 20.

According to Michaelson & Mulholland (2014), in order for this type of protection to be successful it must comply with three main factors:

- limit the amount of basis risk by customizing the hedge exposure
- simplify the modelling and underwriting process
- compress the long-duration risk into a short-term horizon through a commutation function. As the duration of pension liabilities is mainly long-term, in order to make it viable and attractive to institutional investors, the hedge compresses the long-duration risk (more than 60 years horizon) into an investment horizon of approximately 10 to 15 years. This is achieved through a commutation function, which re-parameterizes the longevity model by incorporating the expected present value of long-term cash flows into a shorter term contract structure.

Figure 20 for example, illustrates a payoff profile for a longevity protection structure with tail-risk features, showing the attachment and exhaustion points. The x-axis represents cumulative longevity losses (for example, excess survivor liabilities in \$ millions), and the y-axis represents the payout of the hedge. The hedge becomes active once cumulative longevity risk exceeds the attachment point (for example, \$1.100 million), and pays out linearly up to the exhaustion point (for example, \$1.200 million), after which no further payout is provided.

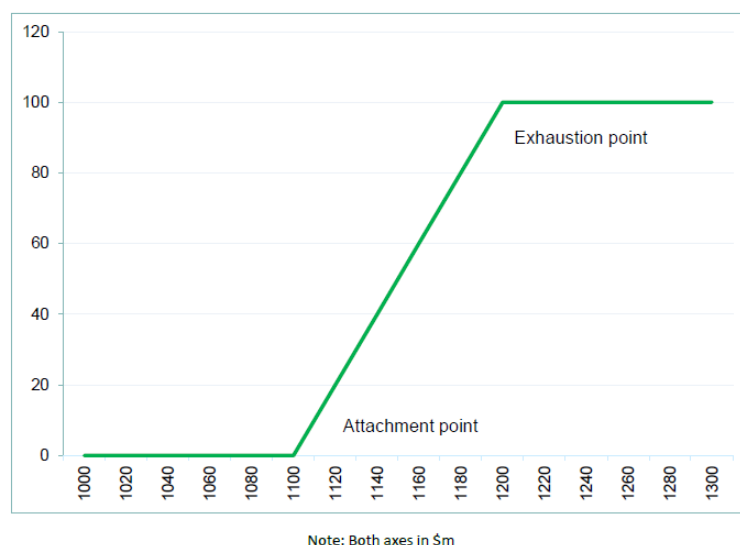
In summary, this instrument is an efficient way to protect against the most financially extreme (tail) risks, as its name indicates, as well as to reduce capital requirements, while keeping manageably low hedging costs.

#### 4.2.5 Superfund transactions

Superfund transactions represent a relatively recent and innovative development in the longevity risk transfer market's evolution. The first superfund transaction was recorded in the UK in 2023, marking a new approach to managing pension liabilities through a simplified capital market-based solutions (WTW, 2024).

In a typical transaction, a defined benefit pension scheme transfers both its assets and liabilities into a superfund. Superfunds are independently run, pooled pension vehicles created to consolidate and manage multiple small or financially weaker pension schemes.

*Figure 20: Payoff profile in tail-risk protection*



*Source: Michaelson & Mulholland (2014).*

For the sponsoring employers, the transfer presents several financial and strategic benefits. Most importantly, it removes the pension liabilities from the balance sheet. This can improve financial stability and leads to a better credit standing of the company. Unlike traditional pension arrangements, superfunds do not rely on the ongoing financial covenant of the employer. Financial covenant is the guarantee backing the pension obligations, which is no longer required in these transactions. However, as schematically represented in Figure 21, the superfund operates with a pre-funded capital buffer, whose role is to absorb any financial shocks, such as poor asset performance or higher longevity than what was initially expected. This buffer is generally financed by external investors, who contribute capital in return for the potential to earn a return, however it also allows for the possibility that the outgoing sponsor to provide an additional support through a lump-sum payment. This is why I group superfund transactions in capital market-based solutions. Figure 21, for example, represents visually the functioning of these mechanisms and the parties involved (WTW, 2024).

According to WTW (2024), the emergence of superfunds could be expected to reshape the longevity risk market as a cheaper alternative to buy-outs. Thus, they have the potential to increase competition and innovation within the industry. However, WTW (2024) also identifies certain risks. Superfunds, unlike traditional solutions provided by insurers and reinsurers, operate outside the traditional regulatory and prudential frameworks of the insurance industry. This raises questions around governance, long-term security, and the depth of risk management expertise within these structures. Therefore, oversight mechanisms must be developed in order to continue with these transactions, securing their position and relevance in the market, and contributing to the long-term security of the transferred liabilities and consequently, the annuitants' payments.

#### 4.2.6 Reinsurance sidecars

Reinsurance sidecar vehicles are financial structures that can be listed as capital market mechanisms, that allow reinsurers to offload some of their exposure to institutional investors (Artemis, 2025). Reinsurers typically manage big risks, however, as the size of longevity risk is very significant, they have developed these structures that first appeared in the non-life segment as part of the natural catastrophe market (specifically in P&C reinsurance after hurricane Katrina occurred in US). Afterwards, they gained traction, and now are considered as a longevity risk transfer mechanism with a lot of potential (Bugler et al., 2020).

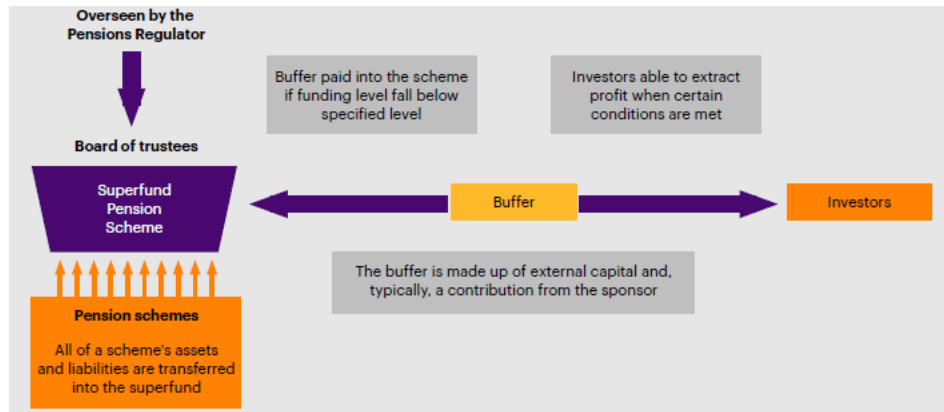
Reinsurance sidecars are financial vehicles, so-called special purpose vehicles (SPVs) that allow external investors, to participate directly in the transfer of longevity risk. In a typical structure, a reinsurer transfers a portion of its longevity exposure, such as a share of pension liabilities, to the SPV. This vehicle is funded by third-party investors and takes on a corresponding share of the premiums and claims, based on its level of risk participation. Third-party investors can be hedge funds, pension funds, or insurance-linked securities (ILS) investors who participate assuming a portion of the longevity risk exposure ceded from the reinsurer through the sidecar. The SPV also shares the premiums and claims experience of the underlying longevity business proportionately to the defined risk share.

The difference to standard reinsurance treaties, is that sidecars allow for structured investment by capital markets into specific blocks of longevity risk, without the investors needing full insurance licenses (Blake et al., 2018). These vehicles are attractive to institutional investors looking for uncorrelated, long-term cash flows, especially in a low-interest-rate environment. As represented in Figure 22 these mechanisms are simple but yet powerful structures, that allow for sovereign wealth funds, ILS hedge funds, private equities or specialty reinsurers act as sidecars insurers to a reinsurer's longevity risk book.

The instrument appeals particularly to those managing portfolios with a long duration and tolerance for tail risk. Namely, Blake et al. (2018) underline the effectiveness of sidecars in transferring tail-risk exposure, which is the most difficult for primary insurers to manage due to extreme uncertainty in mortality improvements over long horizons.

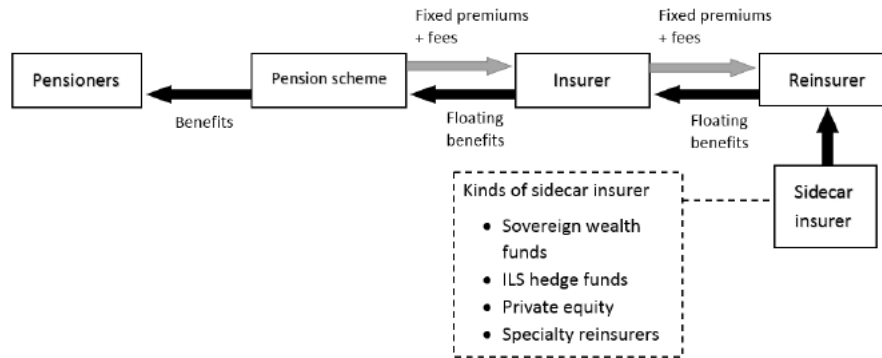
Similar to superfunds, reinsurance sidecars are also considered as potentially becoming one of the key mechanisms for additional capacity and diversification of longevity risk (Blake et al., 2018).

Figure 21: Overview of a pension superfund



Source: WTW (2024).

Figure 22: Overview of a sidecar structure



Source: Blake et al. (2018).

## 5 EFFECTIVENESS OF INSURANCE-BASED SOLUTIONS

In the present chapter, my objective is to quantify and analyze the financial impact of longevity risk on defined benefit pension liabilities and to evaluate the effectiveness of a longevity swap as an insurance-based longevity risk transfer instrument in mitigating longevity risk. Furthermore, I will also analyze how varying assumptions about future mortality affect the valuation of liabilities and the effectiveness of this transfer strategy.

### 5.1 Modelling approach and model description

Before evaluating risk transfer mechanisms, it is very important to first quantify the longevity risk. For the purpose of this analysis, a hypothetical pension fund was constructed with predefined parameters to quantify longevity risk and test varying assumptions. Namely, as explained in Chapters 2 and 3, longevity risk refers to the financial exposure of pension funds (in this particular case) that appears when pensioners live longer than what was

initially expected or estimated, resulting in a greater number of benefit payments over time. This means, that what we are tackling in this work, is the longevity risk after retirement, specifically in the phase of benefit payments or the so-called decumulation period.

In order to make the mentioned assessment, the analysis begins by projecting the pension scheme's liabilities under varying mortality assumptions in order to analyze the sensitivities.

Therefore, a cohort-based liability model was developed in Microsoft Excel simulating a defined group of pensioners: males retiring at age 65 in 2023 and projecting annual pension benefits payable over each member's remaining lifetime (up to 120 years), conditional on their survival probabilities specific to each future year.

We generate survival probabilities by applying yearly mortality improvement rates to a base mortality table for each age (from 65 to 120). The goal of the mortality improvement rates specific to each age is for the model to capture the expected longevity trends for the chosen cohort. Specifically, the base mortality assumptions were drawn from the SAPS S4PMA table, commonly used in UK for pension valuation, while future mortality improvements were based on the CMI core projections model. The underlying data used in the CMI model are drawn from the mortality experience of the England and Wales population, based on data published by the Office of National Statistics (ONS) (CMI, 2024).

The CMI model, was developed by the Continuous Mortality Investigation (CMI) and plays a central role in UK actuarial practice being widely referenced by stakeholders in the international longevity risk transfer market, like insurers, reinsurers and pension funds. As specified in by CMI (2024) it projects future mortality rates by extrapolating from recent trends in mortality improvements, rather than attempting to model causality or rely on socio-economic, medical or behavioral drivers of mortality. Therefore, it can be considered as an extrapolative model, based on a deterministic and trend-based framework (although it incorporates parameters that allow users to adjust for initial improvement levels and convergence speed). In summary, CMI applies a methodology that blends recent observed mortality improvements with a long-term rate, allowing for a gradual convergence from current experience to future expectations. Namely, the ability to blend recent observed experience with a user-defined long-term rate (LTR) is a defining feature of the CMI model that allows for gradual and controlled convergence from short-term data volatility to longer-term expectations of mortality decline.

As illustrated in the heatmaps in Figure 23 (CMI, 2024), the model shows that historical mortality improvements have varied substantially across birth cohorts and age groups. For example, individuals born in the yearly 1930s experienced some of the highest historical improvements, and for many cohorts, the most rapid gains occurred during the early 2000s. The colour scale indicates the annual rate of mortality improvement, with warmer colours representing higher improvements (4 percent or more per year) and cooler colours indicating periods of slowing or negative improvements as the horizontal bar below the heatmap

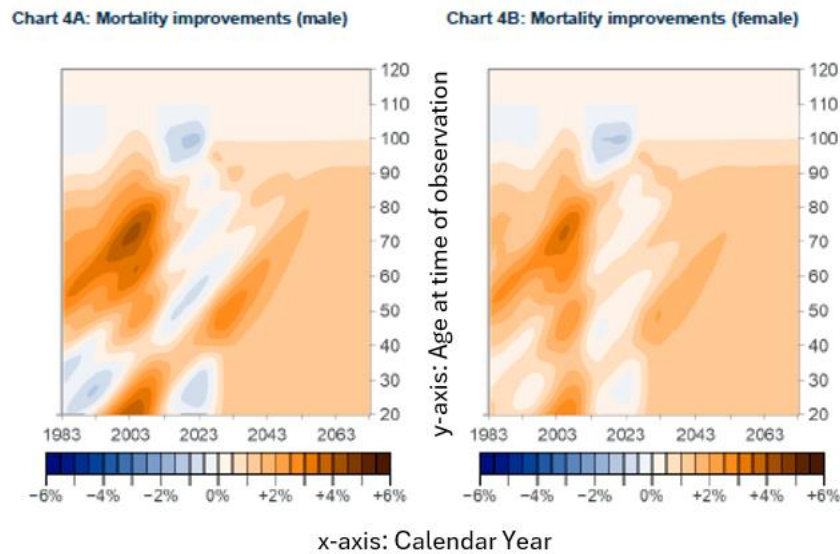
suggests. What regards future improvements, these are assumed to converge toward the long-term rate of 1.5 percent per annum, gradually reaching to zero improvement at the oldest ages. This is the rate I use in my base scenario.

## 5.2 Scenarios' framework and inputs

The inputs for the modelling of the defined pension scheme are as follows:

- Retirement age: 65 years
- Start year: 2023
- End age: 120 years
- Number of members: 1,000
- Flat annual benefit: € 10,000
- Discount rate: 3%
- Base Table: SAPS S4PMA
- Projection Model: CMI
- Long-Term Rate: 1.5%

*Figure 23: Historical mortality improvements in males and females since 1983*



*Source: CMI (2024).*

As mentioned previously, in the model developed for this thesis, the base projection scenario is considering on a long-term mortality rate of 1.5 percent per annum, consistent with the illustrative default values adopted in the CMI\_2023 model.

In the model we simulate a closed group of 1,000 male pensioners retiring at age 65 in the year 2023, each entitled to an annual pension of €10,000 payable in advance by the defined benefit pension plan. Mortality projections are based on the SAPS S4PMA base table,

adjusted using mortality improvements derived from the CMI\_2023 model, as described in the previous sections.

The financial valuation of liabilities is conducted using a real discount rate of 3 percent per annum, consistent with standard practice in illustrative analyses and aligned with assumptions used in the CMI's own publications. Liabilities are projected over a 60-year horizon, with benefit payments ceasing at age 120.

To explore the sensitivity of pension liabilities to variations in expected longevity, two additional stress scenarios are constructed: one with a higher LTR of 2 percent, representing an adverse longevity outcome (or greater life expectancy), and another with a lower rate of 0.5 percent, reflecting a more optimistic view from the scheme's perspective (simulating a favorable longevity).

Furthermore, a longevity swap is considered as a representative and simplistic insurance-based solution, in order to assess its financial impact on the pension scheme under present value calculations. When I talk about financial impact I refer to hedge effectiveness.

The longevity swap simulation compares fixed and floating cash flow legs, where the fixed leg is based on base-case survival assumptions and the floating leg reflects the stressed scenario. These present value comparisons allow for a quantitative assessment of the hedge effectiveness and relative cost of the instrument.

The scenarios described above form the basis for the simulations presented in the following section. There, the key model inputs, such as benefit structure, discount rate, and assumptions applied are disclosed in detail, followed by the resulting impact on the pension scheme's liabilities and risk exposure.

### 5.3 Results

The present section present the results of the liability modeling under different mortality improvement assumptions, followed by the simulation of a longevity instrument and an evaluation of its impact on the scheme's exposure to longevity risk.

The liability projection begins with the extraction of base mortality rates from the SAPS S4PMA mortality tables. To incorporate future mortality improvements, these base rates are adjusted using cumulative improvement factors derived from the CMI\_2023 model (CMI, 2024).

$$q_{x,t} = q_{x,0} \times (1 - m_{x,t}) \quad (2)$$

Where  $q_{x,t}$  is the base mortality rate at age  $x$ , and  $m_{x,t}$  is the cumulative mortality improvement factor provided by the CMI\_2023 model for that age and time.

From these adjusted mortality rates, annual survival probabilities are calculated as:

$$p_{x,t} = 1 - q_{x,t} \quad (3)$$

Cumulative survival probabilities, which represent the probability that an individual aged 65 survives to age  $65 + t$ , are derived as:

$${}_tp_{65} = \prod_{j=0}^{t-1} p_{65+j,j} \quad (4)$$

Using these survival probabilities, the expected annual benefit cash flows are projected for each year  $t$ , based on a cohort of 1,000 male pensioners retiring at age 65 and receiving a fixed annual benefit of €10,000. The expected benefit in year  $t$  is:

$$ExpectedCashFlow_t = N \times B \times {}_tp_{65} \quad (5)$$

where  $N$  is the number of pensioners (1,000),  $B$  is the annual fixed benefit amount and  ${}_tp_{65}$  is the probability of surviving from 65 to  $65 + t$ .

In the next step we use a discount rate ( $r$ ) to compute the present value for each year, applying the following formula:

$$\sum_0^t PV_t = \frac{Expected\ Cash\ Flow_t}{(1+r)^t} \quad (6)$$

In cumulative terms, this output is our best estimate liability value under the base scenario longevity assumptions used and serves as a reference case of what our pension fund's liabilities look like under the base mortality assumptions. The total present value of the liabilities is €149,794,353 as presented in Table 7.

Next, in order to assess the sensitivity of the estimated value of pension fund's liabilities to changes in mortality assumptions, particularly to the long-term rate within the CMI model, two stress scenario are considered. As previously defined, the LTR parameter determines the rate at which mortality improvements converge in the long term. A higher LTR leads to faster declines in mortality at older ages, thereby increasing life expectancy and pension liabilities.

In the adverse longevity scenario (Scenario A, as represented in Table 7), the LTR is increased from 1.5 percent to 2 percent whereas in the favorable scenario (Scenario B, as represented in Table 7), it is decreased to 0.5 percent. Substituting the corresponding CMI\_2023 improvement factors into the model, the recalculated present values of liabilities are compared to the base case.

As shown in Table 7 and Figure 24, increasing the LTR from the base value of 1.5 percent to 2 percent results in a modest liability increase of 0.08 percent, while reducing it to 0.5 percent produces a slightly larger decline of 0.15 percent in the present value of liabilities.

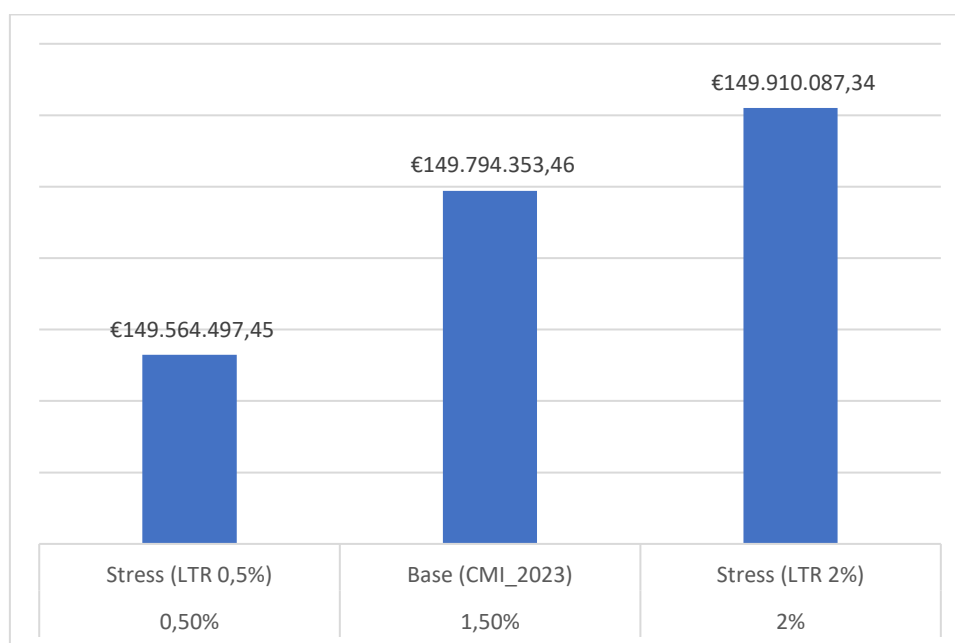
These outcomes highlight the asymmetrical sensitivity of pension liabilities to changes in longevity assumptions. Although the upward adjustment in the LTR is half the magnitude of the downward shift (0.5 versus 1 percentage point), it still yields a notable increase in projected liabilities. This reflects the disproportionate financial impact of longevity increases, where longer life expectancy extends the duration of benefit payments and inflates the present value of obligations. While these percentage changes may appear small, their implications can be significant for large-scale pension funds, where even slight shifts in assumptions can translate into substantial financial differences. Therefore, the presented results underscore the importance of carefully calibrated mortality projections and demonstrate that even modest changes in the long-term rate of improvement can materially influence the financial outlook of defined benefit schemes.

*Table 7: Stress testing*

| Scenario   | Discount Rate | Long-Term Rate | PV of Liabilities | Change vs. Base (Nominal) | Change vs. Base (%) |
|------------|---------------|----------------|-------------------|---------------------------|---------------------|
| Base       | 3%            | 1.50%          | 149,794,353.46 €  | -                         | -                   |
| Scenario A | 3%            | 2%             | 149,910,087.34 €  | 115,733.88 €              | 0.08%               |
| Scenario B | 3%            | 0.50%          | 149,564,497.45 €  | - 229,856.01 €            | -0.15%              |

*Source: Own work*

*Figure 24: NPV of pension liabilities response to stress test*



*Source: Own work*

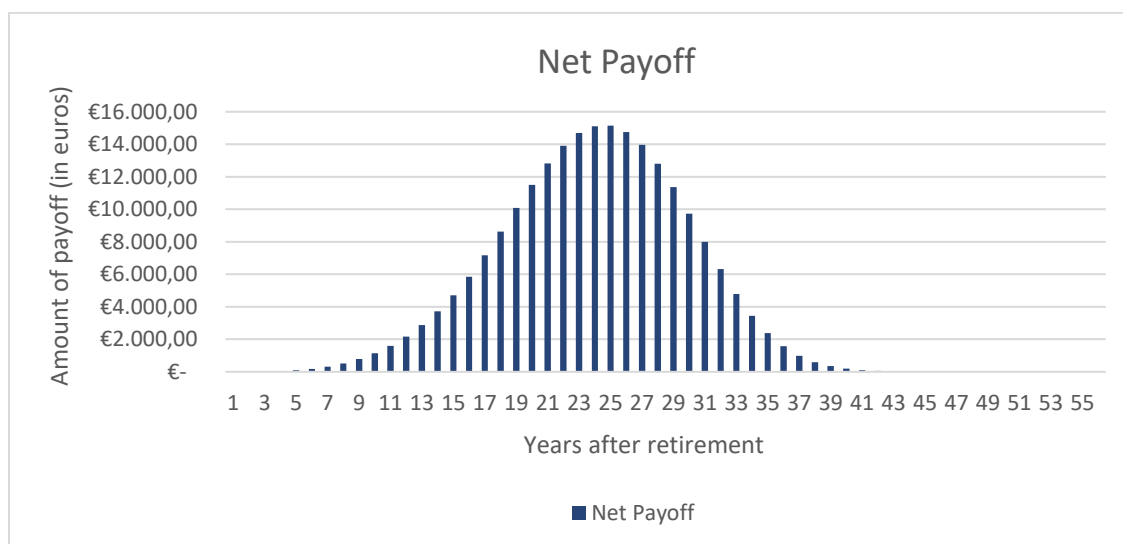
Following the stress testing of the pension liabilities, a longevity swap was simulated using the base scenario (with a LTR of 1.5 percent) as the fixed leg and the Scenario A (with a LTR of 2 percent) as the floating leg, reflecting a more adverse longevity outcome for the

pension fund. The net payoff in each year is the difference between the pension scheme's fixed obligation and the higher projected liabilities under the stress scenario.

As survival probabilities increase under the stress scenario, the floating leg of the longevity swap grows larger than the fixed leg, particularly in later years as the cohort ages into their 80s and 90s. Namely, Figure 25 illustrates the net payoff profile of the longevity swap demonstrating the targeted nature of this instrument. As already mentioned, as survival probabilities begin to diverge significantly around ages 80 to 90, the swap provides increasing compensation to the pension scheme. The bell-shaped curve of the net cash flows of the swap reflect the actuarial pattern of longevity risk exposure - peaking around year 23 to 27 which comprises the ages of 90 to 92, and tapering as the population gets older.

This divergence reflects the extended payout period under improved longevity assumptions, generating positive net payoffs to the pension scheme. The present value of these payoffs, discounted at a 3 percent rate, amounts to €224,563.39 (see Appendix 6). This figure exceeds the €115,733.88 increase in liabilities observed in Scenario A, suggesting that, under the assumptions used, the swap not only offsets the longevity shock but it also results in a net financial gain. However, in practice, insurers or reinsurers would incorporate pricing margins and risk charges, which would reduce the net benefit. Taking this into account, longevity swaps prove to be an effective hedge against longevity risk aligning cash flows with actual experience and stabilizing funding outcomes, though not necessarily eliminating risk entirely or without cost.

*Figure 25: Net payoff of a longevity swap*



*Source: Own work*

For sake of comparison, a second simulation of a longevity swap was performed using the base scenario (with a LTR of 1.5 percent) as the fixed leg and the Scenario B (with a LTR of 0.5 percent) as the floating leg, reflecting an optimistic longevity outcome for the pension

fund. In this case, the net present value is negative (€-445,175.91) clearly showing that the pension scheme would overhedge and the role of the swap is unnecessary given the longevity outcome.

It is important to note that while this thesis does not undertake full market-consistent pricing of longevity instruments, it incorporates actuarial pricing elements. In the case of adding a buy-in valuation in this analysis, the premium could be derived from the insurer's liability valuation under a stressed longevity scenario and adjusted for administrative costs, reflecting common industry practice. Similarly, the buy-out net cost could consider the impact of an asset transfer, simulating the financial outcome of a full risk novation. The longevity swap in this section was not priced per se, but its cash flows were valued under stress conditions to assess hedge effectiveness, which is a critical input to pricing negotiations.

The analysis performed in this thesis confirms that longevity risk can meaningfully affect pension liabilities even when it is driven by subtle changes in improvement rates. Among the instruments considered in Chapter 4, we can see that the longevity swap offers a precise and cost-efficient hedge aligned with the literature, particularly in scenarios where full risk transfer may be unnecessary or unaffordable. In contrast, buy-ins and buy-outs may provide full de-risking, but as defined in literature, come at a measurable financial premium. The choice between these strategies should be guided by the scheme's risk appetite, funding position, risk tolerance, and very importantly, its strategic objectives.

## **6 CONCLUSION**

Longer lives may be one of the biggest achievements of our society but if not considered correctly, they could cause social security systems, individuals and pension plans and annuity providers, as well as insurers and reinsurers, to collapse. Driven by three underlying risks (modelling, idiosyncratic and trend risk), longevity risk's management requires an integral approach to tackle all its aspects. Modelling risk and idiosyncratic risk, for example, can be diversified when dealing with sufficiently large populations and knowing well the characteristics of the affected group, while trend risk requires collaboration on a systemic level for its management or diversification to be effective. Namely, longevity risk can be individual or aggregate, affecting individuals, governments and pension funds, annuity providers or insurers.

With the growing life expectancy, there have been increased awareness and actions taken in the past 20 years in terms of developing solutions for the transfer of this risk. Currently, there are many solutions for longevity risk transfer with different characteristics, both on the side of insurance-based and on the side of capital market-based. Also, with the pace of development of the longevity risk transfer markets, and the innovative approaches coming out, many more will appear in both groups. However, as of today, the main actors in these markets are insurers and reinsurers as hedge providers, making the risk accumulation highly

concentrated in the reinsurance and insurance industry as capital market-based solutions have not shown sufficient success despite numerous attempts to motivate the entrance of external investors to the longevity risk transfer market.

Namely, longevity swaps, buy-ins and buy-outs are one of the most commonly used mechanisms with reported transactions beating records each year in number and volume. Each of the mechanisms has its strengths and weaknesses, and depending on the needs of each pension scheme, the right one can be chosen. Apart from the existing solutions, there are currently also emerging innovations reviewed in this thesis. For example, funded reinsurance solutions and superfund transactions can be said to be hybrid structures that offer greater flexibility in terms of structure and regulation. The latter, also open the way for currently stagnating capital market-based solutions through large-scale participation of external investors and contribute to the democratisation of longevity risk and its transfer.

From an analytical standpoint and in order to confirm that longevity risk-related assumptions have an impact on pension liabilities, the CMI model was employed, as a widely used model in pensions and insurance. This makes it suitable for the analysis in this thesis, especially due to its flexibility in stress testing and scenario analysis. Namely, through its robust and transparent foundation for projecting future mortality we've modelled a pensioner cohort under different long-term mortality improvement rates confirming that longevity assumptions materially affect the present value of pension liabilities. Although improvement rate increases modestly, it produces an important rise in pension liabilities. Also, through a longevity swap simulation, we've shown that, aligned with the literature, longevity swaps are an effective tool for managing longevity risk, given that the simulation provided empirical evidence that such instruments can effectively offset the financial impact of adverse longevity developments. The net payoff from the swap in the stress scenario closely matched the additional liability incurred due to higher survival probabilities, confirming its role as an effective and targeted hedge. This makes longevity swaps a viable alternative to bulk annuities (buy-ins and buy-outs) for many schemes, offering structural adaptability but also operational simplicity.

In general terms, this thesis contributes to the understanding of longevity risk from different aspects, and understanding its drivers, reviewing longevity risk transfer markets and how risk mitigation instruments can support pension schemes. It underscores the importance of consistent and realistic mortality modeling and stress testing. While stochastic mortality models are extensively covered in the actuarial literature, this thesis contributes by operationalizing longevity risk transfer within a simplified but replicable deterministic framework. Thus, going forward, further research could incorporate a deeper analysis of innovative solutions (such as asset intensive reinsurance or superfund transactions), applying heterogeneous cohorts, explore market-consistent pricing, as well as regulatory capital perspectives to deepen the analysis and bridge academic models with industry application.

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## **APPENDICES**





## **Appendix 1: Povzetek vsebine (Summary in Slovene language)**

Podaljševanje življenjske dobe je eden največjih dosežkov sodobne družbe. Dosežek, ki lahko, če ni ustrezno obravnavan, resno ogrozi stabilnost pokojninskih sistemov, zavarovalnic in socialnih sistemov. Tveganje dolgoživosti vsebuje tri osnovne vidike tveganj (modelno tveganje, idiosinkratično oz. posebno tveganje in trendno tveganje) in za obvladovanje le tega je potreben celosten pristop, ki upošteva vse njegove vidike. Modelno in idiosinkratično tveganje se lahko na primer razpršita, če gre za dovolj velike populacije in če so značilnosti ciljne skupine dobro poznane. Za razliko od razpršljivih tveganj, tveganje dolgoživosti zahteva sodelovanje na sistemski ravni zato da bi bilo učinkovito upravljano ali do neke stopnje razpršeno. Tveganje dolgoživosti je lahko individualno ali agregatno in vpliva na posameznike, vlade, socialne sisteme, pokojninske sklade, ponudnike rent ali finančne institucije in vlagateljev na sistemski ravni.

S podaljševanjem pričakovane življenjske dobe se je v zadnjih 20 letih povečala ozaveščenost o tveganju dolgoživosti ter sprejemanje ukrepov za razvoj rešitev za njegov prenos. Trenutno ločimo dve skupini instrumentov za prenos tveganja dolgoživosti: na eni strani zavarovalniške rešitve, na drugi strani pa instrumente kapitalskih trgov. Zavarovalnice in pozavarovalnice so danes ključni akterji na trgih prenosa tveganja dolgoživosti kot ponudniki rešitev za ščitenja. Zaradi tega je tveganje močno koncentrirano v zavarovalništvu in pozavarovalništvu, saj kljub številnim pobudam za vključitev tretjih vlagateljev v sistem prenosa tveganja s pomočjo kapitalskega trga niso dosegle zadostnega uspeha.

Najpogosteje uporabljeni zavarovalniški instrumenti za ščitenje proti tveganju dolgoživosti so odkup obveznosti (v nadaljevanju: buy-out), notranji odkup (v nadaljevanju: buy-in) in zamenjava tveganja dolgoživosti (v nadaljevanju: longevity swap). Na kapitalskih trgih obstajajo tudi obveznice dolgoživosti (ang. longevity bonds) in izvedeni finančni instrumenti, kot so terminske pogodbe. V praksi prevladajo buy-in, buy-out in longevity swaps. Longevity swap zavarovalnicam zagotavlja zaščito pred tveganjem dolgoživosti, medtem ko instrumenta buy-in in buy-out nudita zaščito tudi pred naložbenim in inflacijskim tveganjem. Namen te naloge je raziskati omenjene instrumente glede na njihove značilnosti o prenosu različnih tveganj ter oceniti njihovo primernost.

Cilj te magistrske naloge je bolje razumeti pomen tveganja dolgoživosti ter možnosti njegovega upravljanja ob trendu podaljševanja življenjske dobe zavarovancev. Magistrska naloga temelji na teoretični raziskavi, ki vključuje obsežen pregled literature in zbiranje podatkov iz različnih virov. V nalogi preučujem trende dolgoživosti, finančne posledice tveganja dolgoživosti ter obstoječe in pretekle rešitve za njegovo upravljanje, skupaj z njihovo praktično uporabo. V okviru naloge povzemam tudi ključne nosilce tveganja in njihove vloge ter podrobneje predstavim trg prenosa tveganja dolgoživosti (ang. longevity risk transfer market), vključno z instrumenti in mehanizmi za ščitenje pred tveganju dolgoživosti ter pristope k vrednotenju zavarovalniških instrumentov. Zaključek magistrske naloge se osredotoča na oceno vpliva tveganja dolgoživosti na hipotetično pokojninsko

shemo z uporabo modela CMI ter vključuje analizo učinkovitosti instrumenta longevity swap.

V prvem delu magistrske naloge opišem demografske trende, vpliv na posameznike in institucije ter predstavim razloge za prenos tveganja dolgoživosti glede na tri osnovne gradnike tega tveganja (modelno tveganje, idiosinkratično tveganje in trendno tveganje). V drugem delu obravnavam razvoj svetovnih trgov za prenos tveganja dolgoživosti, njihove značilnosti in trenutno stanje. Sledi poglobljen pregled obstoječih instrumentov, pri čemer ločim med zavarovalniškimi instrumenti in instrumenti kapitalskih trgov. V zadnjem delu naloge s pomočjo modela CMI ocenim vpliv tveganja dolgoživosti in učinkovitost njegovega prenosa z uporabo instrumenta longevity swap.

Analitični del naloge potrjuje, da ima izbira predpostavk o smrtnosti pomemben vpliv na vrednotenje pokojninskih obveznosti zavarovalnic ali pokojninske sklade. S pomočjo scenarijske analize v modelu CMI se je izkazalo, da že manjše povečanje dolgoročne stopnje smrtnosti občutno poveča vrednost obveznosti pokojninskega sklada. Simulacija longevity swap-ov je pokazala, da ti instrumenti učinkovito izravnavajo negativne finančne učinke daljše dolgoživosti, kar potrjuje njihovo vlogo ščitenja proti tveganju dolgoživosti.

Ta magistrska naloga prispeva k boljšemu razumevanju tveganja dolgoživosti, ponuja pregled instrumentov za prenos tega tveganja ter ponudi transparenten okvir za njihovo vrednotenje. Nadaljnje raziskave tematike tveganja dolgoživosti v zavarovalništvu bi lahko vključevale ustvarjalne rešitve (kot so premoženjsko intenzivno pozavarovanje ali transakcije super skladov) ob uporabi stohastičnega modeliranja, vključevanju heterogenih kohort, raziskovanju tržno skladnega vrednotenja ter analizi z vidika regulativnega kapitala. S tem bi lahko dodatno poglobili obseg obstoječe znanstveno razumevanje in ga tesneje povezali z realnim stanjem v zavarovalniški industriji.

## Appendix 2: Survival Probabilities

| Age | Year | Survival probability<br>(Base Scenario) | Cumulative survival probability<br>(Base Scenario) | Survival probability<br>(Scenario A) | Cumulative survival probability<br>(Scenario A) | Survival probability<br>(Scenario B) | Cumulative survival probability<br>(Scenario B) |
|-----|------|-----------------------------------------|----------------------------------------------------|--------------------------------------|-------------------------------------------------|--------------------------------------|-------------------------------------------------|
| 65  | 2023 | 0,992935581                             | 1                                                  | 0,992935581                          | 1                                               | 0,992935581                          | 1                                               |
| 66  | 2024 | 0,992202639                             | 0,992202639                                        | 0,99220292                           | 0,99220292                                      | 0,992202077                          | 0,992202077                                     |
| 67  | 2025 | 0,991359149                             | 0,983629164                                        | 0,991360351                          | 0,983630634                                     | 0,991356747                          | 0,983626224                                     |
| 68  | 2026 | 0,990388438                             | 0,974174951                                        | 0,990391334                          | 0,974179256                                     | 0,990382642                          | 0,974166338                                     |
| 69  | 2027 | 0,989271332                             | 0,963723352                                        | 0,989276862                          | 0,963732998                                     | 0,989260264                          | 0,963704049                                     |
| 70  | 2028 | 0,987985777                             | 0,952144965                                        | 0,987995072                          | 0,952163452                                     | 0,987967167                          | 0,952107959                                     |
| 71  | 2029 | 0,986506373                             | 0,939297076                                        | 0,98652079                           | 0,939329041                                     | 0,986477497                          | 0,939233076                                     |
| 72  | 2030 | 0,984803948                             | 0,925023468                                        | 0,9848251                            | 0,925074816                                     | 0,98476156                           | 0,924920629                                     |
| 73  | 2031 | 0,982845041                             | 0,909154728                                        | 0,982874836                          | 0,909232758                                     | 0,982785306                          | 0,908998403                                     |
| 74  | 2032 | 0,980591449                             | 0,891509352                                        | 0,980632117                          | 0,891622845                                     | 0,980509879                          | 0,891281914                                     |
| 75  | 2033 | 0,977999767                             | 0,871895938                                        | 0,978053889                          | 0,872055191                                     | 0,977891168                          | 0,871576712                                     |
| 76  | 2034 | 0,975020933                             | 0,850116791                                        | 0,975091457                          | 0,850333568                                     | 0,974879372                          | 0,849682157                                     |
| 77  | 2035 | 0,971599736                             | 0,82597325                                         | 0,971689982                          | 0,826260609                                     | 0,971418536                          | 0,825396997                                     |
| 78  | 2036 | 0,96767441                              | 0,799273178                                        | 0,967788049                          | 0,799645143                                     | 0,967446191                          | 0,798527181                                     |
| 79  | 2037 | 0,963176203                             | 0,769840905                                        | 0,963317217                          | 0,770311933                                     | 0,962892983                          | 0,768896219                                     |
| 80  | 2038 | 0,958028991                             | 0,737529905                                        | 0,958201583                          | 0,738114114                                     | 0,957682367                          | 0,736358352                                     |
| 81  | 2039 | 0,952170675                             | 0,702254347                                        | 0,952387717                          | 0,702970816                                     | 0,951734827                          | 0,700817888                                     |
| 82  | 2040 | 0,945482075                             | 0,663968898                                        | 0,94574431                           | 0,664830649                                     | 0,944955759                          | 0,662241899                                     |
| 83  | 2041 | 0,93784277                              | 0,62269843                                         | 0,938143844                          | 0,623706781                                     | 0,937239152                          | 0,620679036                                     |
| 84  | 2042 | 0,929170282                             | 0,578592876                                        | 0,929512667                          | 0,579743353                                     | 0,928484751                          | 0,57629102                                      |
| 85  | 2043 | 0,919364943                             | 0,531938007                                        | 0,919753907                          | 0,533221214                                     | 0,918587343                          | 0,529373637                                     |
| 86  | 2044 | 0,908266378                             | 0,483141407                                        | 0,90868996                           | 0,484532764                                     | 0,90742108                           | 0,480364798                                     |
| 87  | 2045 | 0,895807548                             | 0,432801719                                        | 0,896267107                          | 0,434270778                                     | 0,894892233                          | 0,429874726                                     |
| 88  | 2046 | 0,881885199                             | 0,38168143                                         | 0,882381662                          | 0,383192571                                     | 0,880898464                          | 0,378675986                                     |
| 89  | 2047 | 0,866405403                             | 0,330690853                                        | 0,866939144                          | 0,33220464                                      | 0,865346996                          | 0,327686127                                     |
| 90  | 2048 | 0,849288697                             | 0,280852004                                        | 0,849859403                          | 0,282327237                                     | 0,848159767                          | 0,277930189                                     |
| 91  | 2049 | 0,830475826                             | 0,2332408                                          | 0,831082358                          | 0,234637186                                     | 0,829279172                          | 0,230481717                                     |
| 92  | 2050 | 0,809933843                             | 0,188909617                                        | 0,810574097                          | 0,190190825                                     | 0,808674178                          | 0,186384613                                     |
| 93  | 2051 | 0,787662298                             | 0,148796983                                        | 0,788333065                          | 0,149933716                                     | 0,78634649                           | 0,146562886                                     |
| 94  | 2052 | 0,763699105                             | 0,113636123                                        | 0,764395953                          | 0,114608726                                     | 0,762336373                          | 0,111730219                                     |
| 95  | 2053 | 0,738607363                             | 0,083932477                                        | 0,739323236                          | 0,084732894                                     | 0,737211971                          | 0,082368855                                     |
| 96  | 2054 | 0,713053341                             | 0,059848333                                        | 0,713777455                          | 0,060480429                                     | 0,711646439                          | 0,058617502                                     |
| 97  | 2055 | 0,687141759                             | 0,041124289                                        | 0,687863923                          | 0,041602305                                     | 0,685743317                          | 0,040196561                                     |
| 98  | 2056 | 0,661280966                             | 0,027194709                                        | 0,661990193                          | 0,027540318                                     | 0,659912139                          | 0,026526198                                     |
| 99  | 2057 | 0,635930058                             | 0,017293933                                        | 0,636615084                          | 0,017532582                                     | 0,634612065                          | 0,016833845                                     |
| 100 | 2058 | 0,61158594                              | 0,010576726                                        | 0,612235862                          | 0,010734075                                     | 0,610338798                          | 0,010274349                                     |
| 101 | 2059 | 0,588770319                             | 0,006227263                                        | 0,589374721                          | 0,006326393                                     | 0,587612879                          | 0,00603734                                      |
| 102 | 2060 | 0,568009499                             | 0,003537144                                        | 0,568558231                          | 0,003596923                                     | 0,56696027                           | 0,003422932                                     |
| 103 | 2061 | 0,549820568                             | 0,001944795                                        | 0,550304867                          | 0,001979404                                     | 0,548895328                          | 0,001878831                                     |
| 104 | 2062 | 0,534701404                             | 0,001039884                                        | 0,535114427                          | 0,001059208                                     | 0,5339123                            | 0,001003131                                     |
| 105 | 2063 | 0,521801867                             | 0,000542614                                        | 0,522140134                          | 0,000553055                                     | 0,521154783                          | 0,000522787                                     |
| 106 | 2064 | 0,509081294                             | 0,000276234                                        | 0,509344859                          | 0,000281696                                     | 0,508575673                          | 0,000265877                                     |
| 107 | 2065 | 0,496709903                             | 0,000137208                                        | 0,49690033                           | 0,000139975                                     | 0,496342756                          | 0,000131966                                     |
| 108 | 2066 | 0,484677047                             | 6,65018E-05                                        | 0,484797778                          | 6,78594E-05                                     | 0,484442433                          | 6,39299E-05                                     |

“(table continues)”

“(continued)”

| <b>Age</b> | <b>Year</b> | <b>Survival probability<br/>(Base Scenario)</b> | <b>Cumulative survival probability<br/>(Base Scenario)</b> | <b>Survival probability<br/>(Scenario A)</b> | <b>Cumulative survival probability<br/>(Scenario A)</b> | <b>Survival probability<br/>(Scenario B)</b> | <b>Cumulative survival probability<br/>(Scenario B)</b> |
|------------|-------------|-------------------------------------------------|------------------------------------------------------------|----------------------------------------------|---------------------------------------------------------|----------------------------------------------|---------------------------------------------------------|
| <b>109</b> | 2067        | 0,472973327                                     | 3,14536E-05                                                | 0,473029859                                  | 3,20995E-05                                             | 0,47286217                                   | 3,023E-05                                               |
| <b>110</b> | 2068        | 0,461590405                                     | 1,45187E-05                                                | 0,461590405                                  | 1,48168E-05                                             | 0,461590405                                  | 1,39539E-05                                             |
| <b>111</b> | 2069        | 0,450665414                                     | 6,54306E-06                                                | 0,450665414                                  | 6,67743E-06                                             | 0,450665414                                  | 6,28853E-06                                             |
| <b>112</b> | 2070        | 0,440021649                                     | 2,87909E-06                                                | 0,440021649                                  | 2,93822E-06                                             | 0,440021649                                  | 2,76709E-06                                             |
| <b>113</b> | 2071        | 0,429648935                                     | 1,237E-06                                                  | 0,429648935                                  | 1,2624E-06                                              | 0,429648935                                  | 1,18888E-06                                             |
| <b>114</b> | 2072        | 0,419537783                                     | 5,18967E-07                                                | 0,419537783                                  | 5,29625E-07                                             | 0,419537783                                  | 4,98779E-07                                             |
| <b>115</b> | 2073        | 0,409679328                                     | 2,1261E-07                                                 | 0,409679328                                  | 2,16976E-07                                             | 0,409679328                                  | 2,0434E-07                                              |
| <b>116</b> | 2074        | 0,400065265                                     | 8,50579E-08                                                | 0,400065265                                  | 8,68047E-08                                             | 0,400065265                                  | 8,17491E-08                                             |
| <b>117</b> | 2075        | 0,390687801                                     | 3,32311E-08                                                | 0,390687801                                  | 3,39135E-08                                             | 0,390687801                                  | 3,19384E-08                                             |
| <b>118</b> | 2076        | 0,381539602                                     | 1,2679E-08                                                 | 0,381539602                                  | 1,29394E-08                                             | 0,381539602                                  | 1,21858E-08                                             |
| <b>119</b> | 2077        | 0,372613749                                     | 4,72436E-09                                                | 0,372613749                                  | 4,82138E-09                                             | 0,372613749                                  | 4,54058E-09                                             |
| <b>120</b> | 2078        | 0                                               | 0                                                          | 0                                            | 0                                                       | 0                                            | 0                                                       |

### Appendix 3: Liabilities' valuation (Base scenario)

| Year | Age | tPx        | Annual Benefit | Expected CF   | Discount factor    | PV              |
|------|-----|------------|----------------|---------------|--------------------|-----------------|
| 2023 | 65  | 1          | 10.000,00 €    | 10.000.000,00 | 1,0000000000000000 | 10.000.000,00 € |
| 2024 | 66  | 0,99220264 | 10.000,00 €    | 9.922.026,39  | 0,97087378640777   | 9.633.035,33 €  |
| 2025 | 67  | 0,98362916 | 10.000,00 €    | 9.836.291,64  | 0,94259590913375   | 9.271.648,26 €  |
| 2026 | 68  | 0,97417495 | 10.000,00 €    | 9.741.749,51  | 0,91514165935316   | 8.915.080,81 €  |
| 2027 | 69  | 0,96372335 | 10.000,00 €    | 9.637.233,52  | 0,88848704791569   | 8.562.557,16 €  |
| 2028 | 70  | 0,95214496 | 10.000,00 €    | 9.521.449,65  | 0,86260878438416   | 8.213.286,10 €  |
| 2029 | 71  | 0,93929708 | 10.000,00 €    | 9.392.970,76  | 0,83748425668365   | 7.866.465,13 €  |
| 2030 | 72  | 0,92502347 | 10.000,00 €    | 9.250.234,68  | 0,81309151134335   | 7.521.287,30 €  |
| 2031 | 73  | 0,90915473 | 10.000,00 €    | 9.091.547,28  | 0,78940923431394   | 7.176.951,38 €  |
| 2032 | 74  | 0,89150935 | 10.000,00 €    | 8.915.093,52  | 0,76641673234363   | 6.832.676,84 €  |
| 2033 | 75  | 0,87189594 | 10.000,00 €    | 8.718.959,38  | 0,74409391489673   | 6.487.724,62 €  |
| 2034 | 76  | 0,85011679 | 10.000,00 €    | 8.501.167,91  | 0,72242127659876   | 6.141.424,58 €  |
| 2035 | 77  | 0,82597325 | 10.000,00 €    | 8.259.732,50  | 0,70137988019297   | 5.793.210,19 €  |
| 2036 | 78  | 0,79927318 | 10.000,00 €    | 7.992.731,78  | 0,68095133999318   | 5.442.661,42 €  |
| 2037 | 79  | 0,7698409  | 10.000,00 €    | 7.698.409,05  | 0,66111780581862   | 5.089.555,30 €  |
| 2038 | 80  | 0,73752991 | 10.000,00 €    | 7.375.299,05  | 0,64186194739672   | 4.733.923,81 €  |
| 2039 | 81  | 0,70225435 | 10.000,00 €    | 7.022.543,47  | 0,62316693922011   | 4.376.216,92 €  |
| 2040 | 82  | 0,6639689  | 10.000,00 €    | 6.639.688,98  | 0,60501644584477   | 4.017.121,03 €  |
| 2041 | 83  | 0,62269843 | 10.000,00 €    | 6.226.984,30  | 0,58739460761628   | 3.657.697,00 €  |
| 2042 | 84  | 0,57859288 | 10.000,00 €    | 5.785.928,76  | 0,57028602681193   | 3.299.634,32 €  |
| 2043 | 85  | 0,53193801 | 10.000,00 €    | 5.319.380,07  | 0,55367575418634   | 2.945.211,77 €  |
| 2044 | 86  | 0,48314141 | 10.000,00 €    | 4.831.414,07  | 0,53754927590906   | 2.597.123,13 €  |
| 2045 | 87  | 0,43280172 | 10.000,00 €    | 4.328.017,19  | 0,52189250088259   | 2.258.759,71 €  |
| 2046 | 88  | 0,38168143 | 10.000,00 €    | 3.816.814,30  | 0,50669174842970   | 1.933.948,31 €  |
| 2047 | 89  | 0,33069085 | 10.000,00 €    | 3.306.908,53  | 0,49193373633951   | 1.626.779,87 €  |
| 2048 | 90  | 0,280852   | 10.000,00 €    | 2.808.520,04  | 0,47760556926166   | 1.341.364,81 €  |
| 2049 | 91  | 0,2332408  | 10.000,00 €    | 2.332.408,00  | 0,46369472743850   | 1.081.525,29 €  |
| 2050 | 92  | 0,18890962 | 10.000,00 €    | 1.889.096,17  | 0,45018905576554   | 850.450,42 €    |
| 2051 | 93  | 0,14879698 | 10.000,00 €    | 1.487.969,83  | 0,43707675317043   | 650.357,02 €    |

“(table continues)”

“(continued)”

| Year | Age | tPx        | Annual Benefit | Expected CF             | Discount factor  | PV                      |
|------|-----|------------|----------------|-------------------------|------------------|-------------------------|
| 2052 | 94  | 0,11363612 | 10.000,00 €    | 1.136.361,23            | 0,42434636230138 | 482.210,75 €            |
| 2053 | 95  | 0,08393248 | 10.000,00 €    | 839.324,77              | 0,41198675951591 | 345.790,69 €            |
| 2054 | 96  | 0,05984833 | 10.000,00 €    | 598.483,33              | 0,39998714516108 | 239.385,64 €            |
| 2055 | 97  | 0,04112429 | 10.000,00 €    | 411.242,89              | 0,38833703413697 | 159.700,84 €            |
| 2056 | 98  | 0,02719471 | 10.000,00 €    | 271.947,09              | 0,37702624673492 | 102.531,19 €            |
| 2057 | 99  | 0,01729393 | 10.000,00 €    | 172.939,33              | 0,36604489974264 | 63.303,56 €             |
| 2058 | 100 | 0,01057673 | 10.000,00 €    | 105.767,26              | 0,35538339780839 | 37.587,93 €             |
| 2059 | 101 | 0,00622726 | 10.000,00 €    | 62.272,63               | 0,34503242505669 | 21.486,08 €             |
| 2060 | 102 | 0,00353714 | 10.000,00 €    | 35.371,44               | 0,33498293694824 | 11.848,83 €             |
| 2061 | 103 | 0,00194479 | 10.000,00 €    | 19.447,95               | 0,32522615237693 | 6.324,98 €              |
| 2062 | 104 | 0,00103988 | 10.000,00 €    | 10.398,84               | 0,31575354599702 | 3.283,47 €              |
| 2063 | 105 | 0,00054261 | 10.000,00 €    | 5.426,14                | 0,30655684077381 | 1.663,42 €              |
| 2064 | 106 | 0,00027623 | 10.000,00 €    | 2.762,34                | 0,29762800075127 | 822,15 €                |
| 2065 | 107 | 0,00013721 | 10.000,00 €    | 1.372,08                | 0,28895922403036 | 396,48 €                |
| 2066 | 108 | 6,6502E-05 | 10.000,00 €    | 665,02                  | 0,28054293595180 | 186,57 €                |
| 2067 | 109 | 3,1454E-05 | 10.000,00 €    | 314,54                  | 0,27237178247748 | 85,67 €                 |
| 2068 | 110 | 1,4519E-05 | 10.000,00 €    | 145,19                  | 0,26443862376454 | 38,39 €                 |
| 2069 | 111 | 6,5431E-06 | 10.000,00 €    | 65,43                   | 0,25673652792674 | 16,80 €                 |
| 2070 | 112 | 2,8791E-06 | 10.000,00 €    | 28,79                   | 0,24925876497742 | 7,18 €                  |
| 2071 | 113 | 1,237E-06  | 10.000,00 €    | 12,37                   | 0,24199880094895 | 2,99 €                  |
| 2072 | 114 | 5,1897E-07 | 10.000,00 €    | 5,19                    | 0,23495029218345 | 1,22 €                  |
| 2073 | 115 | 2,1261E-07 | 10.000,00 €    | 2,13                    | 0,22810707978975 | 0,48 €                  |
| 2074 | 116 | 8,5058E-08 | 10.000,00 €    | 0,85                    | 0,22146318426190 | 0,19 €                  |
| 2075 | 117 | 3,3231E-08 | 10.000,00 €    | 0,33                    | 0,21501280025427 | 0,07 €                  |
| 2076 | 118 | 1,2679E-08 | 10.000,00 €    | 0,13                    | 0,20875029150900 | 0,03 €                  |
| 2077 | 119 | 4,7244E-09 | 10.000,00 €    | 0,05                    | 0,20267018593107 | 0,01 €                  |
| 2078 | 120 | 0          | 10.000,00 €    | -                       | 0,19676717080686 | - €                     |
|      |     |            |                | <b>203.324.927,66 €</b> |                  | <b>149.794.353,46 €</b> |

#### Appendix 4: Liabilities' valuation (Scenario A)

| Year | Age | tPx        | Annual Benefit | Expected CF   | Discount factor   | PV              |
|------|-----|------------|----------------|---------------|-------------------|-----------------|
| 2023 | 65  | 1          | 10.000,00 €    | 10.000.000,00 | 1,000000000000000 | 10.000.000,00 € |
| 2024 | 66  | 0,99220292 | 10.000,00 €    | 9.922.029,20  | 0,97087378640777  | 9.633.038,05 €  |
| 2025 | 67  | 0,98363063 | 10.000,00 €    | 9.836.306,34  | 0,94259590913375  | 9.271.662,12 €  |
| 2026 | 68  | 0,97417926 | 10.000,00 €    | 9.741.792,56  | 0,91514165935316  | 8.915.120,21 €  |
| 2027 | 69  | 0,963733   | 10.000,00 €    | 9.637.329,98  | 0,88848704791569  | 8.562.642,86 €  |
| 2028 | 70  | 0,95216345 | 10.000,00 €    | 9.521.634,52  | 0,86260878438416  | 8.213.445,58 €  |
| 2029 | 71  | 0,93932904 | 10.000,00 €    | 9.393.290,41  | 0,83748425668365  | 7.866.732,83 €  |
| 2030 | 72  | 0,92507482 | 10.000,00 €    | 9.250.748,16  | 0,81309151134335  | 7.521.704,80 €  |
| 2031 | 73  | 0,90923276 | 10.000,00 €    | 9.092.327,58  | 0,78940923431394  | 7.177.567,36 €  |
| 2032 | 74  | 0,89162285 | 10.000,00 €    | 8.916.228,45  | 0,76641673234363  | 6.833.546,67 €  |
| 2033 | 75  | 0,87205519 | 10.000,00 €    | 8.720.551,91  | 0,74409391489673  | 6.488.909,61 €  |
| 2034 | 76  | 0,85033357 | 10.000,00 €    | 8.503.335,68  | 0,72242127659876  | 6.142.990,61 €  |
| 2035 | 77  | 0,82626061 | 10.000,00 €    | 8.262.606,09  | 0,70137988019297  | 5.795.225,67 €  |
| 2036 | 78  | 0,79964514 | 10.000,00 €    | 7.996.451,43  | 0,68095133999318  | 5.445.194,31 €  |
| 2037 | 79  | 0,77031193 | 10.000,00 €    | 7.703.119,33  | 0,66111780581862  | 5.092.669,35 €  |
| 2038 | 80  | 0,73811411 | 10.000,00 €    | 7.381.141,14  | 0,64186194739672  | 4.737.673,62 €  |
| 2039 | 81  | 0,70297082 | 10.000,00 €    | 7.029.708,16  | 0,62316693922011  | 4.380.681,72 €  |
| 2040 | 82  | 0,66483065 | 10.000,00 €    | 6.648.306,49  | 0,60501644584477  | 4.022.334,76 €  |
| 2041 | 83  | 0,62370678 | 10.000,00 €    | 6.237.067,81  | 0,58739460761628  | 3.663.620,00 €  |
| 2042 | 84  | 0,57974335 | 10.000,00 €    | 5.797.433,53  | 0,57028602681193  | 3.306.195,33 €  |
| 2043 | 85  | 0,53322121 | 10.000,00 €    | 5.332.212,14  | 0,55367575418634  | 2.952.316,58 €  |
| 2044 | 86  | 0,48453276 | 10.000,00 €    | 4.845.327,64  | 0,53754927590906  | 2.604.602,36 €  |
| 2045 | 87  | 0,43427078 | 10.000,00 €    | 4.342.707,78  | 0,52189250088259  | 2.266.426,62 €  |
| 2046 | 88  | 0,38319257 | 10.000,00 €    | 3.831.925,71  | 0,50669174842970  | 1.941.605,14 €  |
| 2047 | 89  | 0,33220464 | 10.000,00 €    | 3.322.046,40  | 0,49193373633951  | 1.634.226,70 €  |
| 2048 | 90  | 0,28232724 | 10.000,00 €    | 2.823.272,37  | 0,47760556926166  | 1.348.410,61 €  |
| 2049 | 91  | 0,23463719 | 10.000,00 €    | 2.346.371,86  | 0,46369472743850  | 1.088.000,26 €  |
| 2050 | 92  | 0,19019082 | 10.000,00 €    | 1.901.908,25  | 0,45018905576554  | 856.218,28 €    |
| 2051 | 93  | 0,14993372 | 10.000,00 €    | 1.499.337,16  | 0,43707675317043  | 655.325,42 €    |

“(table continues)”

“(continued)”

| Year | Age | tPx        | Annual Benefit | Expected CF             | Discount factor  | PV                      |
|------|-----|------------|----------------|-------------------------|------------------|-------------------------|
| 2052 | 94  | 0,11460873 | 10.000,00 €    | 1.146.087,26            | 0,42434636230138 | 486.337,96 €            |
| 2053 | 95  | 0,08473289 | 10.000,00 €    | 847.328,94              | 0,41198675951591 | 349.088,30 €            |
| 2054 | 96  | 0,06048043 | 10.000,00 €    | 604.804,29              | 0,39998714516108 | 241.913,94 €            |
| 2055 | 97  | 0,04160231 | 10.000,00 €    | 416.023,05              | 0,38833703413697 | 161.557,16 €            |
| 2056 | 98  | 0,02754032 | 10.000,00 €    | 275.403,18              | 0,37702624673492 | 103.834,23 €            |
| 2057 | 99  | 0,01753258 | 10.000,00 €    | 175.325,82              | 0,36604489974264 | 64.177,12 €             |
| 2058 | 100 | 0,01073408 | 10.000,00 €    | 107.340,75              | 0,35538339780839 | 38.147,12 €             |
| 2059 | 101 | 0,00632639 | 10.000,00 €    | 63.263,93               | 0,34503242505669 | 21.828,11 €             |
| 2060 | 102 | 0,00359692 | 10.000,00 €    | 35.969,23               | 0,33498293694824 | 12.049,08 €             |
| 2061 | 103 | 0,0019794  | 10.000,00 €    | 19.794,04               | 0,32522615237693 | 6.437,54 €              |
| 2062 | 104 | 0,00105921 | 10.000,00 €    | 10.592,08               | 0,31575354599702 | 3.344,49 €              |
| 2063 | 105 | 0,00055305 | 10.000,00 €    | 5.530,55                | 0,30655684077381 | 1.695,43 €              |
| 2064 | 106 | 0,0002817  | 10.000,00 €    | 2.816,96                | 0,29762800075127 | 838,41 €                |
| 2065 | 107 | 0,00013997 | 10.000,00 €    | 1.399,75                | 0,28895922403036 | 404,47 €                |
| 2066 | 108 | 6,7859E-05 | 10.000,00 €    | 678,59                  | 0,28054293595180 | 190,37 €                |
| 2067 | 109 | 3,21E-05   | 10.000,00 €    | 321,00                  | 0,27237178247748 | 87,43 €                 |
| 2068 | 110 | 1,4817E-05 | 10.000,00 €    | 148,17                  | 0,26443862376454 | 39,18 €                 |
| 2069 | 111 | 6,6774E-06 | 10.000,00 €    | 66,77                   | 0,25673652792674 | 17,14 €                 |
| 2070 | 112 | 2,9382E-06 | 10.000,00 €    | 29,38                   | 0,24925876497742 | 7,32 €                  |
| 2071 | 113 | 1,2624E-06 | 10.000,00 €    | 12,62                   | 0,24199880094895 | 3,05 €                  |
| 2072 | 114 | 5,2962E-07 | 10.000,00 €    | 5,30                    | 0,23495029218345 | 1,24 €                  |
| 2073 | 115 | 2,1698E-07 | 10.000,00 €    | 2,17                    | 0,22810707978975 | 0,49 €                  |
| 2074 | 116 | 8,6805E-08 | 10.000,00 €    | 0,87                    | 0,22146318426190 | 0,19 €                  |
| 2075 | 117 | 3,3914E-08 | 10.000,00 €    | 0,34                    | 0,21501280025427 | 0,07 €                  |
| 2076 | 118 | 1,2939E-08 | 10.000,00 €    | 0,13                    | 0,20875029150900 | 0,03 €                  |
| 2077 | 119 | 4,8214E-09 | 10.000,00 €    | 0,05                    | 0,20267018593107 | 0,01 €                  |
| 2078 | 120 | 0          | 10.000,00 €    | -                       | 0,19676717080686 | - €                     |
|      |     |            |                | <b>203.549.463,27 €</b> |                  | <b>149.910.087,34 €</b> |

## Appendix 5: Liabilities' valuation (Scenario B)

| Year | Age | tpx        | Annual Benefit | Expected CF   | Discount factor   | PV              |
|------|-----|------------|----------------|---------------|-------------------|-----------------|
| 2023 | 65  | 1          | 10.000,00 €    | 10.000.000,00 | 1,000000000000000 | 10.000.000,00 € |
| 2024 | 66  | 0,99220208 | 10.000,00 €    | 9.922.020,77  | 0,97087378640777  | 9.633.029,88 €  |
| 2025 | 67  | 0,98362622 | 10.000,00 €    | 9.836.262,24  | 0,94259590913375  | 9.271.620,54 €  |
| 2026 | 68  | 0,97416634 | 10.000,00 €    | 9.741.663,38  | 0,91514165935316  | 8.915.001,99 €  |
| 2027 | 69  | 0,96370405 | 10.000,00 €    | 9.637.040,49  | 0,88848704791569  | 8.562.385,66 €  |
| 2028 | 70  | 0,95210796 | 10.000,00 €    | 9.521.079,59  | 0,86260878438416  | 8.212.966,89 €  |
| 2029 | 71  | 0,93923308 | 10.000,00 €    | 9.392.330,76  | 0,83748425668365  | 7.865.929,15 €  |
| 2030 | 72  | 0,92492063 | 10.000,00 €    | 9.249.206,29  | 0,81309151134335  | 7.520.451,12 €  |
| 2031 | 73  | 0,9089984  | 10.000,00 €    | 9.089.984,03  | 0,78940923431394  | 7.175.717,33 €  |
| 2032 | 74  | 0,89128191 | 10.000,00 €    | 8.912.819,14  | 0,76641673234363  | 6.830.933,72 €  |
| 2033 | 75  | 0,87157671 | 10.000,00 €    | 8.715.767,12  | 0,74409391489673  | 6.485.349,28 €  |
| 2034 | 76  | 0,84968216 | 10.000,00 €    | 8.496.821,57  | 0,72242127659876  | 6.138.284,69 €  |
| 2035 | 77  | 0,825397   | 10.000,00 €    | 8.253.969,97  | 0,70137988019297  | 5.789.168,47 €  |
| 2036 | 78  | 0,79852718 | 10.000,00 €    | 7.985.271,81  | 0,68095133999318  | 5.437.581,54 €  |
| 2037 | 79  | 0,76889622 | 10.000,00 €    | 7.688.962,19  | 0,66111780581862  | 5.083.309,82 €  |
| 2038 | 80  | 0,73635835 | 10.000,00 €    | 7.363.583,52  | 0,64186194739672  | 4.726.404,06 €  |
| 2039 | 81  | 0,70081789 | 10.000,00 €    | 7.008.178,88  | 0,62316693922011  | 4.367.265,38 €  |
| 2040 | 82  | 0,6622419  | 10.000,00 €    | 6.622.418,99  | 0,60501644584477  | 4.006.672,40 €  |
| 2041 | 83  | 0,62067904 | 10.000,00 €    | 6.206.790,36  | 0,58739460761628  | 3.645.835,19 €  |
| 2042 | 84  | 0,57629102 | 10.000,00 €    | 5.762.910,20  | 0,57028602681193  | 3.286.507,16 €  |
| 2043 | 85  | 0,52937364 | 10.000,00 €    | 5.293.736,37  | 0,55367575418634  | 2.931.013,48 €  |
| 2044 | 86  | 0,4803648  | 10.000,00 €    | 4.803.647,98  | 0,53754927590906  | 2.582.197,49 €  |
| 2045 | 87  | 0,42987473 | 10.000,00 €    | 4.298.747,26  | 0,52189250088259  | 2.243.483,96 €  |
| 2046 | 88  | 0,37867599 | 10.000,00 €    | 3.786.759,86  | 0,50669174842970  | 1.918.719,97 €  |
| 2047 | 89  | 0,32768613 | 10.000,00 €    | 3.276.861,27  | 0,49193373633951  | 1.611.998,61 €  |
| 2048 | 90  | 0,27793019 | 10.000,00 €    | 2.779.301,89  | 0,47760556926166  | 1.327.410,06 €  |
| 2049 | 91  | 0,23048172 | 10.000,00 €    | 2.304.817,17  | 0,46369472743850  | 1.068.731,57 €  |
| 2050 | 92  | 0,18638461 | 10.000,00 €    | 1.863.846,13  | 0,45018905576554  | 839.083,13 €    |
| 2051 | 93  | 0,14656289 | 10.000,00 €    | 1.465.628,86  | 0,43707675317043  | 640.592,31 €    |

“(table continues)”

“(continued)”

|      |     |            |             |                         |                  |                         |
|------|-----|------------|-------------|-------------------------|------------------|-------------------------|
| 2052 | 94  | 0,11173022 | 10.000,00 € | 1.117.302,19            | 0,42434636230138 | 474.123,12 €            |
| 2053 | 95  | 0,08236886 | 10.000,00 € | 823.688,55              | 0,41198675951591 | 339.348,78 €            |
| 2054 | 96  | 0,0586175  | 10.000,00 € | 586.175,02              | 0,39998714516108 | 234.462,47 €            |
| 2055 | 97  | 0,04019656 | 10.000,00 € | 401.965,61              | 0,38833703413697 | 156.098,13 €            |
| 2056 | 98  | 0,0265262  | 10.000,00 € | 265.261,98              | 0,37702624673492 | 100.010,73 €            |
| 2057 | 99  | 0,01683385 | 10.000,00 € | 168.338,45              | 0,36604489974264 | 61.619,43 €             |
| 2058 | 100 | 0,01027435 | 10.000,00 € | 102.743,49              | 0,35538339780839 | 36.513,33 €             |
| 2059 | 101 | 0,00603734 | 10.000,00 € | 60.373,40               | 0,34503242505669 | 20.830,78 €             |
| 2060 | 102 | 0,00342293 | 10.000,00 € | 34.229,32               | 0,33498293694824 | 11.466,24 €             |
| 2061 | 103 | 0,00187883 | 10.000,00 € | 18.788,31               | 0,32522615237693 | 6.110,45 €              |
| 2062 | 104 | 0,00100313 | 10.000,00 € | 10.031,31               | 0,31575354599702 | 3.167,42 €              |
| 2063 | 105 | 0,00052279 | 10.000,00 € | 5.227,87                | 0,30655684077381 | 1.602,64 €              |
| 2064 | 106 | 0,00026588 | 10.000,00 € | 2.658,77                | 0,29762800075127 | 791,32 €                |
| 2065 | 107 | 0,00013197 | 10.000,00 € | 1.319,66                | 0,28895922403036 | 381,33 €                |
| 2066 | 108 | 6,393E-05  | 10.000,00 € | 639,30                  | 0,28054293595180 | 179,35 €                |
| 2067 | 109 | 3,023E-05  | 10.000,00 € | 302,30                  | 0,27237178247748 | 82,34 €                 |
| 2068 | 110 | 1,3954E-05 | 10.000,00 € | 139,54                  | 0,26443862376454 | 36,90 €                 |
| 2069 | 111 | 6,2885E-06 | 10.000,00 € | 62,89                   | 0,25673652792674 | 16,14 €                 |
| 2070 | 112 | 2,7671E-06 | 10.000,00 € | 27,67                   | 0,24925876497742 | 6,90 €                  |
| 2071 | 113 | 1,1889E-06 | 10.000,00 € | 11,89                   | 0,24199880094895 | 2,88 €                  |
| 2072 | 114 | 4,9878E-07 | 10.000,00 € | 4,99                    | 0,23495029218345 | 1,17 €                  |
| 2073 | 115 | 2,0434E-07 | 10.000,00 € | 2,04                    | 0,22810707978975 | 0,47 €                  |
| 2074 | 116 | 8,1749E-08 | 10.000,00 € | 0,82                    | 0,22146318426190 | 0,18 €                  |
| 2075 | 117 | 3,1938E-08 | 10.000,00 € | 0,32                    | 0,21501280025427 | 0,07 €                  |
| 2076 | 118 | 1,2186E-08 | 10.000,00 € | 0,12                    | 0,20875029150900 | 0,03 €                  |
| 2077 | 119 | 4,5406E-09 | 10.000,00 € | 0,05                    | 0,20267018593107 | 0,01 €                  |
| 2078 | 120 | 0          | 10.000,00 € | -                       | 0,19676717080686 | - €                     |
|      |     |            |             | <b>202.879.723,98 €</b> |                  | <b>149.564.497,45 €</b> |

# Appendix 6: NPV of Longevity Swap's payoff (Floating Leg LTR of 2%)

| Year | Age | Base tPx    | Stress tPx  | Fixed Leg       | Floating Leg    | Net Payoff  | Discount Factor | PV of Payoff |
|------|-----|-------------|-------------|-----------------|-----------------|-------------|-----------------|--------------|
| 2023 | 65  | 1           | 1           | 10.000.000,00 € | 10.000.000,00 € | - €         | 1               | 1,00 €       |
| 2024 | 66  | 0,992202639 | 0,99220292  | 9.922.026,39    | 9.922.029,20 €  | 2,81 €      | 0,97087379      | 3,78 €       |
| 2025 | 67  | 0,983629164 | 0,983630634 | 9.836.291,64    | 9.836.306,34 €  | 14,70 €     | 0,94259591      | 15,64 €      |
| 2026 | 68  | 0,974174951 | 0,974179256 | 9.741.749,51    | 9.741.792,56 €  | 43,05 €     | 0,91514166      | 43,96 €      |
| 2027 | 69  | 0,963723352 | 0,963732998 | 9.637.233,52    | 9.637.329,98 €  | 96,46 €     | 0,88848705      | 97,35 €      |
| 2028 | 70  | 0,952144965 | 0,952163452 | 9.521.449,65    | 9.521.634,52 €  | 184,88 €    | 0,86260878      | 185,74 €     |
| 2029 | 71  | 0,939297076 | 0,939329041 | 9.392.970,76    | 9.393.290,41 €  | 319,65 €    | 0,83748426      | 320,48 €     |
| 2030 | 72  | 0,925023468 | 0,925074816 | 9.250.234,68    | 9.250.748,16 €  | 513,48 €    | 0,81309151      | 514,29 €     |
| 2031 | 73  | 0,909154728 | 0,909232758 | 9.091.547,28    | 9.092.327,58 €  | 780,30 €    | 0,78940923      | 781,09 €     |
| 2032 | 74  | 0,891509352 | 0,891622845 | 8.915.093,52    | 8.916.228,45 €  | 1.134,93    | 0,76641673      | 1.135,70 €   |
| 2033 | 75  | 0,871895938 | 0,872055191 | 8.718.959,38    | 8.720.551,91 €  | 1.592,53 €  | 0,74409391      | 1.593,27 €   |
| 2034 | 76  | 0,850116791 | 0,850333568 | 8.501.167,91    | 8.503.335,68 €  | 2.167,76 €  | 0,72242128      | 2.168,48 €   |
| 2035 | 77  | 0,82597325  | 0,826260609 | 8.259.732,50    | 8.262.606,09 €  | 2.873,58 €  | 0,70137988      | 2.874,28 €   |
| 2036 | 78  | 0,799273178 | 0,799645143 | 7.992.731,78    | 7.996.451,43 €  | 3.719,65 €  | 0,68095134      | 3.720,33 €   |
| 2037 | 79  | 0,769840905 | 0,770311933 | 7.698.409,05    | 7.703.119,33 €  | 4.710,29 €  | 0,66111781      | 4.710,95 €   |
| 2038 | 80  | 0,737529905 | 0,738114114 | 7.375.299,05    | 7.381.141,14 €  | 5.842,09 €  | 0,64186195      | 5.842,73 €   |
| 2039 | 81  | 0,702254347 | 0,702970816 | 7.022.543,47    | 7.029.708,16 €  | 7.164,69 €  | 0,62316694      | 7.165,31 €   |
| 2040 | 82  | 0,663968898 | 0,664830649 | 6.639.688,98    | 6.648.306,49 €  | 8.617,51 €  | 0,60501645      | 8.618,12 €   |
| 2041 | 83  | 0,62269843  | 0,623706781 | 6.226.984,30    | 6.237.067,81 €  | 10.083,50 € | 0,58739461      | 10.084,09 €  |
| 2042 | 84  | 0,578592876 | 0,579743353 | 5.785.928,76    | 5.797.433,53 €  | 11.504,77 € | 0,57028603      | 11.505,34 €  |
| 2043 | 85  | 0,531938007 | 0,533221214 | 5.319.380,07    | 5.332.212,14 €  | 12.832,07 € | 0,55367575      | 12.832,63 €  |
| 2044 | 86  | 0,483141407 | 0,484532764 | 4.831.414,07    | 4.845.327,64 €  | 13.913,57 € | 0,53754928      | 13.914,11 €  |
| 2045 | 87  | 0,432801719 | 0,434270778 | 4.328.017,19    | 4.342.707,78 €  | 14.690,59 € | 0,5218925       | 14.691,12 €  |
| 2046 | 88  | 0,38168143  | 0,383192571 | 3.816.814,30    | 3.831.925,71 €  | 15.111,41 € | 0,50669175      | 15.111,92 €  |
| 2047 | 89  | 0,330690853 | 0,33220464  | 3.306.908,53    | 3.322.046,40 €  | 15.137,87 € | 0,49193374      | 15.138,36 €  |
| 2048 | 90  | 0,280852004 | 0,282327237 | 2.808.520,04    | 2.823.272,37 €  | 14.752,33 € | 0,47760557      | 14.752,81 €  |
| 2049 | 91  | 0,2332408   | 0,234637186 | 2.332.408,00    | 2.346.371,86 €  | 13.963,86 € | 0,46369473      | 13.964,32 €  |
| 2050 | 92  | 0,188909617 | 0,190190825 | 1.889.096,17    | 1.901.908,25 €  | 12.812,08 € | 0,45018906      | 12.812,53 €  |

“(table continues)”

“(continued)”

|      |     |             |             |                         |                         |                     |            |                     |
|------|-----|-------------|-------------|-------------------------|-------------------------|---------------------|------------|---------------------|
| 2051 | 93  | 0,148796983 | 0,149933716 | 1.487.969,83            | 1.499.337,16 €          | 11.367,33 €         | 0,43707675 | 11.367,77 €         |
| 2052 | 94  | 0,113636123 | 0,114608726 | 1.136.361,23            | 1.146.087,26 €          | 9.726,03 €          | 0,42434636 | 9.726,45 €          |
| 2053 | 95  | 0,083932477 | 0,084732894 | 839.324,77              | 847.328,94 €            | 8.004,17 €          | 0,41198676 | 8.004,58 €          |
| 2054 | 96  | 0,059848333 | 0,060480429 | 598.483,33              | 604.804,29 €            | 6.320,96 €          | 0,39998715 | 6.321,36 €          |
| 2055 | 97  | 0,041124289 | 0,041602305 | 411.242,89              | 416.023,05 €            | 4.780,17 €          | 0,38833703 | 4.780,55 €          |
| 2056 | 98  | 0,027194709 | 0,027540318 | 271.947,09              | 275.403,18 €            | 3.456,09 €          | 0,37702625 | 3.456,46 €          |
| 2057 | 99  | 0,017293933 | 0,017532582 | 172.939,33              | 175.325,82 €            | 2.386,49 €          | 0,3660449  | 2.386,85 €          |
| 2058 | 100 | 0,010576726 | 0,010734075 | 105.767,26              | 107.340,75 €            | 1.573,49 €          | 0,3553834  | 1.573,85 €          |
| 2059 | 101 | 0,006227263 | 0,006326393 | 62.272,63               | 63.263,93 €             | 991,30 €            | 0,34503243 | 991,65 €            |
| 2060 | 102 | 0,003537144 | 0,003596923 | 35.371,44               | 35.969,23 €             | 597,78 €            | 0,33498294 | 598,12 €            |
| 2061 | 103 | 0,001944795 | 0,001979404 | 19.447,95               | 19.794,04 €             | 346,09 €            | 0,32522615 | 346,42 €            |
| 2062 | 104 | 0,001039884 | 0,001059208 | 10.398,84               | 10.592,08 €             | 193,23 €            | 0,31575355 | 193,55 €            |
| 2063 | 105 | 0,000542614 | 0,000553055 | 5.426,14                | 5.530,55 €              | 104,41 €            | 0,30655684 | 104,72 €            |
| 2064 | 106 | 0,000276234 | 0,000281696 | 2.762,34                | 2.816,96 €              | 54,61 €             | 0,297628   | 54,91 €             |
| 2065 | 107 | 0,000137208 | 0,000139975 | 1.372,08                | 1.399,75 €              | 27,66 €             | 0,28895922 | 27,95 €             |
| 2066 | 108 | 6,65018E-05 | 6,78594E-05 | 665,02                  | 678,59 €                | 13,58 €             | 0,28054294 | 13,86 €             |
| 2067 | 109 | 3,14536E-05 | 3,20995E-05 | 314,54                  | 321,00 €                | 6,46 €              | 0,27237178 | 6,73 €              |
| 2068 | 110 | 1,45187E-05 | 1,48168E-05 | 145,19                  | 148,17 €                | 2,98 €              | 0,26443862 | 3,25 €              |
| 2069 | 111 | 6,54306E-06 | 6,67743E-06 | 65,43                   | 66,77 €                 | 1,34 €              | 0,25673653 | 1,60 €              |
| 2070 | 112 | 2,87909E-06 | 2,93822E-06 | 28,79                   | 29,38 €                 | 0,59 €              | 0,24925876 | 0,84 €              |
| 2071 | 113 | 1,237E-06   | 1,2624E-06  | 12,37                   | 12,62 €                 | 0,25 €              | 0,2419988  | 0,50 €              |
| 2072 | 114 | 5,18967E-07 | 5,29625E-07 | 5,19                    | 5,30 €                  | 0,11 €              | 0,23495029 | 0,34 €              |
| 2073 | 115 | 2,1261E-07  | 2,16976E-07 | 2,13                    | 2,17 €                  | 0,04 €              | 0,22810708 | 0,27 €              |
| 2074 | 116 | 8,50579E-08 | 8,68047E-08 | 0,85                    | 0,87 €                  | 0,02 €              | 0,22146318 | 0,24 €              |
| 2075 | 117 | 3,32311E-08 | 3,39135E-08 | 0,33                    | 0,34 €                  | 0,01 €              | 0,2150128  | 0,22 €              |
| 2076 | 118 | 1,2679E-08  | 1,29394E-08 | 0,13                    | 0,13 €                  | 0,00 €              | 0,20875029 | 0,21 €              |
| 2077 | 119 | 4,72436E-09 | 4,82138E-09 | 0,05                    | 0,05 €                  | 0,00 €              | 0,20267019 | 0,20 €              |
| 2078 | 120 | 0           | 0           | -                       | - €                     | - €                 | 0,19676717 | 0,20 €              |
|      |     |             |             | <b>203.324.927,66 €</b> | <b>203.549.463,27 €</b> | <b>224.535,61 €</b> |            | <b>224.563,39 €</b> |

## Appendix 7: NPV of Longevity Swap's payoff (Floating Leg LTR of 0.5%)

| Year | Age | Base tPx    | Stress tPx  | Fixed Leg       | Floating Leg    | Net Payoff    | Discount Factor | PV of Payoff  |
|------|-----|-------------|-------------|-----------------|-----------------|---------------|-----------------|---------------|
| 2023 | 65  | 1           | 1           | 10.000.000,00 € | 10.000.000,00 € | - €           | 1               | 1,00 €        |
| 2024 | 66  | 0,992202639 | 0,992202077 | 9.922.026,39    | 9.922.020,77 €  | - 5,62 €      | 0,970873786     | - 4,65 €      |
| 2025 | 67  | 0,983629164 | 0,983626224 | 9.836.291,64    | 9.836.262,24 €  | - 29,41 €     | 0,942595909     | - 28,46 €     |
| 2026 | 68  | 0,974174951 | 0,974166338 | 9.741.749,51    | 9.741.663,38 €  | - 86,13 €     | 0,915141659     | - 85,21 €     |
| 2027 | 69  | 0,963723352 | 0,963704049 | 9.637.233,52    | 9.637.040,49 €  | - 193,03 €    | 0,888487048     | - 192,14 €    |
| 2028 | 70  | 0,952144965 | 0,952107959 | 9.521.449,65    | 9.521.079,59 €  | - 370,06 €    | 0,862608784     | - 369,19 €    |
| 2029 | 71  | 0,939297076 | 0,939233076 | 9.392.970,76    | 9.392.330,76 €  | - 640,00 €    | 0,837484257     | - 639,16 €    |
| 2030 | 72  | 0,925023468 | 0,924920629 | 9.250.234,68    | 9.249.206,29 €  | - 1.028,39 €  | 0,813091511     | - 1.027,58 €  |
| 2031 | 73  | 0,909154728 | 0,908998403 | 9.091.547,28    | 9.089.984,03 €  | - 1.563,25 €  | 0,789409234     | - 1.562,46 €  |
| 2032 | 74  | 0,891509352 | 0,891281914 | 8.915.093,52    | 8.912.819,14 €  | - 2.274,38    | 0,766416732     | - 2.273,61 €  |
| 2033 | 75  | 0,871895938 | 0,871576712 | 8.718.959,38    | 8.715.767,12 €  | - 3.192,27 €  | 0,744093915     | - 3.191,52 €  |
| 2034 | 76  | 0,850116791 | 0,849682157 | 8.501.167,91    | 8.496.821,57 €  | - 4.346,34 €  | 0,722421277     | - 4.345,62 €  |
| 2035 | 77  | 0,82597325  | 0,825396997 | 8.259.732,50    | 8.253.969,97 €  | - 5.762,53 €  | 0,70137988      | - 5.761,83 €  |
| 2036 | 78  | 0,799273178 | 0,798527181 | 7.992.731,78    | 7.985.271,81 €  | - 7.459,97 €  | 0,68095134      | - 7.459,29 €  |
| 2037 | 79  | 0,769840905 | 0,768896219 | 7.698.409,05    | 7.688.962,19 €  | - 9.446,85 €  | 0,661117806     | - 9.446,19 €  |
| 2038 | 80  | 0,737529905 | 0,736358352 | 7.375.299,05    | 7.363.583,52 €  | - 11.715,53 € | 0,641861947     | - 11.714,89 € |
| 2039 | 81  | 0,702254347 | 0,700817888 | 7.022.543,47    | 7.008.178,88 €  | - 14.364,59 € | 0,623166939     | - 14.363,97 € |
| 2040 | 82  | 0,663968898 | 0,662241899 | 6.639.688,98    | 6.622.418,99 €  | - 17.269,98 € | 0,605016446     | - 17.269,38 € |
| 2041 | 83  | 0,62269843  | 0,620679036 | 6.226.984,30    | 6.206.790,36 €  | - 20.193,94 € | 0,587394608     | - 20.193,35 € |
| 2042 | 84  | 0,578592876 | 0,57629102  | 5.785.928,76    | 5.762.910,20 €  | - 23.018,55 € | 0,570286027     | - 23.017,98 € |
| 2043 | 85  | 0,531938007 | 0,529373637 | 5.319.380,07    | 5.293.736,37 €  | - 25.643,69 € | 0,553675754     | - 25.643,14 € |
| 2044 | 86  | 0,483141407 | 0,480364798 | 4.831.414,07    | 4.803.647,98 €  | - 27.766,09 € | 0,537549276     | - 27.765,55 € |
| 2045 | 87  | 0,432801719 | 0,429874726 | 4.328.017,19    | 4.298.747,26 €  | - 29.269,92 € | 0,521892501     | - 29.269,40 € |
| 2046 | 88  | 0,38168143  | 0,378675986 | 3.816.814,30    | 3.786.759,86 €  | - 30.054,44 € | 0,506691748     | - 30.053,93 € |
| 2047 | 89  | 0,330690853 | 0,327686127 | 3.306.908,53    | 3.276.861,27 €  | - 30.047,26 € | 0,491933736     | - 30.046,77 € |
| 2048 | 90  | 0,280852004 | 0,277930189 | 2.808.520,04    | 2.779.301,89 €  | - 29.218,14 € | 0,477605569     | - 29.217,67 € |
| 2049 | 91  | 0,2332408   | 0,230481717 | 2.332.408,00    | 2.304.817,17 €  | - 27.590,82 € | 0,463694727     | - 27.590,36 € |
| 2050 | 92  | 0,188909617 | 0,186384613 | 1.889.096,17    | 1.863.846,13 €  | - 25.250,04 € | 0,450189056     | - 25.249,59 € |

“(table continues)”

“(continued)”

|      |     |             |             |                         |                         |                      |             |                      |
|------|-----|-------------|-------------|-------------------------|-------------------------|----------------------|-------------|----------------------|
| 2051 | 93  | 0,148796983 | 0,146562886 | 1.487.969,83            | 1.465.628,86 €          | - 22.340,97 €        | 0,437076753 | - 22.340,53 €        |
| 2052 | 94  | 0,113636123 | 0,111730219 | 1.136.361,23            | 1.117.302,19 €          | - 19.059,04 €        | 0,424346362 | - 19.058,61 €        |
| 2053 | 95  | 0,083932477 | 0,082368855 | 839.324,77              | 823.688,55 €            | - 15.636,22 €        | 0,41198676  | - 15.635,81 €        |
| 2054 | 96  | 0,059848333 | 0,058617502 | 598.483,33              | 586.175,02 €            | - 12.308,31 €        | 0,399987145 | - 12.307,91 €        |
| 2055 | 97  | 0,041124289 | 0,040196561 | 411.242,89              | 401.965,61 €            | - 9.277,28 €         | 0,388337034 | - 9.276,89 €         |
| 2056 | 98  | 0,027194709 | 0,026526198 | 271.947,09              | 265.261,98 €            | - 6.685,11 €         | 0,377026247 | - 6.684,74 €         |
| 2057 | 99  | 0,017293933 | 0,016833845 | 172.939,33              | 168.338,45 €            | - 4.600,88 €         | 0,3660449   | - 4.600,51 €         |
| 2058 | 100 | 0,010576726 | 0,010274349 | 105.767,26              | 102.743,49 €            | - 3.023,77 €         | 0,355383398 | - 3.023,42 €         |
| 2059 | 101 | 0,006227263 | 0,00603734  | 62.272,63               | 60.373,40 €             | - 1.899,23 €         | 0,345032425 | - 1.898,88 €         |
| 2060 | 102 | 0,003537144 | 0,003422932 | 35.371,44               | 34.229,32 €             | - 1.142,12 €         | 0,334982937 | - 1.141,79 €         |
| 2061 | 103 | 0,001944795 | 0,001878831 | 19.447,95               | 18.788,31 €             | - 659,63 €           | 0,325226152 | - 659,31 €           |
| 2062 | 104 | 0,001039884 | 0,001003131 | 10.398,84               | 10.031,31 €             | - 367,53 €           | 0,315753546 | - 367,22 €           |
| 2063 | 105 | 0,000542614 | 0,000522787 | 5.426,14                | 5.227,87 €              | - 198,27 €           | 0,306556841 | - 197,96 €           |
| 2064 | 106 | 0,000276234 | 0,000265877 | 2.762,34                | 2.658,77 €              | - 103,58 €           | 0,297628001 | - 103,28 €           |
| 2065 | 107 | 0,000137208 | 0,000131966 | 1.372,08                | 1.319,66 €              | - 52,42 €            | 0,288959224 | - 52,14 €            |
| 2066 | 108 | 6,65018E-05 | 6,39299E-05 | 665,02                  | 639,30 €                | - 25,72 €            | 0,280542936 | - 25,44 €            |
| 2067 | 109 | 3,14536E-05 | 3,023E-05   | 314,54                  | 302,30 €                | - 12,24 €            | 0,272371782 | - 11,96 €            |
| 2068 | 110 | 1,45187E-05 | 1,39539E-05 | 145,19                  | 139,54 €                | - 5,65 €             | 0,264438624 | - 5,38 €             |
| 2069 | 111 | 6,54306E-06 | 6,28853E-06 | 65,43                   | 62,89 €                 | - 2,55 €             | 0,256736528 | - 2,29 €             |
| 2070 | 112 | 2,87909E-06 | 2,76709E-06 | 28,79                   | 27,67 €                 | - 1,12 €             | 0,249258765 | - 0,87 €             |
| 2071 | 113 | 1,237E-06   | 1,18888E-06 | 12,37                   | 11,89 €                 | - 0,48 €             | 0,241998801 | - 0,24 €             |
| 2072 | 114 | 5,18967E-07 | 4,98779E-07 | 5,19                    | 4,99 €                  | - 0,20 €             | 0,234950292 | 0,03 €               |
| 2073 | 115 | 2,1261E-07  | 2,0434E-07  | 2,13                    | 2,04 €                  | - 0,08 €             | 0,22810708  | 0,15 €               |
| 2074 | 116 | 8,50579E-08 | 8,17491E-08 | 0,85                    | 0,82 €                  | - 0,03 €             | 0,221463184 | 0,19 €               |
| 2075 | 117 | 3,32311E-08 | 3,19384E-08 | 0,33                    | 0,32 €                  | - 0,01 €             | 0,2150128   | 0,20 €               |
| 2076 | 118 | 1,2679E-08  | 1,21858E-08 | 0,13                    | 0,12 €                  | - 0,00 €             | 0,208750292 | 0,20 €               |
| 2077 | 119 | 4,72436E-09 | 4,54058E-09 | 0,05                    | 0,05 €                  | - 0,00 €             | 0,202670186 | 0,20 €               |
| 2078 | 120 | 0           | 0           | -                       | - €                     | - €                  | 0,196767171 | 0,20 €               |
|      |     |             |             | <b>203.324.927,66 €</b> | <b>202.879.723,98 €</b> | <b>-445.203,68 €</b> |             | <b>-445.175,91 €</b> |