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MANAGING LONGEVITY RISK IN POLISH PENSION SYSTEM WITH THE USE OF BEHAVIORAL INCENTIVES

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Abstract. The longevity risk is the risk of living longer than expected. In relation to pension systems, the concept of pension longevity is utilized. On an individual basis, the realization of longevity risk can lead to the depletion of pension savings. Group (aggregate) longevity risk – the risk that a specific age cohort will live longer than expected – is significant for public and private institutions obligated to pay lifetime annuities. The aim of this paper is to present preliminary research results on the implementation of behavioral incentives to mitigate longevity risk in the Polish pension system.

Keywords: risk management, longevity risk, pension systems, behavioral incentives.

JEL Classification: G2, J32, C18.

1. Introduction

The economic and fiscal effects of an aging society have been extensively researched and are widely acknowledged in scientific literature (Hoagland, 2016; Nerlich & Schroth, 2018; Vlandas et al., 2021), international organizations reports (Amaglobeli et al., 2020; European Commission, Directorate-General for Economic and Financial Affairs, 2021), and by policymakers. Demographic risk associated with population aging was one of the primary motivators for pension reforms in many countries, including the significant overhaul in Poland in 1999. However, the financial and economic implications of longevity risk (life expectancy risk) have garnered comparatively less focus.

Life expectancy has been increasing globally throughout the 20th century and the first two decades of the 21st century, especially in developed OECD countries. The COVID-19 pandemic temporarily reduced life expectancy in many countries, including Poland, in 2020 and 2021. However, since the pandemic's end, life expectancy has begun to rise again, with many indications suggesting this demographic trend will persist. The increase in life expectancy is generally viewed as a positive phenomenon, a result of civilization's progress, particularly in medicine – enhancing the effectiveness of preventing infectious diseases, improving preventive healthcare, promoting healthy eating, bettering material conditions, and raising education levels (Costa, 2005, p. 23). It also creates new opportunities due to the increased demand for goods and services for the elderly (silver economy). Yet, the growing number of older individuals living longer poses significant challenges, especially for pension systems, healthcare, and long-term care systems for the elderly population.

However, future trends in lifespan for different countries and demographic cohorts remain uncertain. One of the many economic and social consequences of this uncertainty is the increase in age-related risks in social security systems.

The focus of this paper is a particular risk associated with the increase in average life expectancy: the longevity risk in pension systems. Blake (2006 a) has defined the longevity risk as "the risk that individuals will outlive their retirement savings" (p. 174). Longevity risk is sometimes also referred to as life expectancy risk, age risk, or uncertainty about future life expectancy (Blake & Morales, 2017; Hull, 2015; Szczepański, 2016). Generally, it is risk that a person or a group (a demographic cohort, for example) will live longer than expected. It is one of the most significant, but often underestimated

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risk in pension schemes. The longevity risk coexists with other risk in decumulation (consumption) phase of pension systems (Gómez, 2011), such as demographic risk, inflation risk, operative risk, liquidity risk or political risk (especially tax regulations in public and private pension schemes).

The most significant impact of aging on both public and private pension systems arises not only from improvements in life expectancy and demographic structure changes (demographic risk) but particularly from the uncertainty surrounding these improvements (longevity risk). Inaccuracies or insufficiently precise estimates of demographic trends lead to both group (aggregate) longevity risk and individual longevity risk (Antolín, 2007; Bartkowiak, 2019). Even sophisticated models of mortality and longevity trends, such as the widely cited Lee-Carter model (Lee & Carter, 1992), result in unpredictable predictions by statistical offices or private financial institutions, including life insurance companies and pension funds (Blake et al., 2009; Pitacco 2009; Jajuga, 2013; Olivieri & Pitacco, n.d., Glenn, 1999).

Determining the longevity risk, or the risk of living longer than expected life expectancy, requires clarification. It is difficult to disagree with Bartkowiak's (2019) opinion that this concept might provoke resistance for linguistic reasons (p. 5). After all, a long life is commonly seen as desirable. However, there is no doubt that if an individual or a group reaches an age beyond what is expected, it may also trigger certain economic, financial, and social risks. The effects of this risk impact various stakeholder groups, including public and private institutions obligated to pay annuities, individuals living longer than expected and their families, local communities, and the state.

The longevity risk is associated with demographics and the challenges of accurately forecasting life expectancy – both for individuals and for groups, across entire demographic cohorts. Longevity risk is the converse of mortality risk: it encompasses the risk that an individual, a group of people (such as life insurance policyholders), or a demographic cohort will surpass expected lifespans.

Individual longevity risk, also known as **idiosyncratic longevity risk**, arises from the possibility that some individuals will outlive their retirement savings. Mistakes made in estimating one's own life expectancy can lead to several general consequences:

- Depletion of resources (financial, property) accumulated for old age (savings, additional pension schemes, etc.) may lead to a decreased standard of living, an inability to meet or only partially satisfy life and social needs, including healthcare, and in extreme cases, poverty in old age.
- The inability to leave a material legacy for heirs.
- The overly cautious use of savings, investments, or assets accumulated for old age, resulting in leaving excessive, larger-than-intended resources after death.

The risk of longevity, or life expectancy, is particularly significant for the elderly, especially in cases of incomplete health and other age-related limitations, affecting quality of life (Trzpiot, 2016). Aggregate longevity risk, also known as systemic longevity risk, affects entire populations. It arises when, on average, a specific cohort (demographic year) or group of insured individuals lives longer than expected. Together, individual and aggregate longevity risks contribute to the **overall longevity risk**.

Opinions vary on whether life expectancy will continue to increase. This uncertainty underlies longevity risk – the uncertainty of future life expectancy (Blake, 2006b, p. 158, Riley, 2005). Longevity risk, affecting both individuals and groups, contrasts with mortality risk, which is the risk of dying sooner than expected.

Inaccurate or imprecise forecasts of demographic trends and underestimation of survival rates, leading to the realization of aggregated longevity risk, result in increased liabilities for entities offering lifelong benefits, both public (e.g., Social Insurance Institutions (ZUS) in Poland) and private (e.g., life insurance companies, occupational pension schemes), particularly those with defined benefit plans. This issue affects both the social security system's public liabilities and the obligations of private financial institutions (Antolín, 2007; Bartkowiak, 2019).

This situation often leads to significant financial challenges for these institutions. Blake (2006b, p. 257) describes it in the following way: "If pension providers underestimate the improvement in life expectancy, the cost of providing pensions will be higher than it was anticipated, which might have been 40 years or more before pension begins to be drawn".

In the US, there have been instances where occupational pension schemes with defined benefits (based on earnings) and guaranteed lifetime benefits have gone bankrupt. Similarly, life insurance companies with annuity policies have faced bankruptcies due to longevity risk realization. Despite advanced models like the Lee-Carter model for predicting mortality and longevity trends, forecasts by statistical offices or private financial institutions, including life insurance companies and pension funds, remain prone to errors (Jajuga, 2013; Jajuga 2019, Pitacco, 2009; Olivieri & Pitacco, n.d., Outreville, 2011).

This paper examines the management of longevity risk within Poland's pension system, specifically focusing on the development of public and supplementary pension systems and their capability to address challenges posed by longevity risk. The article utilizes methods of critical literature review, description and explanation, and a comparative method. Empirical data are grounded in historical demographic statistics and life expectancy forecasts (life tables) for the Polish population, as prepared by the Polish Central Statistical Office (GUS). For international comparisons, the Human Mortality Database (HMD) and the World Health Organization (WHO) data, along with a comparative method, have been employed.

2. Historic approach to longevity

Life expectancy at birth has significantly increased over the past century. In the 1750s, it was below 40 years in Northern and Western Europe. Since around 1900, life expectancy has steadily risen, experiencing nearly linear growth, and has reached 80 years in some of the highest-performing countries, including the Nordic Countries, New Zealand, and Japan.

There are basically two schools of thought about future increase or decrease of mortality. Once based on the prediction that there is no limit to the expectancy of life. The second contends that due to biological, medicine and life style limitations, in the long term the life expectancy will only slowly increase or stall (Olshansky et al., 2005).

Oeppen and Vaupel (2002), who represent the first school, found that since the 1840s, longevity has been improving at a linear rate of three months every year. This trend has contributed to the ongoing process of demographic aging throughout the 20th and into the 21st century, as highlighted by Strulik and Volmer (2013).

The percentage of older individuals in the total population is on the rise, particularly in developed countries, where population aging is most pronounced. This trend of demographic aging persisted throughout the 20th and into the 21st century, with the elderly population growing both in absolute terms and relative to other age groups. Demographic projections indicate that by mid-century, the number of people aged 60 and over will reach 2 billion, surpassing the number of children worldwide for the first time in human history (McWilliam et al., 2019). Demographic aging, most pronounced in economically developed countries, results from two long-term trends: increasing average life expectancy and declining fertility rates.

The aging process also affects the European Union, where the elderly already constitute a significant portion of the population. As of 2018, 20.0% of the EU-27's population, approximately 89 million, was aged 60 or over, with women making up 57% and men 42%. Projections for 2060 anticipate the number of elderly in the EU-27 will increase to 131 million, with women representing 55% and men 45% of this demographic.

Over the past 50 years, life expectancy at birth has increased by 10 years for both men and women. In 2020, the average life expectancy at birth in the EU member states was 80.4 years, a slight decrease from 2019 due to the COVID-19 pandemic, with women at 83.2 years and men at 77.5 years. For those turning 65 in 2020, life expectancy was 18.1 years for men and 21.6 years for women, according to WHO 2022. This trend is detailed in Table 1.

In 2020 in Poland, the life expectancy was 72.6 years for male infants and 80.7 years for female infants (Główny Urząd Statystyczny, 2021a), showing a decline from the previous year due to COVID-19, with men experiencing a greater decrease (1.5 years) than women (1.1 years). At 60 years old, men had an expected 17.9 more years to live, while women had 23.2, as reported by the Central Statistical Office. The population structure's analysis, considering age groups and gender, provides essential data for assessing age risk level (Table 2).

Table 1. Longevity trends 1970–2010 (source: Trzpiot, 2016)

	Observed		
	1970–2010	Increase per year	Standard deviation
Change in life expectancy at birth			
US and Canada	8.2	0.20	0.11
Advanced Europe	8.6	0.21	0.13
Emerging Europe	1.1	0.03	0.36
Australia and New Zealand	10.8	0.27	0.27
Japan	10.8	0.27	0.23
Change in life expectancy at 60			
US and Canada	4.9	0.12	0.11
Advanced Europe	5.7	0.14	0.13
*Emerging Europe	0.6	0.02	0.18
Australia and New Zealand	7.2	0.18	0.23
Japan	7.7	0.19	0.19

Note: * Emerging Europe – statistics of the new European Union Members States, which joint EU since 2004.

Table 2. Amount and structure of Poland's population in 2021 (Source: Główny Urząd Statystyczny, 2021b)

Total population (in tsd.)	38 800	
By age groups	Men	Women
15–64	12 510	12 491,3
65+	2 903	4 45, 7
65–69	1130,3	1387, 4
70–74	843,6	1156,60
75–79	418,1	661, 8
80–84	283,6	552, 9
85 +	227	587, 0
Old-age dependency ratio* for the entire population (men and women combined)	38,2	
Median age (middle age)	40.4 years	43.6 years
Median age (middle age) for all population (men and women combined)	42 years	

Note: * The demographic old-age dependency ratio is defined as the number of individuals aged 65 and over per 100 people of working age defined as those aged between 20 and 64.

Comparing actual statistical data with demographic forecasts reveals discrepancies, confirming longevity risk. Korbela and Feliczkowska (2020), using the Lee-Carter model, estimated life expectancy in Poland for

2001–2018, based on data from 1958–2000 and compared it with real-world data. This analysis helped assess the forecast's accuracy for the female population in Poland, showing the variance between the forecasted values (based on demographic forecasts and mortality modelling) and the actual life expectancy figures during 2001–2018, as detailed in Table 3.

Table 3. Comparison of demographic forecast and actual observations of life expectancy in Poland for the period 2001–2018 – errors in predictions (source: Korbela & Feliczkowska, 2020)

Indicator	Error value for women	Error value for men
Mean Error (ME)	–0.91	–4.49
Mean Absolute Error (MAE)	0.931	4.49
Mean Absolute Percentage Error (MAPE)	1.1711	6.65

Explanation of indicators:

ME (Mean Error): Represents the average of all errors within a dataset, indicating an overall uncertainty in measurements. It calculates the mean difference between predicted values and actual values, providing an insight into the measurement's precision.

MAE (Mean Absolute Error): The average magnitude of errors in a set of forecasts, disregarding their direction. It is computed as the average of the absolute differences between forecasts and actual observations across a test sample, with each difference being weighted equally. This metric is useful for understanding the average error magnitude without considering error direction.

MAPE (Mean Absolute Percentage Error): Represents the average of absolute percentage errors for each time period, where errors are calculated as the absolute difference between predicted and actual values, divided by the actual values. This is a commonly used measure to assess forecast accuracy, offering a normalized perspective on the errors in terms of percentage, making it easier to interpret across different scales of data.

3. Chosen methods of longevity risk management

Individual longevity risk can be mitigated through additional pension savings and insurance products, such as life annuities. However, aggregate longevity risk, which is associated with general demographic trends (also known as trend risk), cannot be diversified and must be acknowledged as a systemic risk. Nonetheless, it is feasible to manage aggregate (group) longevity risk within smaller populations, for instance, among those insured by a life insurance company or participants of a specific private pension fund.

Hedging longevity risk is a crucial aspect of risk management for many organizations, particularly life insurance companies and defined benefit (DB) pension funds, which are committed to providing lifetime payments to their customers/participants Majewska and Trzpiot (2019). The traditional method of managing longevity risk for insurance companies involves reinsurance. However, the reinsurance market lacks sufficient capacity to absorb such risk fully. As Ceylan and Tezergil (2017) point out, "If longevity risk is neglected, this case will cause to put false financial equivalence and also will bring the institutions face to face with serious losses during their capital adequacy calculations" (p. 87). Insurance companies have their limitation in hedging longevity risk, connected with their capital adequacy requirements, specified in Solvency II Directive (The European Parliament & the Council of the European Union, 2009), and in their internal risk management procedures. In response, the capital market has introduced additional potential for hedging longevity risk, serving as a complement to the insurance market. The longevity risk transfer markets, developed in the early 21st century (Crowson et al., 2023), offer various types of transactions (refer to Table 4).

Table 4. Longevity transfer solutions (source: Own elaboration based on (Biffis & Blake, 2009 and Bartkowiak, 2011; Bartkowiak, 2019)

Insurance solutions	Capital market instruments
Pension buyouts –transfer of pension assets and liabilities as well as risks related to an insurance company *Pension buy-ins* – transfers part of the longevity risk and investment risk by mass purchase of disability insurance for participants of retirement plans. *Collective transfer of risk* from disability insurance contracts to other insurance and reinsurance undertakings	*Longevity Bond, longevity swaps, forward contracts* – instruments transferring longevity risk to other capital market entities *Life securitizations* – instruments transferring a specific group of risks from insurance companies to capital markets

The mechanism of longevity risk transfers with the use of insurance solutions are shown in Figures 1 and 2.

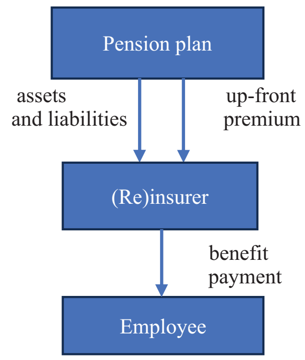

Figure 1. Structure of pension buy-out (source: Basel Committee on Banking Supervision, 2013)

Different mechanism has been applied for the pension buy-in solutions (see Figure 2).

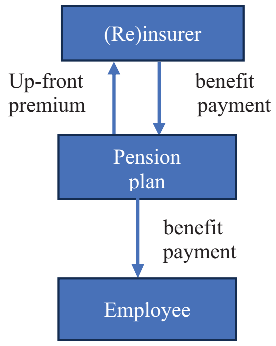

Figure 2. The Structure of pension Buy-in (source: Basel Committee on Banking Supervision, 2013, p. 6)

Despite these developments, the majority of assets and liabilities of life insurance companies and pension funds still do not utilize longevity risk hedging strategies. One of the reasons for this includes the lack of liquidity of PRT instruments, counterparty risk, and solvency challenges for insurance companies. These companies are required to report longevity risk under regulations such as Solvency II and cannot assume excessive life expectancy risk from pension funds.

4. Analysis of the pay-out phase of Polish pension system

The pension system in Poland has undergone continuous modifications aimed at enhancing its functionality. In response to demographic trends and recognizing the shortcomings of existing frameworks, a significant reform of the pay-as-you-go (PAYG) system was implemented in 1999. This year witnessed the launch of a comprehensive systemic pension reform, with one of its key goals being the distribution of risk between the financial and labor markets through the establishment of a three-pillar structure. This included the introduction of a second, capital-funded pillar and private pension funds (known as "OFE") within this framework.

A mixed PAYG-funded scheme was established as a result. In this arrangement, the first pillar, managed by the Social Insurance Institution, is financed by the current pension contributions of the working population (referred to as the generational contract). Meanwhile, the second pillar consists of pension savings from the working generations invested in the financial market. Presently, the Polish pension system is structured around three pillars (refer to Table 5).

Table 5. Current design of the Polish pension system in 2024 (source: own elaboration)

Pillar 1	Pillar 2	Pillar 3
Account in the Social Insurance Institution (ZUS)	Sub-account at the ZUS or sub-account at the ZUS and Open Pension Fund (OFE) account*	Individual Pension Account (IKE) Individual Pension Insurance Account (IKZE), Employee Pension Scheme (PPE), Employee Capital Scheme—voluntary saving accounts (PPK)**

Notes: * Participation in open pension funds (OFE) is currently voluntary.
** Employee Capital Plans (PPK) with automatic enrolment are obligatory for employers, but employees have an option to opt-out (withdraw from the program any time after the automatic enrolment).

The first and second pillars of the pension system are mandatory and funded by pension contributions from the employed, which are calculated and collected based on remuneration. Within the obligatory part of the pension system, a pension contribution amounting to 19.52% of the so-called calculation basis, namely, the gross salary, is allocated. Of this contribution, 12.22% is directed to the participant's individual account at the Social Insurance Institution (ZUS). The funds accumulated in ZUS are designated for the current disbursement of pensions under the pay-as-you-go system. The remaining 7.3% of the contribution is allocated to the second pillar -either entirely to the participant's subaccount at ZUS or divided, with 4.38% going to the subaccount at ZUS and 2.92% to the account in the Open Pension Fund (OPF). The funds in the ZUS subaccount within the second pillar undergo valorization similar to those in the first pillar, whereas the funds in the OPF are adjusted based on the rate of return from investments in the capital market (capital system).

The third pillar of the pension system is optional, aimed at accumulating additional private savings for retirement. Since the implementation of the comprehensive pension reform in 1999, this voluntary pension scheme (the third pillar) has seen limited development in Poland. A significant advancement for the third pillar occurred with the launch of company pension schemes featuring automatic enrolment – Employee Capital Plans (PPK) – in 2019. The strategy of automatically enrolling employees into the program by their employer, with the option to opt-out, proved to be an effective behavioral incentive. Contributions to PPKs are jointly financed by employees (2.0% of gross salary) and employers (1.5% of gross salary), with additional support from the state. As of now, approximately 3.4 million individuals are enrolled in PPKs, representing a participation rate of 46%.

From the perspective of managing longevity risk, the pay-out phase is of critical importance. Generally, there are three methods for disbursing pension benefits: a lump sum payment (where the entire amount of savings is paid out at once), a life annuity (a guaranteed income for life), and programmed withdrawals (where a portion of the savings is paid out and the remaining capital is reinvested). Additionally, there can be a combination of these three forms. The prevailing opinion in pension economics literature suggests that only the disbursement of benefits in the form of a life annuity effectively safeguards against longevity risk (Blake, 2006a; Panis, 2004).

The available forms of benefit payments in the Polish pension system are detailed in Table 6.

Table 6. Pay-out phase of Polish pension system (source: own elaboration)

Pillar 1	Pillar 2	Pillar 3
Life annuity (adjusted to inflation and partly to average wage increase)	Life annuity (adjusted to inflation and partly to average wage increase)	Individual Pension Account (IKE) – lump sum payment (tax-exempt from the age of 60) or programmed withdrawal Individual Pension Assurance Account IKZE) – lump sum payment (tax-exempt from the age of 605) or programmed withdrawal Employee Pension Scheme (PPE) – lump sum payment or programmed withdrawal, tax-exempt from the age of 60 Employee Capital Plan (PPK) 25% lump sum, the rest – programmed withdrawal, in at least 120 instalments (at least 10 years), tax-exempt from the age of 60

In public pension schemes, benefits are typically disbursed in the form of a life annuity. However, for savings accumulated in supplementary pension schemes, there is a broader range of payment options, though annuity payments are not commonly chosen. This phenomenon, known as the "annuity puzzle" or "annuitization puzzle," has been extensively discussed in the relevant literature (Benartzi et al., 2011; Peijnenburg et al., 2016). Similarly, in Poland, the preferred method for withdrawing savings from additional, voluntary pension systems (such as individual pension schemes – IKE and IKZE, and company pension schemes – PPE) is through a lump sum payment or programed withdrawal. As of now, benefits from the newly established occupational pension scheme – the Capital Pension Plan (PPK) – have yet to be disbursed. The PPK schemes are structured using incentives based on behavioral economics, such as default options (automatic enrolment of an employee in the pension plan by the employer and automatic allocation of contributions into life-cycle funds to reduce investment risk. During the consumption phase of pension savings, 25% of the capital accumulated in PPK can be withdrawn at once (lump sum payment), and the remainder in 120 installments.

5. Conclusions

The analysis of the current structure of the Polish pension system reveals that the public component (pillars 1st and 2nd) of the pension system provides comprehensive protection against individual longevity risk through the disbursement of retirement benefits in the form of a life annuity by the Social Insurance Institution (ZUS). Participants of additional pension schemes (3rd pillar of Polish pension system) are not protected against individual longevity risk in pay-out phase of their retirement savings Private financial institutions operating in Poland have very limited options for protection against aggregate longevity risk, primarily through reinsurance available to life insurance companies.

To enhance protection against longevity risk, it is proposed to introduce, as a default option, the disbursement of pension savings accumulated in third-pillar individual and occupational pension schemes in the form of a life annuity, with the provision for an opt-out option. To date, capital market solutions for transferring longevity risk have not been adopted. To improve on the hedging of aggregate longevity risk, the development of capital market solutions is essential. This effort necessitates the collaboration of various stakeholders, including the state as a market regulator and private financial institutions such as life insurance companies and pension funds.

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References

Antolín, P. (2007). *Longevity risk and private pensions* (OECD Working Papers on Insurance and Private Pensions No. 3) OECD Publishing. https://doi.org/10.1787/261260613084

Amaglobeli, D., Dabla-Norris, E., & Gaspar, V. (2020). Getting older but not poorer. As societies age worldwide, pensions and public must adapt. *Finance & Development*. International Monetary Fund. https://www.imf.org/en/Publications/fandd/issues/2020/03/impact-of-aging-on-pensions-and-public-policy-gaspar

Benartzi, S, Previtero A., & Thaler R. H. (2011). Annuitization puzzles. *Journal of Economic Perspectives*, *25*(4), 143–164. https://doi.org/10.1257/jep.25.4.143

Biffis, E., & Blake, D. P. (2009). Mortality-linked securities and derivatives. *SSRN*. https://doi.org/10.2139/ssrn.1340409

Bartkowiak, M. (2011). Transfer ryzyka długowieczności [The longevity risk transfer]. *Polityka Społeczna*, *3,* 22–24. https://polityka-spoleczna.ipiss.com.pl/resources/html/article/details?id=200677&language=en

Bartkowiak, M. (2019). *Modelowanie śmiertelności i transfer ryzyka długowieczności* [Mortality modeling and longevity risk transfer]. Publishing House of the Poznań University of Economics.

Basel Committee on Banking Supervision. (2013). *Longevity risk transfer markets: Market structure, growth drivers and impediments, and potential risks*. Bank for International Settlements. https://www.bis.org/publ/joint34.pdf

Blake, D. (2006a). *Pension economics*. Wiley.

Blake D. (2006b). *Pension finance*. Wiley.

Blake, D., De Waegenaere, A., Mcminn, R., & Nijman, T. (2009). *Longevity risk and capital market: The 2008–2009 update* (Discussion Paper PI-0907). Pensions Institute. http://doi.org/10.2139/ssrn.1362485

Blake, D., & Morales, M. (2017). Longevity risk and capital markets: The 2014–15 update. *Journal of Risk and Insurance*, *84*(S1), 279–297. https://doi.org/10.1111/jori.12213

Ceylan, E., Tezergil S.A. (2017). Longevity risk in life Insurance. In: N. Özataç & K. Gökmenoglu (Eds.), *New challenges in banking and finance. Springer Proceedings in Business and Economics* (pp. 87–104). Springer. https://doi.org/10.1007/978-3-319-66872-7_8

Costa, D. L. (2005). Causes of improving health and longevity at older ages: A review of the explanations. *Genus*, *61*, 21–38. https://www.jstor.org/stable/29788834

Crowson, J., van Delft, L., Manning, K., Mulder, C., Ng, F., Patel, D., Pringle, J., Silverman, S., & Sun, L. (2023). *Global pension risk transfer outlook* (Millman Report). https://us.milliman.com/-/media/milliman/pdfs/2023-articles/11-7-23_global-prt-market_risk-transfer.ashx

European Commission, Directorate-General for Economic and Financial Affairs. (2021). *The 2021 ageing report: Economic & budgetary projections for the EU Member States (2019–2070)*. Publications Office of the European Union. https://data.europa.eu/doi/10.2765/84455

Korbela, G., & Filiczkowska, J. (2020, June 23). The risk of longevity on the example of Poland. In *Proceedings of the XIV International Scientific Conference Analysis of International Relations 2020. Methods and Models of Regional Development* (pp. 108–120). Katowice, Poland. https://air.ue.katowice.pl/pdf/2020b/11_Korbela_Filiczkowska.pdf

Glenn, B. J. (1999). [Review of against the Gods: The remarkable story of risk by P. L. Bernstein] *The Journal of Risk and Insurance*, *66*(3), 517–518. https://doi.org/10.2307/253563

Gómez, T. R. (2011). *The decumulation phase: Design considerations* (Special Seminar on Annuities and Pensions) OECD. https://www.oecd.org/finance/private-pensions/48130027.pdf

Główny Urząd Statystyczny. (2021a). *Life expectancy tables of Poland* 2020. https://stat.gov.pl/en/topics/population/life-expectancy/life-expectancy-tables-of-poland-2020,2,14.html

Główny Urząd Statystyczny. (2021b). *National population and housing Census 2021 population. Size and demographic-social structure in the light of the 2021 Census results*. https://stat.gov.pl/en/national-census/national-population-and-housing-census-2021/final-results-of-the-national-population-and-housing-census-2021/size-and-demographic-social-structure-in-the-light-of-the-2021-census-results,6,1.html

Hoagland, C. W. (2016). The economic, fiscal, and financial implications of an aging society. *Generations: Journal of the American Society on Aging*, *40*(4), 16–22. https://www.jstor.org/stable/26556242

Hull, J. C. (2015). *Risk management and financial institutions* (4th ed.). Wiley.

Human Mortality Database. (n.d.). https://mortality.org

Jajuga, K. (2013). *Ryzyko modelu a miary ryzyka* [Model risk and risk measures]. *Economic Studies/ University of Economics in Katowice*, *152*, 73–81.

Jajuga, K. (2019). *Zarządzanie ryzykiem* [Risk management]. PWN Scientific Publishing House.

Lee, R. D., & Carter, L. (1992). Modelling and forecasting U.S. mortality. *Journal of the American Statistical Association*, *87*(419), 659–671. https://doi.org/10.1080/01621459.1992.10475265

Majewska, J., & Trzpiot, G. (2019). The transition in health in a population aged 65 years and over in Europe. *Communications in Statistics: Case Studies, Data Analysis and Applications*, *6*(1), 3–18. https://doi.org/10.1080/23737484.2019.1613456

McWilliam, E., Howie T., & Matt T. (Eds.). (2019). *Longevity risk* (2nd ed.). Risk Books.

Nerlich, C., & Schroth, J. (2018). The economic impact of population ageing and pension reforms. *Economic Bulletin Articles*, *2*, 85–109. https://econpapers.repec.org/article/ecbecbart/2018_3a0002_3a2.htm

Oeppen, J., & Vaupel, J. W. (2002). Broken limits of life expectancy. *Science*, *296*(5570), 1029–1031. https://doi.org/10.1126/science.1069675

Olivieri A., & Pitacco E. (n.d.). *Longevity risk in life annuities and pensions*: *Hedging or sharing?* https://actuaries.org/CTTEES_TFM/Documents/Hague_Item19_Longevity_Risk_Life_Annuities_Pensions.pdf

Olshansky S. J., Antonucci, T., Berkman, Binstock, R. Boersch-Supan, A., Cacioppo, J. Carstensen, L. L., Fried, L. P., Goldman, D. P., Jackson, J., Kohli, M., Rother, J., Zheng, Y., & Rowe, J. (2012). Differences in life expectancy due to race and educational differences are widening, and many may not catch. *Health Affairs*, *31*(8). https://doi.org/10.1377/hlthaff.2011.0746

Outreville, J. F. (2011). The Geneva risk and insurance review 2010: We have learned much since Willett and Knight. *The Geneva Papers on Risk and Insurance – Issues and Practice*, *36*(3), 476–487. https://doi.org/10.1057/gpp.2011.17

Panis, C. W. A. (2004). Annuities and retirement well-being. In O. S. Mitchel & S. P. Utkus (Eds.), *Pension design and structure: New lessons from behavioural finance* (pp. 259–274). Oxford Academic. https://doi.org/10.1093/0199273391.003.0014

Peijnenburg, K., Nijman, T., Werker, Bas J. M. (2016). The annuity puzzle remains a puzzle. *Journal of Economic Dynam-*

ics and Control, *70*, 18–35. https://doi.org/10.1016/j.jedc.2016.05.023

Pitacco, E. (2007, June 10–13). *Mortality and longevity: A risk management perspective*. In *Proceedings of the 1st International IAA Life Colloquium.* Stockholm, Sweden. University of Trieste. https://www.actuaries.org/life/events/stockholm/pitacco.pdf

Riley, J. C. (2005). Estimates of regional and global life expectancy, 1800–2001. *Population and Development Review*, *31*(3), 537–543. https://doi.org/10.1111/j.1728-4457.2005.00083.x

Strulik, H., & Vollmer, S. (2013). Long-run trends of human aging and longevity. *Journal of Population Economics*, *26*(4), 1303–1323. https://doi.org/10.1007/s00148-012-0459-z

Szczepański, M. (2016). Managing longevity risk in pension system: The case study of Poland. In M. Bilgin, H. Danis, E. Demir, & U. Can (Eds.), *Country experiences in economic development, management and entrepreneurship: Vol 5. Eurasian studies in business and economics* (pp. 705–714). Springer. https://doi.org/10.1007/978-3-319-46319-3_44

The European Parliament & the Council of the European Union. (2009). *Directive of the European Parliament and the Council of taking up and pursuit of the business of insurance and reinsurance (Solvency II)* (2009, November 25, No. 2009/138/EC). Official Journal of European Union, L *335*, (17.12.2009). https://www.academia.edu/30246200/Directive_Solva_II

Trzpiot, G. (2016). Global aging – the nature of longevity risk. *Folia Oeconomica*, *5*(325), 165–179. https://doi.org/10.18778/0208-6018.325.13

Vlandas, T., McArthur, D., & Ganslmeier, M. (2021). Ageing and the economy: A literature review of political and policy mechanisms. *Political Research Exchange*, *3*(1), Article 1932532. https://doi.org/10.1080/2474736X.2021.1932532

World Health Organization. (2022). *Ageing and health*. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health