



City Research Online

City, University of London Institutional Repository

Citation: Blake, D. & Li, J. (2024). Longevity risk and capital markets: the 2022–2023 update. *The Geneva Papers on Risk and Insurance - Issues and Practice*, 49(2), pp. 229–233. doi: 10.1057/s41288-024-00314-3

This is the accepted version of the paper.

This version of the publication may differ from the final published version.

Permanent repository link: <https://openaccess.city.ac.uk/id/eprint/33566/>

Link to published version: <https://doi.org/10.1057/s41288-024-00314-3>

Copyright: City Research Online aims to make research outputs of City, University of London available to a wider audience. Copyright and Moral Rights remain with the author(s) and/or copyright holders. URLs from City Research Online may be freely distributed and linked to.

Reuse: Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge. Provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

Longevity Risk and Capital Markets: The 2022-23 Update

David Blake and Johnny Li⁺

April 2024

The Geneva Papers on Risk and Insurance: Issues and Practice, Special Issue on Longevity Risks, April 2024, 49(2), doi.org/10.1057/s41288-024-00314-3; Supplementary materials: static-content.springer.com/esm/art%3A10.1057%2Fs41288-024-00314-3/MediaObjects/41288_2024_314_MOESM1_ESM.pdf

Abstract

We discuss the papers presented at *Longevity 17: The Seventeenth International Longevity Risk and Capital Markets Solutions Conference* that was held online on 12-13 September 2022. We also discuss 1) the development of the longevity risk transfer market since it started in 2005-06 and 2) key factors that will affect the future of the market: peak cash flows; the volatility of life expectancy trends; population aging; the aging process and anti-aging treatments; preventative health care and later life wellness; artificial intelligence, machine learning, robotics, and quantum computing; the implications of global aging for financial markets and economic growth; and climate change and sustainable development.

Key words: longevity risk transfer, capital markets

⁺ David Blake [D.Blake@city.ac.uk] is Professor of Finance and Director of the Pensions Institute, City, University of London, UK. Johnny Li [johnny.li@cuhk.edu.hk] is Tan Bingzhao Professor of Actuarial Science, The Chinese University of Hong Kong, Hong Kong. David Blake and Richard MacMinn are co-founders of the *Longevity Risk and Capital Markets Solutions Conferences*. We are extremely grateful to Marilyn Parris-Bell and Cvent for their superb organization of the conference.

Table of Contents

Longevity 1: 2005	1
Longevity 2: 2006	1
Longevity 3: 2007	2
Longevity 4: 2008	3
Longevity 5: 2009	4
Longevity 6: 2010	4
Longevity 7: 2011	4
Longevity 8: 2012	6
Longevity 9: 2013	6
Longevity 10: 2014	8
Longevity 11: 2015	10
Longevity 12: 2016	11
Longevity 13: 2017	13
Longevity 14: 2018	20
Longevity 15: 2019	24
The introduction of third-party capital.....	30
2020.....	33
Longevity risk transfers	33
The Covid-19 pandemic.....	45
Longevity 16: 2021	47
2022.....	52
2023.....	68
Securitizing mortality risk.....	87
Setbacks	88
Academic contributions	89
Looking into the future	93
Peak cash flows.....	93
The volatility of life expectancy trends	94
Population aging	97
The aging process and anti-aging treatments.....	104
Preventative health care and later life wellness	117
Artificial intelligence, machine learning, robotics and quantum computing.....	128

Implications of global aging for financial markets and economic growth	134
Climate change and sustainable development	139
The problem: climate change.....	139
The solution: sustainable development.....	144
Longevity 17: 2022	168
References	177

This Special Issue of the *Geneva Papers on Risk and Insurance* contains 9 contributions to the academic literature all dealing with longevity risk and capital markets. Draft versions of the papers were presented at *Longevity 17: The Seventeenth International Longevity Risk and Capital Markets Solutions Conference* that was held online on 12-13 September 2022. It was hosted by the University of Waterloo and the Pensions Institute at City, University of London.

Longevity risk and related capital market solutions have grown increasingly important in recent years, both in academic research and in the markets we refer to as the Life Market, i.e., the capital market that trades longevity-linked assets and liabilities.¹ Mortality improvements around the world are putting more and more pressure on governments, pension funds, life insurance companies, as well as individuals, to deal with the longevity risk they face. At the same time, capital markets can, in principle, provide vehicles to hedge longevity risk effectively and transfer the risk from those unwilling or unable to manage it to those willing to invest in this risk in exchange for appropriate risk-adjusted returns or to those who have a counterpoising risk that longevity risk can hedge, e.g., life offices and reinsurers with mortality risk on their books. Many new investment products have been created both by the insurance/reinsurance industry and by the capital markets. Mortality catastrophe bonds are an early example of a successful insurance-linked security. Some new innovative capital market solutions for transferring longevity risk include longevity (or survivor) bonds, longevity (or survivor) swaps, mortality (or q -) forward contracts and reinsurance sidecars (also called strategic reinsurance vehicles). The aim of the *International Longevity Risk and Capital Markets Solutions Conferences* is to bring together academics and practitioners from all over the world to discuss and analyze these exciting new developments.

Longevity 1: 2005

The conferences have closely followed the developments in the market. The first conference (*L1*) was held at Bayes Business School² in London in February 2005. This conference was prompted by the announcement of the Swiss Re Vita mortality catastrophe bond in December 2003 and the European Investment Bank/BNP Paribas/PartnerRe longevity bond in November 2004.

Longevity 2: 2006

The second conference (*L2*) was held in April 2006 in Chicago and hosted by the Katie School at Illinois State University.³ Since *L1*, there have been further issues of mortality catastrophe bonds, as well as the release of the Credit Suisse Longevity Index. In the UK, new life companies backed by global investment banks and private equity firms were setting up for the express purpose of buying out the defined benefit (DB) pension liabilities

¹ Blake et al. (2013).

² Formerly Cass Business School.

³ The conference proceedings for *L2* were published in the December 2006 issue of the *Journal of Risk and Insurance*.

of UK corporations.⁴ Goldman Sachs announced it was setting up such a buy-out company itself (Rothsay Life) because the issue of pension liabilities was beginning to impede its mergers and acquisitions activities. It decided that the best way of dealing with pension liabilities was to remove them altogether from the balance sheets of takeover targets. So there was firm evidence that a new global market in longevity risk transference had been established. However, as with many other economic activities, not all progress follows a smooth path. The EIB/BNP/PartnerRe longevity bond did not attract sufficient investor interest and was withdrawn in late 2005. A great deal, however, was learned from this failed issue about the conditions and requirements needed to launch a successful capital market instrument.

Longevity 3: 2007

The third conference (*L3*) was held in Taipei, Taiwan on 20-21 July 2007. It was hosted by National Chengchi University.⁵ It was decided to hold *L3* in the Far East, not only to reflect the growing importance of Asia in the global economy, but also to recognize the fact that population aging and longevity risk are problems that affect all parts of the world and that what we need is a global approach to solving these problems.⁶ Since the Chicago conference, there had been a number of new developments, including: the release of the LifeMetrics Indices covering England & Wales, the US, Holland and Germany in March 2007 by J.P. Morgan, the Pensions Institute and Towers Watson;⁷ the world's first publicly announced longevity swap between Swiss Re and the UK life office Friends Provident in April 2007 (although this was structured as an insurance or indemnification contract rather than a capital market transaction).

Since the Taiwan conference, there were further developments in the capital markets. In December 2007, Goldman Sachs launched a monthly index suitable for trading life settlements.⁸ The index, QxX.LS, was based on a pool of 46,290 anonymized US lives over the age of 65 from a database of life policy sellers assessed by the medical underwriter AVS. In 2008, Institutional Life Services (ILS) and Institutional Life Administration (ILA), a life settlements trading platform and clearing house, were launched by Goldman Sachs, Genworth Financial, and National Financial Partners. ILS and ILA were designed to modernize dealing in life settlements and meet the needs of consumers by ensuring permanent anonymity of the insured and of the capital markets by providing a central

⁴ With a buy-out, an insurance company buys out the liabilities of a pension scheme which is paid for with the pension scheme assets and a loan if the scheme is in deficit at the time. Both the pension scheme assets and liabilities are removed from the corporate sponsor's balance sheet. Each member has a personal annuity from the insurer who takes over responsibility for paying the pensions. This contrasts with a buy-in, where the liabilities remain on the sponsor's balance sheet, but the scheme buys a bulk purchase annuity (BPA) from an insurance company and pays members' pensions from the annuity payments it receives from the insurer. The BPA is an asset of the scheme, not the members. A BPA is more commonly known as a group annuity in other countries, such as the US and Canada.

⁵ The conference proceedings for *L3* were published in the Fall 2008 issue of the *Asia-Pacific Journal of Risk and Insurance*.

⁶ In fact, Asia has the world's largest and fastest growing aging population (United Nations, 2007).

⁷ www.lifemetrics.com

⁸ Life settlements are traded life policies. In April 2007, the Institutional Life Markets Association started in New York, as the dedicated institutional trade body for the life settlements industry.

clearing house for onward distribution of life settlement assets, whether individually or in structured form.⁹

Longevity 4: 2008

The fourth conference (*L4*) was held in Amsterdam on 25-26 September 2008. It was hosted by the Netspar Network for Studies on Pensions, Aging and Retirement and the Pensions Institute.¹⁰

Xpect Age and Cohort Indices were launched in March 2008 by Deutsche Börse. These indices cover, respectively, life expectancy at different ages and survival rates for given cohorts of lives in Germany and its regions, Holland and England & Wales.

The world's first capital market derivative transaction, a *q*-forward contract¹¹ between J. P. Morgan and the UK pension fund buy-out company Lucida, took place in January 2008. The world's first capital market longevity swap was executed in July 2008. Canada Life hedged £500m of its UK-based annuity book (purchased from the defunct UK life insurer Equitable Life). This was a 40-year swap customized to the insurer's longevity exposure to 125,000 annuitants. The longevity risk was fully transferred to investors, which included hedge funds and insurance-linked securities (ILS) funds. J. P. Morgan acted as the intermediary and assumed counter-party credit risk. In August 2011, ITV, the UK's largest commercial TV producer, completed a £1.7bn bespoke longevity swap with Credit Suisse for its £2.2bn pension plan: the cost of the swap is reported as £50m (3% of the swap value). The largest to date in the UK, covering £16bn of pension liabilities, was the longevity swap for the British Telecom Pension Scheme, arranged by the Prudential Insurance Co of America (PICA)¹² in July 2014. In February 2010, Mercer launched a pension buy-out index for the UK to track the cost charged by insurance companies to buy out corporate pension liabilities: at the time of launch, the cost was some 44% higher than the accounting value of the liabilities which highlighted the attraction of using cheaper alternatives, such as longevity swaps.¹³

Also in 2008, Credit Suisse initiated a longevity swap with Centurion Fund Managers, whereby Centurion acquired a portfolio of synthetic (i.e., simulated) life policies, based on a longevity index built by Credit Suisse.

⁹ In 2010, National Financial Partners became the sole owner of ILS/ILA.

¹⁰ The conference proceedings for *L4* were published in the February 2010 issue of *Insurance: Mathematics and Economics*.

¹¹ Coughlan et al. (2007).

¹² We will use PICA to refer to the US-based insurer, which is a Prudential Financial Inc. company, as well as Prudential Retirement and Prudential Retirement Insurance and Annuity Company (PRIAC).

¹³ The Index tracks the relationship between the accounting liability for retirees of a defined benefit pension plan and two cost measures: the estimated cost of transferring the pension liabilities to an insurance company (i.e., a buy-out) and the approximate total economic cost of retaining the pension obligations on the balance sheet.

Longevity 5: 2009

The fifth conference (*L5*) was held in New York on 25-26 September 2009.¹⁴

In 2009, survivor swaps began to be offered to the market based on Deutsche Börse's Xpect Cohort Indices.

Longevity 6: 2010

The sixth conference (*L6*) was held in Sydney on 9-10 September 2010.¹⁵

On 1 February 2010, the Life and Longevity Markets Association (LLMA) was established in London. Its members were Aviva, AXA, Deutsche Bank, J.P. Morgan, Morgan Stanley, Prudential (UK) PLC, and Swiss Re. LLMA was formed to promote the development of a liquid market in longevity- and mortality-related risks. This market is related to the ILS market and is also similar to other markets with trend risks, e.g., the market in inflation-linked securities and derivatives. LLMA aims to support the development of consistent standards, methodologies and benchmarks to help build a liquid trading market needed to support the future demand for longevity protection by insurers and pension funds. In April 2011, the LifeMetrics indices were transferred to LLMA with the aim of establishing a global benchmark for trading longevity and mortality risk.

In December 2010, building on its successful mortality catastrophe bonds and taking into account the lessons learned from the EIB bond, Swiss Re launched a series of eight-year longevity-based ILS notes valued at \$50m. To do this, it used a special purpose vehicle, Kortis Capital, based in the Cayman Islands. As with the mortality bonds, the longevity notes are designed to hedge Swiss Re's own exposure to mortality and longevity risk. In particular, holders of the notes were exposed to an increase in the spread between mortality improvements in 75-85-year-old English & Welsh males and 55-65-year-old US males, indicating that Swiss Re has life insurance (mortality risk) exposure in the US and pension (longevity risk) exposure in the UK.

Longevity 7: 2011

The seventh conference (*L7*) was held at the House of Finance, Goethe University, Frankfurt, Germany on 8-9 September 2011.¹⁶

In January 2011, the Irish government announced that it would issue bonds that allow the creation of sovereign annuities.¹⁷ This followed a request from the Irish Association of

¹⁴ The conference proceedings for *L5* were published in the *North American Actuarial Journal* (Volume 15, Number 2, 2011).

¹⁵ The conference proceedings for *L6* were published in the October 2011 issue of *Geneva Papers on Risk and Insurance - Issues and Practice*.

¹⁶ The conference proceedings for *L7* were published in the September 2013 issue of the *Journal of Risk and Insurance*.

¹⁷ A sovereign annuity, introduced by the 2011 Social Welfare and Pensions Act, is an annuity contract issued by insurance companies where the annual income payment is linked directly to payments under

Pension Funds and the Society of Actuaries in Ireland. If the bonds are purchased by Irish pension funds, this will have a beneficial effect on the way in which the Irish funding standard values pension liabilities. On account of a statutory deadline to submit a deficit repair plan, 2013 was a record year for bulk annuity transactions in Ireland with sovereign annuities being used in a significant number of transactions.

The world's first longevity swap for non-pensioners (i.e., for active and deferred members of a pension plan) took place in January 2011, when J. P. Morgan executed a £70m 10-year *q*-forward contract with the Pall (UK) pension fund. This was a value swap designed to hedge the longevity risk in the value of Pall's pension liabilities, rather than the longevity risk in its pension payments as in the case of cash flow swaps which have been the majority of the swaps that had so far taken place. Longevity risk prior to retirement is all valuation risk: there is no cash flow risk and most of the risk lies in the forecasts of mortality improvements. Further, the longevity exposure of deferreds is not well defined as a result of the options that plan members have, e.g., lump sum commutation options, early retirement options, and the options to increase spouses' benefits at the expense of members' benefits.

In April 2011, the International Society of Life Settlement Professionals (ISLSP)¹⁸ formed a life settlement and derivatives committee and announced that it was developing a life settlement index. The purpose of the index was to benchmark net asset values in life settlements trading. Investors need a reliable benchmark to measure performance and the index will help turn US life insurance policies into a tradable asset class according to ISLSP. The calculation agent for the index was AA Partners.

The first pension risk transfers deals outside the UK took place in 2009-11. The first buy-in deal outside the UK took place in 2009 in Canada; it was arranged by Sun Life Financial and valued at C\$50m. The first buy-in deal in Europe took place in December 2010 between the Dutch food manufacturer Hero and the Dutch insurer Aegon (€44m). The first buy-in deal in the US took place in May 2011 between Hickory Springs Manufacturing Company and PICA (\$75m). The first buy-out deal outside the UK was announced in May 2011 and involved the C\$2.5bn Nortel pension plan in Canada. In September 2011, CAMRADATA Analytical Services launched a new pension risk transfer (PRT) database for US pension plans. The database provides insurance company organizational information, pension buy-in and buy-out product fact sheets and screening tools, pricing data, up-to-date information on each PRT provider's financial strength and relevant industry research. Users can request pension buy-in and buy-out quotes directly from providers, including American General Life Companies, MetLife, Pacific Life, Principal Financial Group, PICA, Transamerica and United of Omaha.

bonds issued by Ireland or any other EU member state (known as reference bonds). The payments can be reduced if there is an event of non-performance in relation to the bonds to which the annuity is referenced. This contrasts with a standard annuity where the insurer guarantees to make the agreed payments for the lifetime of the annuitant.

¹⁸ www.islsp.org

The first international longevity reinsurance¹⁹ transaction took place in June 2011 between Rothesay Life (UK) and PICA and was valued at £100m. The first life book reinsurance swap since the 2007-08 Global Financial Crisis took place in June 2011 between Atlanticlux and institutional investors and was valued at €60m.

Longevity 8: 2012

The eighth conference (*L8*) was held at the University of Waterloo, Ontario, Canada on 7-8 September 2012.²⁰

In February 2012, Deutsche Bank executed a massive €12bn index-based longevity swap for Aegon in the Netherlands. This solution was based on Dutch population data and enabled Aegon to hedge the liabilities associated with a portion of its annuity book. Because the swap²¹ was out of the money, the notional amount of longevity risk transferred (€300mn) was far less than that suggested by the headline €12bn figure. Nonetheless, the key driver for this transaction from Aegon's point of view was the reduction in economic capital it hoped to achieve. Most of the longevity risk was passed on to capital markets investors in the form of private bonds and swaps. The duration of the hedge was 10 years.

In June 2012, General Motors Co. (GM) in the US announced a huge deal to transfer up to \$26bn of pension obligations to PICA. This is by far the largest ever longevity risk transfer deal globally. The transaction is effectively a partial pension buy-out involving the purchase of a group annuity contract for GM's salaried retirees who retired before 1 December 2011 and refused a lump sum offer in 2012. To the extent retirees accepted a lump sum payment in lieu of future pension payments, the longevity risk was transferred directly to the retiree.²² The deal was classified as a partial buy-out rather than a buy-in because it involved the settlement of the obligation. In other words, the portion of the liabilities associated with the annuity contract will no longer be GM's obligation. Moreover, in contrast to a buy-in, the annuity contract will not be an asset of the pension plan, but instead an asset of the retirees. In October 2012, GM did a \$3.6bn buy-out of the pension obligations of its white-collar retirees. Also in October 2012, Verizon Communications executed a \$7.5bn bulk annuity buy-in with PICA. The buy-out deals in the US in 2012 amounted to \$36bn.

Longevity 9: 2013

The ninth conference (*L9*) was held in Beijing, China on 6-7 September 2013.²³

¹⁹ The insurance industry's name for a longevity swap.

²⁰ The conference proceedings for *L8* were published in the *North American Actuarial Journal* (Volume 18(1), 2014).

²¹ It is structured as a bull call option spread – see Michaelson and Mullholland (2014).

²² In fact, the lump sum was only being offered to limited cohorts of plan members.

²³ The conference proceedings for *L9* were published in July 2015 in *Insurance: Mathematics and Economics* 63(C): 1-203.

The first £1bn+ PRT in the UK took place in July 2013, when Citigroup executed a £1.5bn buy-out for its EMI Group Pension Fund with Pension Insurance Corporation (PIC), a specialist UK buy-out insurer, covering all 20,000 members.²⁴

In February 2013, the first medically underwritten bulk annuity (MUBA) transaction was executed in the UK by the UK insurer Partnership.²⁵ This involved each member filling in a medical questionnaire in order to get a more accurate assessment of their life expectancy based on their medical history or lifestyle. This was particularly useful in the case of ‘top slicing’, where scheme trustees insure the pensioners (who will typically be the company directors) with the largest liabilities and who therefore represent a disproportionate risk concentration for the scheme. In December 2014, Partnership executed a £206m medically underwritten bulk annuity transaction with a ‘top slicing’ arrangement for the £2bn Taylor Wimpey pension scheme. UK insurer Legal & General (L&G) transacted a £230m medically-underwritten buy-in in December 2015. The process of collecting medical information has been streamlined in recent years using third-party medical data collectors, such as MorganAsh, Age Partnership and Aon’s AHEAD platform. It is expected that the share of medically underwritten de-risking deals will increase significantly over the next few years in the UK, with new business more than doubling from £540m in 2014 to £1,200m in 2015.²⁶

In April 2013, L&G reported its first non-UK deal, the buy-out of a €136m annuity book from New Ireland Life. In June 2013, the Canadian Wheat Board executed a C\$150m pension buy-in from Sun Life of Canada, involving inflation-linked annuities, while in March 2014, an unnamed Canadian company purchased C\$500m of annuities from an insurer (reported to be Industrial Alliance), making it the largest ever Canadian pension risk transfer deal to date.

In August 2013, Numerix, a risk management and derivatives valuation company, introduced a new asset class called ‘life’ on its risk modeling platform (in addition to equities, bonds and commodities). In November 2013, SPX Corp. of Charlotte, NC, purchased a buy-out contract with Massachusetts Mutual Life Insurance Co. (MassMutual) as part of a deal that moved \$800m in pension obligations off SPX’s balance sheet.

In September 2013, UK consultant Barnett Waddingham launched an insurer financial strength review service which provides information on an insurer’s structure, solvency position, credit rating, and key risks in their business model. This service was introduced in response to concerns about the financial strength of some buy-out insurers.

In November 2013, Deutsche Bank introduced the Longevity Experience Option (LEO). It is structured as an out-of-the-money call option spread on 10-year forward survival rates and has a 10-year maturity. The survival rates will be based on males and females in five-year age cohorts (between 50 to 79) derived from the England & Wales and Netherlands

²⁴ <https://www.professionalpensions.com/news/2280322/emi-scheme-agrees-recordbreaking-gbp15bn-buyout>

²⁵ Harrison and Blake (2013).

²⁶ Hunt and Blake (2016).

LLMA longevity indices. LEOs will be traded over-the-counter under a standard ISDA²⁷ contract. They allow longevity risk to be transferred between pension funds, insurance companies and investors. They are intended to provide a cheaper and more liquid alternative to bespoke longevity swaps which are generally costly and time consuming to implement. Purchasers of the option spread, such as a pension fund, will gain if realized survival rates are higher than the forward rates, but the gains will be limited, thereby providing some comfort to the investors providing the longevity hedge. The 10-year maturity is the maximum that Deutsche Bank believes investors will tolerate in the current stage in the development of a market in longevity risk transfers. It was reported that Deutsche Bank executed its first LEO transaction with an ILS fund in January 2014.

In December 2013, Aegon executed a second risk transfer to capital markets investors and reinsurers, including SCOR. The €1.4bn index-based hedge involved Dutch longevity risk and US mortality risk, had a notional value of €200m and a duration of 20 years. Société Générale was the intermediary in the deal and Risk Management Solutions (RMS) was the modelling agent.

Also in December 2013, the Joint Forum reported on the results of its consultation on the longevity risk transfer market. It concluded that this market is not yet big enough to raise systemic concerns, but ‘their massive potential size and growing interest from investment banks to mobilize this risk make it important to ensure that these markets are safe, both on a prudential and systemic level’ (Joint Forum (2013, p.2)).

Longevity 10: 2014

The tenth conference (*L10*) was held at Universidad Diego Portales in Santiago, Chile on 3-4 September 2014.²⁸

In February 2014, the Mercer Global Pension Buy-out Index was introduced. It shows the benchmark prices of 18 independent third-party insurers in the four countries with the greatest interest in buying out DB liabilities: UK, US, Canada and Ireland. Costs were highest in the UK where the cost of insuring £100m of pension liabilities was 123% of the accounting value of the liabilities – equivalent to £32 per £1 p.a. of pension.²⁹ The comparable costs in Ireland, the U.S. and Canada were 117%, 108.5% and 105%, respectively. The higher cost in the UK is in part due to the greater degree of inflation uprating in the UK compared with the other countries. The difference between the US and Canada is explained by the use of different mortality tables. Rising interest rates and equity markets will lower funding deficits and hence lead to lower buy-out costs in future, especially in the US.

In March 2014, L&G announced the biggest single buy-out in the UK to date when it took on £3bn of assets and liabilities from ICI’s pension fund, a subsidiary of AkzoNobel. In

²⁷ International Swaps and Derivatives Association; <https://www.isda.org/>

²⁸ The conference proceedings for L10 were published in the *Journal of Risk and Insurance*, Volume 84, Number S1, April 2017, 273-532.

²⁹ Towers Watson (2015) *Corporate Briefing*, April.

December 2014, L&G announced the largest ever UK buy-in valued at £2.5bn with US manufacturer TRW. Around £13bn of bulk annuity deals were executed in the UK in 2014, the largest volume of business since the de-risking market began in 2006 and beating the previous best year of 2008, just before the Global Financial Crisis, when £7.9bn of deals were completed. The total volume of de-risking deals in the UK in 2014 (covering buy-outs, buy-ins and longevity swaps) was £35bn, a significant proportion of which is accounted for by the £16bn BT longevity swap.

In July 2014, Mercer and Zurich launched Streamlined Longevity Solution, a longevity swap hedge for smaller pension schemes with liabilities above £50m. This is part of a new Mercer SmartDB service which provides bespoke longevity de-risking solutions and involves a panel of reinsurers led by Zurich. It reduces the costs by having standardized processes for quantifying the longevity risk in each pension scheme. The first deal, valued at £90m, was transacted with an unnamed UK pension scheme in December 2015.

In August 2014, the Dutch insurer Delta Lloyd executed a six-year index-based longevity hedge with Reinsurance Group of America (RGA Re) with a notional value of €300m and providing partial cover on €12bn of liabilities.³⁰

In November 2014, the Longevity Basis Risk Working Group (2014) of the Institute and Faculty of Actuaries (IFoA) and LLMA published ‘Longevity Basis Risk: A Methodology for Assessing Basis Risk’. This study develops a new framework for insurers and pension schemes to assess longevity basis risk.³¹ This, in turn, will enable simpler, more standardized and easier to execute index-based longevity swaps to be implemented. Index-based longevity swaps allow insurers and pension schemes to offset the systematic risk of increased liabilities resulting from members living longer than expected. It had hitherto been difficult to assess how effectively an index-based longevity swap could reduce the longevity risk in a particular insurance book or pension scheme. The methodology developed in the report is applicable to both large schemes (which are able to use their own data in their models) and smaller schemes (by capturing demographic differences such as socio-economic class and deprivation).

In December 2014, Towers Watson launched Longevity Direct, an off-shore longevity swap hedging service that gives medium-sized pension schemes with liabilities between £1-3bn direct access to the reinsurance market, via its own cell (or captive) insurance company. This allows schemes to bypass insurers and investment banks, the traditional de-risking intermediaries, and significantly reduces transactions costs and completion times, while still getting the best possible reinsurance pricing. The first reported transaction on

³⁰ <https://www.bloomberg.com/news/articles/2014-08-22/delta-lloyd-completes-16-billion-longevity-swap-with-rga>

³¹ According to the Institute and Faculty of Actuaries: ‘Longevity basis risk arises because different populations, or subpopulations, will inevitably experience different longevity outcomes. This is a significant issue for those wishing to hedge longevity risk using a published mortality index – whether they be pension schemes, insurers, reinsurers, or banks’. The IFoA and Life and Longevity Markets Association have developed a readily-applicable methodology for quantifying the basis risk arising from the use of population-based mortality indices for managing longevity risk; <https://www.actuaries.org.uk/learn-and-develop/research-and-knowledge/actuarial-research-centre-arc/recent-research/longevity-basis-risk>

the Longevity Direct platform was the £1.5bn longevity swap executed by the Merchant Navy Officers Pension Fund (MNOF) in January 2015 which was insured by MNOF IC, a newly established cell insurance company based in the Channel Island of Guernsey, and then reinsured with Pacific Life Re. In February 2015, PwC launched a similar off-shore longevity swap service for pension schemes as small as £250m. It used a Guernsey-based incorporated cell company called Iccaria, established by Artex Risk Solutions, to pass longevity risk directly on to reinsurers. The arrangement is fully collateralized and each scheme owns a cell within Iccaria which again avoids the costs of dealing with insurer and investment bank intermediaries.

There is increasing demand from reinsurance companies for exposure to large books of pension annuity business to offset the risk in their books of life insurance.³² For example, in 2014, Warren Buffett's Berkshire Hathaway agreed to a £780m quota-reinsurance deal with PIC.³³ Similarly, in August 2014, AXA France executed a €750m longevity swap with Hannover Re.

Longevity 11: 2015

The eleventh conference (*L11*) was hosted by Université Lyon 1, Lyon, France on 7-8 September 2015.³⁴

In March 2015, the UK government announced that it would introduce a new competitive corporate tax structure to allow ILS to be domiciled in the UK and the associated Risk Transformation Regulations 2017, creating a new regulated activity of insurance risk transformation, came into effect in December 2017. In May 2015, Rothesay Life, the insurance company owned by Goldman Sachs, bought out the liabilities of Lehman Brothers' UK pension scheme for £675m, thereby securing the pensions of former employees of the company associated with the beginning of the Global Financial Crisis. In April 2016, Rothesay bought two-thirds of Aegon's UK annuity book – representing 187,000 policy holders – for £6bn, bringing total assets under management to £20bn and total lives assured to over 400,000. This was the first substantial annuity transfer since the introduction of Solvency II³⁵ in January 2016. This new solvency regime for EU-based insurers increased capital requirements and has reduced the attractiveness of annuities as a business line for certain insurers and raised buy-out prices by 5-7%.³⁶

In 2015, L&G entered both the US and European pension risk transfer markets. It executed a \$450m transaction with the US subsidiary of Royal Philips covering 7,000 scheme

³² The key risk in life books, mortality risk (the risk that life policy holders die sooner than expected, so payouts are made before sufficient premiums have been collected), can be offset (at least partially) by assuming the longevity risk in annuity books (the risk that annuitants live longer than expected). If there is an unanticipated reduction in life expectancy, the increased payouts on the life book are offset by the reduced payouts on the annuity book, and vice versa. This is known as a 'natural hedge'.

³³ Reported in *Financial News*, 14 July 2014.

³⁴ The conference proceedings for *L11* were published in *Insurance: Mathematics and Economics*, 78 (2018), 157–380.

³⁵ https://www.eiopa.europa.eu/browse/solvency-2_en and https://en.wikipedia.org/wiki/Solvency_II

³⁶ *Financial News*, 28 March–3 April 2016.

members in October and a €200m deal with ASR Nederland NV, a Dutch insurer in December. The pension obligations were transferred to L&G Re in cooperation with Hannover Re. L&G said: ‘The pension risk transfer market has become a global business... The potential market for pension risk transfer in the US, UK and Europe is huge, and will play out over many decades’. Two US insurers were also involved in the Royal Philips deal: PICA also acquired \$450m of scheme liabilities covering another 7,000 members, while American United Life Insurance Company issued annuity contracts to 3,000 deferred scheme members, valued at \$200m.

In January 2015, the Bell Canada Pension Plan executed a C\$5bn longevity swap with Sun Life Financial,³⁷ SCOR, and RGA Re; it was SCOR’s first transaction in North America. In the process, Canada became the first country apart from the UK to have all three pension risk transfer solutions actively in use. In the same year, it completed its first inflation-linked buy-in annuity transaction, while in 2017, it completed its first buy-in annuity covering active future benefits.³⁸ In June 2015, Delta Lloyd did a second €12bn longevity swap with RGA Re: the swap was also index-based, with an 8-year duration and had a notional value of €350m.³⁹ In July 2015, Aegon executed one valued at €6bn with Canada Life Re, a new entrant to the de-risking market in 2015. Another new entrant was Scottish Widows.

In June 2015, the Mercer Pension Risk Exchange was launched. It gives clients in the US, UK and Canada up-to-date buy-in and buy-out pricing based on their plan’s data. It collects prices provided monthly by insurers in the bulk market, based on plan benefit structures and member data. Mercer said: ‘Many companies have the appetite to transfer pension risk off their balance sheet, but they face barriers: lack of clear information about the true cost of a buy-in or buy-out, limited transparency, the fluctuation of market rates and plan economics to name but a few. [The exchange will enable] sponsoring employers and trustees to be more strategic and sophisticated in their approach and to know that they are executing a buy-in or a buy-out at the best time for them and at a competitive price’.

Longevity 12: 2016

The twelfth conference (*L12*) was held in Chicago on 29-30 September 2016 and hosted by the Society of Actuaries and the Pensions Institute.⁴⁰

In April 2016, Willis Towers Watson (WTW⁴¹) released PulseModel which uses medical science and the opinions of medical experts to improve longevity predictions. For example, the model predicts that 16% of 50-year-old men in the UK will develop type-2 diabetes in the next 20 years, but this rises to 50% for those who are both obese and heavy smokers. Overall, the model predicts that longevity improvements in the future will be lower than

³⁷ Sun Life Financial uses the RMS Longevity Risk Model, which RMS describes as a ‘structural meta-model of geroscience advancement’.

³⁸ Eckler Consultants (2017) *Pension Risk Transfer Report*, November.

³⁹ <http://www.artemis.bm/blog/2015/06/26/delta-lloyd-rga-in-second-e12-billion-longevity-swap-deal/>

⁴⁰ The conference proceedings for *L12* were published in volume 25(S1) of the *North American Actuarial Journal* in 2021.

⁴¹ The Willis Group and Towers Watson merged in 2016 to form WTW.

currently predicted, at around 1% p.a. rather than 1.5%. If this turned out to be correct, then the current price of longevity of risk transfer products would be overestimated.

The largest buy-in in 2016 (in December) was Phoenix Life's £1.2bn buy-in for the 4,400 pensioners in the PGL Pension Scheme, which is sponsored by the Phoenix Group, Phoenix Life's parent company. This replaced a longevity swap that it had set up for the plan in 2014. This is the first example of a transaction which transforms a longevity swap into a bulk annuity. Phoenix Life saw this as an opportunity to bring £1.2bn of liquid assets (mostly UK government bonds) onto its balance sheet, which could then be swapped into a higher yielding, matching portfolio, structured to maximize the capital benefit under Solvency II. This, in turn, meant that Phoenix Life would be assuming the market risks associated with the PGL scheme pension liabilities in addition to the longevity risks – and already does this on its existing book of individual annuities which are backed by £12bn of assets. The timing was also critical. Phoenix wanted to ensure that its internal model under Solvency II had bedded down well and that the capital and balance sheet impacts of the transaction were well understood, and that Phoenix had elicited the full support of the UK Prudential Regulation Authority (PRA)⁴² for the transaction, thereby ensuring execution certainty. Phoenix also provided comfort to the plan's trustees by giving them 'all-risks' cover from point of buy-in ('all-risks' cover is not usually provided until buy-out) and strong collateral protection.⁴³

2016 saw the beginning of a trend towards consolidation amongst insurance companies involved in the longevity risk transfer business in the UK. In April 2016, the two largest UK medical underwriters, Partnership and Just Retirement merged to form the Just Group valued at £16bn. Aegon sold its £9bn UK annuity portfolio to Rothesay Life and L&G between April and May, as part of a strategy to free up capital from non-core businesses. Part of the reason for this is the additional capital requirements under Solvency II. In September, Deutsche Bank sold its Abbey Life subsidiary to Phoenix Life – a consolidator of closed insurance books – for £935m, as part of a planned program of disposals aimed at restoring its capital base. There is an estimated £100bn of UK individual annuities in back books and further consolidation of these back books is anticipated. In December 2017, L&G sold its £33bn closed book of traditional insurance-based pensions, savings and investment policies to the ReAssure division of Swiss Re for £650m.

Solvency II has also been blamed for some companies pulling out of the bulk annuities market altogether, a key example being Prudential (UK) in January 2016. Prudential (UK) announced it would be selling a portion of its £45bn UK annuity and pension liability businesses due to an inadequate return on capital and to transfer that capital to its growing businesses in the Far East.⁴⁴ Reinsurance deals have also increased in response to Solvency II, involving non-EU reinsurers. For example, PIC executed a £1.6bn longevity reinsurance agreement with PICA in June 2016.

⁴² This is the regulatory authority for insurance companies in the UK.

⁴³ Stephanie Baxter (2017) How PGL's longevity swap was converted into a buy-in, *Professional Pensions*, 10 April.

⁴⁴ <https://www.ftadviser.com/pensions/2016/12/05/prudential-seeks-buyers-for-45bn-annuity-business/>

2016 also witnessed the increasing streamlining and standardization of contracts. This is particularly beneficial to small plans below £100m. Previously, smaller plans have been less attractive to insurers due to the higher costs of arranging such deals relative to the profit earned. To circumvent this, consultants have begun offering services that allow smaller plans to access improved pricing and better commercial terms using a standardized off-the-shelf process incorporating pre-negotiated legal contracts. Pricing is more competitive because the insurer's costs are kept low. An example is WTW's Streamlined Bulk Annuity Service. The increasing maturity of the market has meant that some larger plans have also been prepared to use pre-negotiated contracts.

2016 was also the tenth anniversary of the longevity transfer market. Since its beginning in the UK in 2006, £40bn of buy-outs and £31bn of buy-ins have taken place in the UK, covering one million people.⁴⁵ Yet this equates to just 5% of the £1.5trn of UK DB pension assets and 3% of the £2.7trn of DB pension liabilities on a buy-out basis in 2016. In addition, forty eight longevity swaps are known to have been completed in the United Kingdom between 2007 and 2016, valued at £75bn and covering 13 insurance companies' annuity and buy-out books, 22 private sector pension funds, and one local authority pension fund (some of which executed more than one swap).⁴⁶

Longevity 13: 2017

The thirteenth conference (*L13*) was held in Taipei, Taiwan on 21-22 September 2017. It was hosted by the Department of Risk Management and Insurance and the Risk and Insurance Research Center at National Chengchi University, and by the Pensions Institute.⁴⁷

At the beginning of 2017, there were eight UK-domiciled insurers actively participating in the pension risk transfer market in the UK. The largest players were PIC and L&G, with market shares of 37% and 30%, respectively. The others were Rothesay Life, Canada Life, Zurich, Scottish Widows, Standard Life, and new entrant Phoenix (since August). Occasionally, the insurers co-operate in a transaction. To illustrate, in August 2017, L&G executed a longevity swap in respect of £800m of the pension liabilities of Scottish and Southern Energy (SSE), while PIC completed a £350m buy-in for the company. Consultant LCP estimated that £12bn buy-ins and buy-outs took place in 2017 and £19bn took place in 2018, with total insurer capacity at £25bn: 'There remains significant capacity and competition – even if a large back-book comes to market – providing attractive opportunities for pension plans to transfer longevity risk through a buy-in or buy-out'.⁴⁸

One of the largest deals in 2017 (in September) involved a £3.4bn longevity swap between the Marsh & McLennan Companies (MMC) UK Pension Fund and both Canada Life Re

⁴⁵ LCP, *Professional Pensions* (15 December 2016 and 26 January 2017). Since 2007, some 92 buy-ins have been completed.

⁴⁶ www.artemis.bm/library/longevity_swaps_risk_transfers.html.

⁴⁷ The conference proceedings for *L13* were published in volume 25(S1) of the *North American Actuarial Journal* in 2021.

⁴⁸ <https://www.lcp.uk.com/media-centre/press-releases/2017/08/buy-in-and-buy-out-volumes-nearly-double>; LCP (2018) *Pension De-risking 2018*.

and PICA, using Guernsey-based incorporated cell companies, Fission Alpha IC Limited and Fission Beta IC Limited. MMC subsidiary Mercer led the transaction as adviser to the pension fund trustee and the deal was the first to be completed using the Mercer Marsh longevity captive solution, with no upfront premium. The two reinsurers shared the risk equally and the use of the captive ICC vehicle meant that no insurer intermediary was required, making the deal more cost-effective for the pension fund.⁴⁹ Also in September, the British Airways' Airways Pension Scheme used a similar Guernsey-based captive insurer to set up a £1.7bn longevity swap. The longevity risk was then reinsured with Partner Re and Canada Life Re. The scheme had previously hedged £2.6bn of liabilities through two longevity swap transactions executed by Rothesay Life in 2010 and 2011.⁵⁰ In November 2017, PIC executed a £900m longevity swap with PICA, while in December 2017, L&G executed a £600m longevity swap with PICA.⁵¹

In December 2017, NN Life, part of the Nationale-Nederlanden Group, the largest Dutch insurance company, executed an index-based longevity hedge with reinsurer Hannover Re, in a deal covering the insurer against the longevity trend risk in €3bn of its liabilities (the notional value was €100m). The intermediary was Longitude Solutions, run by Avery Michaelson and David Schrager. The hedge structure is similar to the 2013 Aegon tail-risk deal arranged by Société Générale and builds on subsequent work including Michaelson and Mulholland (2014) and Cairns and El Boukfaoui (2021). While the term of the transaction is 20 years, NN Life is protected over a longer time period via a commutation function⁵² that applies at maturity. If longevity improvements have been much stronger than expected, this will be assumed to continue until the liabilities run-off and NN will receive a payment under the hedge. The transaction helped to reduce the solvency capital requirement of NN's Netherlands life business by €35m. The index attachment point for the hedge is close to NN's best estimate, which helps maintain the SCR (Solvency Capital Requirement)⁵³ relief and effective risk transfer over time.^{54, 55}

⁴⁹<http://www.artemis.bm/blog/2017/09/14/mmc-pension-offloads-huge-3-4bn-of-longevity-risk-to-reinsurers>. The counter to this cost-effectiveness is that the hedger takes on additional counterparty risk. If a reinsurer fails then there is no insurer to protect MMC's pension scheme.

⁵⁰ Nick Reeve (2017) BA scheme uses 'captive insurer' in £1.6bn longevity risk hedge, *IPE*, 13 September.

⁵¹ [https://www.pensioncorporation.com/media/press-releases/Prudential_PIC_Reach_\\$1.2_Billion_Longevity_Reinsurance_Agreement](https://www.pensioncorporation.com/media/press-releases/Prudential_PIC_Reach_$1.2_Billion_Longevity_Reinsurance_Agreement); L&G reinsures £600m of longevity risk through Prudential, *Professional Pensions*, 21 December 2017.

⁵² The role of the 'commutation function' is to 'compress' the risk period. As explained in Michaelson and Mulholland (2014, pp.32-33): 'This is accomplished by basing the final index calculations on the combination of two elements: (i) the actual mortality experience, as published by the national statistical reporting agency, applied to the exposure defined for the risk period; and (ii) the present value of the remaining exposure at the end of the risk period calculated using a 're-parameterized' longevity model that takes into account the realized mortality experience over the life of the transaction'.

⁵³ The SCR is the amount of funds that insurance and reinsurance companies are required to hold under Solvency II in order to have a 99.5% confidence they could survive the most extreme expected losses over the course of a year. The SCR incorporates market, credit, operational and counterparty risks, and must be recalculated at least once per year; <https://www.risk.net/definition/solvency-capital-requirement>

⁵⁴ <http://www.artemis.bm/blog/2017/12/01/nn-life-gets-index-based-longevity-hedge-from-hannover-re/>

⁵⁵ <https://www.nn-group.com/Investors/Capital-Markets-Day-2017.htm>

In order to reduce the costs of de-risking, pension plans are encouraged to perform some liability reduction exercises, the key ones being:⁵⁶

- Enhanced transfer values (ETVs) – allow deferred members to transfer an uplifted value of their benefits to an alternative arrangement. In August 2017, a 64-year old entitled to an annual index-linked pension starting at £10,000 from age 65 would be offered a transfer value of £237,000, according to the Xafinity Transfer Value Index.⁵⁷ In October 2019, the transfer value was £244,200. In 2019, around 50,000 members transferred out of their DB scheme, around 1% of eligible members.⁵⁸
- Flexible retirement options (FROs) – allow deferred members aged 55 and over to retire early, or to take a transfer value and secure benefits in a different format from their plan benefits, or to use funds for drawdown purposes.
- Pension increase exchanges (PIEs) – allow pensioners to exchange non-statutory increases for a higher immediate pension with lower or even zero future increases (e.g., a £10,000 annual pension with inflation uplifting is replaced by a £12,000 annual pension with no further increases).
- Trivial commutations (TCs) – allow members with low value benefits to cash these in.

The most common exercises currently in the UK are PIEs and TCs – and these can be conducted either before or at the same time as a bulk purchase annuity broking exercise. Hymans Robertson has estimated that the use of these liability reduction exercises could reduce the buy-out cost for UK DB schemes by around £100bn or 6% of total liabilities.⁵⁹

Innovation is a continuing feature of this market. Some examples include (see, e.g., Legal & General and Engaged Investor, 2016):⁶⁰

- Buy-ins and buy-outs with deferred premium payments – to spread costs, schemes that cannot afford the upfront premium of a de-risking solution pay for it in instalments over a number of years.
- Buy-outs combined with a longevity hedge.⁶¹
- Phased buy-ins, where the largest risks or the lowest cost risks are insured first.
- Phased de-risking using a sequence of partial buy-ins with an ‘umbrella’ structure to avoid more than one set of contract negotiations – to spread costs.
- Accelerated buy-ins – the insurer provides a loan to the plan equal to the deficit (sometimes called a winding up lump sum (WULS)), so that a partial buy-in can take place immediately, with this converting to a full buy-in when the loan has been repaid, or with the option of a full buy-out at a later date.

⁵⁶ *Professional Pensions* (2016) Risk reduction and the extent of trust in pension scheme advisers and providers, June, p.26.

⁵⁷ Hannah Godfrey (2017) DB transfer values back on the rise in August, *Professional Adviser*, 7 September.

⁵⁸ Sophie Smith (2019) DB transfer values in record fall – XPS, *Pensions Age*, 7 November.

⁵⁹ <https://www.ipe.com/news/uk-roundup-clear-member-options-could-reduce-buyout-db-costs-by-100bn/10060598.article>

⁶⁰ Legal & General and Engaged Investor (2016) *De-risking Journeys of Mid-sized Pension Schemes*, June.

⁶¹ An example of this was the Philips Pension Fund which in 2015 completed a full buy-out valued at £2.4bn with PIC. The longevity risk was simultaneously reinsured with Hannover Re. Another interesting feature of this deal was that it covered both retired and deferred members.

- Forward start buy-ins – a standard buy-in with the start date delayed to reflect the level of funding available, with additional options, such as paying deferred members as and when they retire if this is prior to the start date, or the ability to bring forward the start date for an additional fee.
- Self-managed buy-ins – which allows pension schemes to run their own asset management strategy at lower cost and with a lighter regulatory burden than if an insurer was involved (introduced in 2018 by the UK asset manager Insight Investment). The strategy uses swaps to hedge interest, inflation and longevity risks and is estimated to be 10-15% cheaper than the equivalent insurance product.⁶²
- Automated bulk plan transfers – to reduce risks (introduced in November 2017 by Scottish Widows and Standard Life).⁶³
- Top-slice buy-ins – to target the highest value liabilities.
- Named-life longevity swap – if the named member lives longer than expected, the insurer pays out the difference (examples being the £400m Bentley plan and an unnamed plan with 90 named pensioners valued at £50m).
- Tranching by age – to reduce costs; according to consultant Punter Southall, a buy-in for pensioners up to age 70 will make a subsequent buy-out within the following 10 years cheaper than a buy-in for the over 70s.⁶⁴
- Longevity swaps for small pension plans with liabilities of £50-100m – previously only available for medium (£100-500m) and large plans (above £500m).
- Novation – the ability to transfer a longevity hedge from one provider to another, thereby introducing some liquidity into what had previously been a completely illiquid market. An example would be the reinsurance of a small bulk annuity transaction. Contract simplicity is a desirable feature of such arrangements.
- Longevity swap to buy-in conversions – as pioneered by Phoenix Life in December 2016 for its parent company's pension plan. Solvency II incentivizes buy-in providers to hold longevity insurance, otherwise they pay an additional risk margin. This encourages buy-in providers to seek out plans which already have a longevity hedge and encourage them to do a buy-in. Another driver is longevity swap providers that are not currently active in the market – such as J.P. Morgan and Credit Suisse – but are still responsible for running off their existing swaps. They might have an incentive to encourage the associated pension plan to novate the swap to a buy-in provider and hence extinguish their liability.⁶⁵
- Insuring away the extreme tail of liabilities in a closed plan after a specified term, such as 5 or 10 years – to reduce costs.
- Increasing optionality in contracts to improve flexibility – for example, the option to switch the indexation measure for pensions in payment from the Retail Price

⁶² Angus Peters (2018) Insurers compete with fund managers for lucrative pension pots, FTfm, 15 January. The article points out that 'insurers and asset managers are engaged in a turf war for the £1.6tn sitting in the UK's defined benefit schemes'.

⁶³ Michael Klimes (2017) How the first automated bulk scheme transfers happened, *Professional Pensions*, 10 November.

⁶⁴ James Phillips (2017) DB schemes insuring wrong tranche of members in buy-ins, *Professional Pensions*, 14 August.

⁶⁵ Stephanie Baxter (2017) Converting longevity swaps into bulk annuities: The next de-risking innovation?, *Professional Pensions*, 13 April.

- Index to the Consumer Price Index if government legislation changes; or the option to secure discretionary benefits, such as actual inflation above a 5% cap; or surrender options.
- Insuring the tail of the liabilities – whereby a closed scheme that cannot afford a full buy-out insures only the liabilities after a certain point in time, say, 10 years’ ahead.
 - Combining liability management solutions (such as interest rate and inflation swaps, and ETV, FRO and PIE exercises) and bulk annuities in a buy-out – so instead of completing liability management before considering a buy-out, plans do this in a single exercise.
 - ‘Buy-out aware’ investment portfolios – used to reduce buy-out price volatility and close the funding shortfall, with the buy-out price locked to the value of the buy-out aware funds once a target shortfall has been reached and whilst the contract documentation for a buy-out is being completed.
 - Improved arrangements for handling data errors that arise after a deal has been executed – to reduce pre-deal negotiation requirements and post-deal transaction uncertainty. Common data errors include member gender, date of birth, and benefit amounts for both member and partner. A simplified data error process could deal with these issues in the following way: locking down benefits, removing the need for re-pricing; mechanistically adjusting demographic errors; and using due diligence to check for systematic errors with the data.⁶⁶
 - Residual risk insurance, covering, e.g., benefit specification errors, data errors, and unidentified beneficiary cover.
 - Arrangements to handle deferred members – to improve insurer appetite to assume the additional risk and cost involved. Deferred lives make up almost half (45%) of the membership of UK DB plans in the UK.⁶⁷ They are much more expensive to hedge for a number of reasons. First, there can be problems with their existence and identification. Second, they enjoy a large number of options which need to be priced.⁶⁸ Third, their longevity risk is greater, because the longevity improvement assumption used for pricing has greater reliance on the assumed long-run trend.⁶⁹ Fourth, as a direct consequence of the previous points, more capital is needed and this, in turn, increases the demand for reinsurance. These issues can be at least partially mitigated as follows: a robust existence checking procedure is needed involving electronic tracing, assuming a fixed percentage of the pension is exchanged for tax-free cash, setting the assumed retirement date to the plan’s

⁶⁶ Andrew Murphy (2017) Developments in longevity swaps, Pacific Life Re, 23 November, IFoA Life Conference. Provided due diligence has been carried out at the outset, subsequent data errors tend to be unbiased in terms of their impact and so average out close to zero.

⁶⁷ That is 4.9m members (The Pension Regulator and the Pension Protection Fund, *Purple Book 2015*).

⁶⁸ For example, lump sum commutation, trivial commutation, early/late retirement, increasing a partner’s benefits at the expense of the member’s benefits, and pension increase exchanges.

⁶⁹ Valuation and risk assessment of a deferred annuity can be broken down into five overlapping components: survival to retirement; the socio-economic group of the pensioner at the date of retirement; the base mortality table at the time of retirement for that socio-economic group; general mortality improvements (e.g., age 65+) up to the date of retirement; and the mortality improvement rate after retirement. Uncertainty in the probability of survival to retirement will typically be quite small in relation to the other risks.

normal retirement date, assuming no pension is exchanged for additional partner pension, restricting the age profile to older deferred members, and restricting the proportion of deferred members in the transaction.⁷⁰

These are all innovations in the space linking pension plans and insurance companies designed to ease the transfer of pension liabilities (or at least the longevity risk in them) from pension plans to insurance companies.

The innovations have helped to encourage more business, but this, in turn, has exposed potential longer term capacity constraints within insurance companies. As one consultant said: ‘Given the market has historically completed only 150-200 deals in any one year, there is a real risk of capacity constraints in the market, not just from an insurer capital perspective, but also from a resource and expertise perspective’.⁷¹

A total of £12.4bn in buy-ins and buy-outs and £6.4bn in longevity swaps took place in the UK in 2017.

In April 2015, the UK government introduced ‘Freedom and Choice’ pension reforms which gave more flexibility to how individuals could draw down their defined contribution (DC) pension pots.⁷² In particular, there was no longer a requirement to purchase an annuity.⁷³ This immediately led to a fall in annuity sales by around 75% (Cannon et al (2016)). The situation was not helped by the fall in gilt (UK government bond) yields (which led to a corresponding fall in annuity rates) arising from the government’s quantitative easing program introduced after the Global Financial Crisis. In August 2017, a 65-year old with a £100,000 pension pot, could get a level income for life of £4,894: two years before, the amount would have been £5,292.⁷⁴ By 2017, the following insurers had pulled out of the open market for annuities: Aegon, LV=, Partnership (before it merged with Just Retirement to form Just Group), Prudential (UK), Standard Life, Friends Life (merged with Aviva), Reliance Mutual, B&CE, and Retirement Advantage. This left just six providers in what was once the world’s largest annuity market: Aviva (offering standard and enhanced (i.e., medically underwritten) annuities), Canada Life (standard and

⁷⁰ Andrew Murphy (2017) Developments in longevity swaps, Pacific Life Re, 23 November, IFoA Life Conference.

⁷¹ Martyn Phillips, Mercer (quoted in *Professional Pensions* (2016) Risk Reduction and the Extent of Trust in Pension Scheme Advisers and Providers, June, p.28). Hannover Re had previously warned about this: ‘The number of risk-takers is limited and there is no unlimited capacity in the market for taking on longevity risk. The increasing worldwide demand for longevity cover will challenge the capacity for securing longevity risk’ (quoted in Punter Southall (2015) *De-risking Bulletin*, March). At the time, there were significant human resource bottlenecks in some parts of the transaction chain, in particular, a shortage of qualified lawyers.

⁷² The proposal was announced by the UK finance minister (George Osborne) in his Budget Speech on 19 April 2014.

⁷³ <https://www.pensionsadvisoryservice.org.uk/about-pensions/pension-reform/freedom-and-choice>

⁷⁴ Josephine Cumbo (2017), Pensioners hit as annuity rates drop 10% in two years, *Financial Times*, 1 September.

enhanced), Hodge Lifetime (standard only), Just Group (enhanced only), L&G (standard and enhanced) and Scottish Widows (standard and enhanced).⁷⁵

In place of annuities, individuals took their pension pot either as a lump sum or they purchased an income drawdown product. In both cases, they bear their own longevity risk. Evidence shows that people systematically underestimate their life expectancy which implies that there is a significant probability that many people will spend their pension pot before they die. A study by Just Group found that UK men aged 40-54 expect to live until 78.9 years on average, whereas the official estimate of their life expectancy is 87.5; the figures for women are 80.5 and 90.1.⁷⁶

A number of UK insurers providing bulk annuities for buy-ins are also involved in the UK equity release mortgage (ERM, or reverse mortgage or lifetime mortgage) market which allows home owners to borrow against the equity in their homes. The modern form of the market began when the Equity Release Council (ERC) representing providers was established in 1991 with a voluntary code of conduct that offered a number of guarantees. Before this, users of the product could lose their homes when the value of the loan plus interest exceeded the value of the property. Since 1991, there is a guaranteed right to remain living in the property, either for life or until entry into long-term care. In addition, there is a 'no negative equity guarantee' (NNEG)⁷⁷ which means that the value of the loan plus interest can never exceed the value of the property, and so no debt can be passed on to the estate of the equity release borrower. The providers in the new market therefore face longevity risk in a way that those in the old market did not. In 2017, a total of £3bn in equity release loans were made with an average size loan of £102,000. In 2018, the UK Prudential Regulation Authority (2018) raised concerns that providers were not properly reflecting the cost of the NNEG in their capital reserving. Instead of valuing the NNEG using the Black (1976) model as a series of put options on the forward house price (which is lower than the current price to reflect the loss of rental income due to deferred possession) weighted by the probability of mortality, morbidity and pre-payment, it pointed out that most providers were using the expected future house price which required assumptions about property growth.

There were also important developments outside the UK in 2017, although many of these involve innovations adopted from the UK market. Apart from the US, Canada, and the Netherlands, new markets include Germany, Switzerland and Ireland. Examples of innovations in the US include: plan-specific mortality data – with \$250m as the minimum transaction size; asset-in-kind premium funding – where bonds are used to fund the transaction. Insurer capacity has also increased, with 14 insurers engaged in pension buy-outs. Three new insurers joined: Athene,⁷⁸ Mutual of America, and CUNA Mutual. Athene wrote more than \$2bn of business in 2017. A total of \$24.7bn pension risk transfers were

⁷⁵ Source: Hargreaves Lansdown, August 2017. Scottish Widows introduced a standard annuity in September 2019.

⁷⁶ Chris Seekings (2018) Millions of Brits underestimating their life expectancy by a decade, *The Actuary*, 3 May. There were similar findings in a study by the Institute for Fiscal Studies, see James Phillips (2018) New retirees overly pessimistic about life expectancy, *Professional Pensions*, 17 April.

⁷⁷ See Dowd et al. (2019).

⁷⁸ Athene is majority owned by private equity company Apollo Global Management, LLC.

conducted in the US in 2017. In Canada, group annuity sales amounted to C\$3.7bn, and a new group annuity provider, Brookfield Annuity, joined the market. In Germany, many schemes were considering using lump sum settlement payments to pensioners to transfer longevity risk. In Switzerland, insurers are now willing to consider transfers involving active members. In Ireland, Danske Bank transferred €335m of its Irish DB pension liabilities to Irish Life.⁷⁹

In April 2017, the International Monetary Fund (IMF) released a new edition of its *Global Financial Stability Report*. Chapter 2 ('Low Growth, Low Interest Rates, and Financial Intermediation') suggests that DB pension funds across the globe might have to cut benefits 'significantly' in the long term because of ultra-low interest rates. Attempts to increase returns by changing asset allocations 'appears feasible only by taking potentially unacceptable levels of risk'. In the face of such low rates, the IMF argues that 'life insurers and pension funds would face a long-lasting transitional challenge to profitability and solvency, which is likely to require additional capital' or would require a 'very high' level of volatility risk to meet their funding goals. However, a combination of risk aversion and regulatory constraints was likely to deter the vast majority from taking this second path. The IMF instead believes that the current situation might work to the benefit of insurers backing buy-ins and buy-outs. With investors increasingly monitoring the size of DB liabilities and the effects on company share prices, profits, and dividends, the IMF said offloading these liabilities to insurers 'is an attractive option' and 'may represent a market-efficient arrangement' and that 'regulation could play an important role in this area by facilitating such transactions'.

Longevity 14: 2018

The fourteenth conference (*L14*) was held in Amsterdam on 20-21 September 2018. It was hosted by the Pensions Institute and the Netspar Network for Studies on Pensions, Aging and Retirement.⁸⁰

2018 saw the start of a trend towards consolidation amongst pension schemes in the UK. This was led by a group of private equity investors. One example is the Pension Superfund which was launched in March with £500m in seed capital provided by Edi Truell's Disruptive Capital and Warburg Pincus. Another example is Clara-Pensions which has £500m in seed capital from TPG Sixth Street Partners. Both have set up as occupational pension scheme master trusts. Antony Barker of the Pension Superfund predicted that if the UK follows the experience of the Dutch and the Australian markets, consolidation could lead to the 5,500 UK DB schemes being reduced to 1,500 by the end of the decade. He argued that, while many will go into insurance buy-outs and another 50-100 insolvent schemes could end up in the Pension Protection Fund (PPF),⁸¹ this leaves potentially 2,000

⁷⁹ Navigating you through your de-risking journey: Overseas, *Aon Risk Settlement Market Review 2018*.

⁸⁰ The conference proceedings for *L14* were published in volume 14(2) of the *Annals of Actuarial Science* in 2020.

⁸¹ The Pension Protection Fund is a statutory fund in the UK which takes on the assets and liabilities of the defined benefit schemes of UK companies that have become insolvent. Any member who is over their normal retirement age or who retired early due to ill health will receive 100% of their current pension.

that could end up with a superfund. That could represent £800bn in assets out of a total of £1.8trn in UK DB pension assets.⁸²

The business models of the two consolidators are different, however. Clara-Pensions takes over the obligations and risks from pension scheme sponsors, but then becomes a ‘bridge to a buy-out’. Its shareholders do not see a return on capital until every member has their full benefits secured in the insured market. In the meantime, it will need to hedge these risks, including longevity risk. By contrast, the Pension Superfund operates as a long-term run-off scheme. But instead of being supported by an operating company covenant, as in a standard occupational pension scheme trust, it is supported by a financial covenant in the form of a partnership holding material financial commitments from the former sponsor and new external capital providers, that should ensure members get at least 99% certainty of receiving their promised benefits in full. Any surplus of assets above 115% of liabilities ‘on a prudent actuarial basis’ will be shared one-third to members and two-thirds to the investors. The liabilities would be hedged and the investment strategy would be ‘fairly low risk’. The Pension Superfund planned to use reinsurance through a captive model in due course. It would be initially targeting schemes with assets between £200m-£1bn with a strong sponsor covenant.⁸³

Insurers have expressed concerns that, since such pension consolidation vehicles come under the Pensions Regulator (TPR) (i.e., are classified as pension schemes), they do not have to satisfy the much stricter solvency requirements of insurers which are regulated by the Prudential Regulation Authority, which is part of the Bank of England.⁸⁴ Both the Pension Superfund and Clara-Pensions aim to undercut insurance buy-out pricing by up to 10-15%.⁸⁵ The two consolidators justify themselves as filling a gap between a full insurance buy-out and schemes entering into the PPF following the insolvency of their sponsor. Each year, around 2% of the UK’s 5,500 schemes either buy-out or enter the PPF. The consolidators offer a solution to solvent companies that cannot afford a full buy-out. Insurers have responded to the challenge from the consolidators by offering these companies access to an investment and hedging strategy that moves them closer to the goal of a full buy-out or buy-in. The Pension Superfund agreed two deals in 2019, but these have been delayed due to an absence of regulatory approval and the government was at the time still considering an authorization, supervision and solvency regime.⁸⁶ An interim

Other members will receive 90% of their pension entitlement at the time of insolvency up to a cap. The sponsors of all eligible schemes must pay a levy to the PPF. See <https://www.ppf.co.uk/>

⁸² Quoted in Mona Dohle (2020) Superfunds - New entrants to the DB consolidation market, *Portfolio Institutional*, 17 August.

⁸³ Adam Saron, Chief Executive Officer, Clara-Pensions, and Antony Barker, Managing Director, The Pension Superfund, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020. See also Willis Towers Watson *De-risking Report 2020*, January (p.24).

⁸⁴ James Phillips (2018) The Pension Superfund to split surplus with members and capital providers, *Professional Pensions*, 12 July.

⁸⁵ *Superfunds: New solutions for DB pension plans?*, KPMG, August 2018; <https://assets.kpmg/content/dam/kpmg/uk/pdf/2018/08/kpmg-superfunds-solutions-for-db-pension-plans.PDF>

⁸⁶ Nick Reeve (2019) Pension Super Fund signs up second client in £300m deal, *IPE*, 30 July; James Phillips (2019) Clara: ‘Shadow market’ is huge for DB consolidation, *Professional Pensions*, 22 October.

regime for superfunds was introduced in June 2020. In November 2021, Clara-Pensions became the first superfund to complete TPR's assessment process and meet its 'tough new standards' of governance and administration. It appointed Kempen Capital Management as fiduciary manager and Hymans Robertson as scheme administrator.⁸⁷

The General Data Protection Regulation (GDPR) was introduced in all EU member states in May 2018 and will affect longevity risk transfers since they involve the exchange of personal data. There are fines for data protection breaches. The GDPR distinguishes between data controllers – people who determine how and why data should be used – and data processors – who process data on behalf of data controllers. Pension scheme trustees will be data controllers, as will insurers if they have received personal data in connection with a potential buy-out transaction (e.g., if they are conducting a data cleansing or medical underwriting exercise). In other cases, insurers might be classified as data processors. International data transfers, e.g., in the case where an insurer wants to transfer data to a reinsurer located outside the European Economic Area, can only take place if adequate data protections are in place. Care needs to be taken even if anonymized data is transferred, since it might still be possible to identify the individuals to whom the data relates, e.g., company directors might be identified from information about the size of their pension benefits and date of birth.

For 2018, the key highlights in the UK longevity risk transfer market were:⁸⁸

- PIC reinsured all its pensioner liabilities (73% of its total exposure) with Partner Re in January. It also helped to fund University Partnerships Programme acquisitions of student accommodation with index-linked bonds in February.
- Scottish Widows executed a £1.3bn longevity swap with PICA in February.⁸⁹ It was the last UK insurer to hedge at least some of its longevity risk. It did this to reduce its Solvency II capital requirements.
- Standard Life Aberdeen sold £2.93bn of its annuity back-book to Phoenix in February, with the rest of Standard Life Assurance sold to Phoenix in September.
- Prudential (UK) sold £12bn of its annuity back-book covering 400,000 policies to Rothesay Life in March, making Rothesay the UK's largest specialist annuity insurer with more than £37bn of assets and 750,000 lives insured.⁹⁰

The government passed a Pension Schemes Act in February 2021, but it did not contain legislation for a DB consolidator regime.

⁸⁷ <https://www.pensionsage.com/pa/BREAKING-Clara-Pensions-becomes-first-TPR-assessed-DB-superfund.php>

⁸⁸ There were £24.2bn of transfers (buy-outs and buy-ins) in the UK in 2018 plus another £7bn in longevity swaps. The biggest insurers in the market were L&G, PIC, Zurich, Scottish Widows, Aviva, Canada Life, Just, Phoenix Life, and Rothesay Life (*LCP De-risking Report 2020*).

⁸⁹ Since 2011, PICA has completed more than £32bn in international reinsurance deals, including the £16bn deal with the BT Pension Scheme in 2014.

⁹⁰ In August 2019, the High Court in London blocked the Prudential-Rothesay transfer on the grounds that Rothesay was a 'relatively new entrant without an established reputation in the business' and although it had solvency ratios at least equal to Prudential's, 'it does not have the same capital management policies or the backing of a large group with the resources and a reputational imperative to support a company that carries its business name if the need were to arise over the lifetime of the annuity policies' (Susanna Rust (2019) High Court blocks £12bn Prudential-Rothesay annuities transfer, *IPE*, 19 August). In September 2019, Prudential and Rothesay announced that they would appeal against the decision on the basis that the

- In March, the Marks & Spencer Pension Scheme executed two buy-ins totalling £1.4bn with Aviva and Phoenix covering 15% of its pension liabilities. It was Aviva's largest buy-in to date (at £925m) and Phoenix's first external buy-in (at £475m).
- In March, PIC and PICA introduced a 'flow reinsurance' system which automates the longevity reinsurance element of buy-outs and buy-ins for schemes with liabilities below £200m. The system allows PIC to secure a commitment from PICA to assume the longevity risk early on in a transaction.
- In March, employee benefits consultant, JLT, launched a 'buy-out comparison service' and monitoring tool which allows schemes to upload their own data and receive regular bulk annuity quotations from eight insurers currently active in the market.
- In April, JLT became the first consultant to implement Club Vita's longevity analytics capabilities which have been incorporated into RiskFirst's PFaroe modelling system for DB plans. This will allow JLT clients to set best-estimate longevity assumptions.⁹¹ Club Vita data shows that pension schemes can have a very different demographic composition compared with the national population, with liabilities that could be up to 10% higher or lower as a result of different mortality experience.
- PIC executed a £900m longevity swap with PICA in May, covering 7,500 pensioners.⁹²
- In June, Canada Life sold its £2.7bn back book of 155,000 UK life and pension savings policies to Scottish Friendly. The company said it wanted to concentrate on developing new retirement products following its acquisition of Retirement Advantage, an annuity and retirement income specialist, in January.
- Siemans completed a £1.3bn buy-in of its UK pension liabilities covering 6,000 members with PIC in July.
- Aviva executed a £1bn longevity swap with PICA in August.
- National Grid Electricity Group completed a £2bn longevity swap with Zurich⁹³ for the Electricity Supply Pension Scheme also in August.
- In August, L&G entered the small scheme longevity insurance market after completing a £300m longevity swap with an unnamed pension fund. The deal had a 'streamlined structure' with simplified data requirements which helped to keep fixed costs down. The swap was later reinsured with SCOR. According to L&G,

judgement 'contains material errors of law' and should be reconsidered. On 2 December 2020, the Appeal Court granted an appeal against the High Court decision to block the Prudential to Rothesay Life transfer, on the grounds that the High Court had not given adequate weight to analysis by industry bodies and conclusions by the Prudential Regulation Authority and the Financial Conduct Authority, neither of which objected to the transfer. The issue of whether to sanction the scheme would be passed to the High Court for a second hearing. In November 2021, the High Court approved the transfer of the £12bn portfolio of annuities from Prudential (now a subsidiary of M&G) to Rothesay Life.

⁹¹ Club Vita is a longevity data analytics company which pools data from over 220 UK DB schemes covering 2.8m pensioners, approximately one quarter of the total. RiskFirst is a fintech company which launched the PFaroe software in 2009 to enable pension funds to manage their asset and liability risks.

⁹² This brought the total value of all the deals between the two companies to £4.4bn.

⁹³ Zurich reinsured a significant proportion of the longevity risk with Canada Life Re. It has executed £3.5bn longevity risk transfer deals since it entered the market in 2016.

‘the transaction demonstrates that longevity reinsurance is a realistic option for most pension schemes, including for trustees whose schemes are not quite at the point they can enter into buy-in or buy-out, but want to manage their longevity risk’.

- In September, the British Airways’ Airways Pension Scheme entered into the UK’s largest buy-in agreement to date (at £4.4bn) with L&G, covering 60% of pensioner liabilities; taking account of the £1.7bn longevity swap agreed in 2017, the scheme has now hedged 90% of its longevity risk.
- The Automobile Association Pension Scheme completed a £351m buy-in with Canada Life also in September.
- In October, the UK pension scheme of Nortel, the Canadian telecoms company which became insolvent in 2009, agreed a £2.4bn buy-out deal with L&G, covering 15,000 pensioners and 7,200 deferred members, thereby avoiding entering the Pension Protection Fund.
- In December, PIC executed another longevity swap, this time with SCOR, covering 8,000 pensioners and valued at £1.2bn.⁹⁴

In April 2018, the PRA said it was concerned that too much longevity risk was being transferred offshore through reinsurance arrangements, preferring that more of it be retained in the UK. It said it would consider amending Solvency II risk charges to encourage greater retention. While it said it understood the need for risk transfer, it said that it was concerned that pension assets were being transferred overseas, taking them outside of its regulation, so that if an offshore reinsurance firm failed, UK pensioners might not get their pensions.⁹⁵

The first ever longevity swap in the US was executed by RGA in 2018. In Canada, the Life Insurance Capital Adequacy Test (LICAT) regulations came into effect at the start of 2018. RGA redesigned a longevity transaction structure to create two LICAT-compliant cash flow swaps which transferred longevity risk but not investment risk, and improved capital efficiency for both parties⁹⁶

Longevity 15: 2019

The fifteenth conference (*L15*) was held in Washington DC on 12-13 September 2019. It was hosted by the Pensions Institute.⁹⁷

A total of £43.8bn longevity risk transfer deals were announced for the UK in 2019.⁹⁸ XPS reported that for a buy-out for a medium-sized scheme, pensioner member transfers used a

⁹⁴ This brought the total value of the deals between the two companies to £2.2bn.

⁹⁵ Steve Evans (2018) Bank of England wants more longevity risk retained, less reinsured, *Reinsurance News*, 27 April; <https://www.reinsurancene.ws/bank-of-england-wants-more-longevity-risk-retained-less-reinsured/>

⁹⁶ https://www.rgare.com/docs/default-source/investor-relations/rga_ar18.pdf

⁹⁷ The conference proceedings for *L15* were published in 2021 in *Insurance: Mathematics and Economics*, 99(C): 130-508.

⁹⁸ *LCP De-risking Report 2020*. This compares with £1bn when the market started in 2006. The eight insurance companies involved were: Rothesay Life (37% market share), L&G (24%), PIC (16%), Aviva

‘gilts + 0.3% p.a.’ discount rate to value the liabilities (i.e., technical provisions), while for deferred members the discount rate was ‘gilts – 0.5% p.a.’.⁹⁹ Willis Towers Watson reported an average buy-in price at 0.15% p.a. above gilts.¹⁰⁰

Highlights included:

- In January, PIC invested £125m in Exeter University accommodation in order to generate index-linked cash flows to pay its pensioners.
- In the same month, PIC completed a £425m buy-in with the Co-operative Group’s Somerfield Pension Scheme.
- L&G executed buy-ins with the Pearson Pension Plan (£500m in February), Howden Group Pension Plan (£230m in March) and 3i Group (£95m in April).

(9%), Phoenix Life (9%), Scottish Widows (5%), Just (3%), and Canada Life (1%). Their total assets and asset allocations are given below. In terms of transaction volumes, 65% of deals were over £1bn, 29% of deals were between £100m and £1bn, and 6% of deals were below £100m.

<i>Total assets and asset allocations of the main UK PRT providers 2019</i>								
	L&G	Rothesay Life	Aviva	PIC	Scottish Widows	Just	Canada Life	Phoenix Life
Total assets (£bn)	75.9	53.7	46	40.9	22	21.6	18.7	11.7
Government bonds & cash (%)	72	47	14	44	30	57	61	28
Corporate bonds (%)		14	29	53	30			44
Equity release/lifetime mortgages (%)	6	5	16	3	40 (alternative credit investments)	37	6	23
Commercial mortgages and healthcare (%)	-	-	16	-		-	8	-
Secured Lending and residential mortgages (%)	-	25	-	-		-	-	-
Infrastructure (%)	-	9	17	-	-	4	-	-
Private placement and structured finance	-	-	4	-	-	2	-	5
Direct investments (%)	22	-	-	-	-	-	-	-
Real estate (%)	-	-	-	-	-	-	5	-
Other (%)	-	-	4	-	-	-	-	-
Source: LCP De-Risking Report 2020								

⁹⁹ XPS Risk Transfer News, 10/19.

¹⁰⁰ Figure 2 in Willis Towers Watson De-risking Report 2020, January.

- Rothesay completed a buy-in (amount undisclosed) with the Teachers Assurance Group Pension Scheme in February, and a £110m buy-out with the Laird Pension Scheme in April.
- Also in April, PIC completed a £1.2bn buy-in with Commerzbank in respect of the Dresdner Kleinwort Pension Plan of its UK subsidiary. This involved three transactions. The first was a £900m buy-in of the DB section. The second and third involved the DC section and gave members of the hybrid scheme the option of transferring their DC pension out or convert it into a DB equivalent for transfer to PIC.
- In May 2019, the British American Tobacco UK Pension Fund completed a £3.4bn buy-in with PIC, the second-largest buy-in to date.
- Also in May, PIC and Phoenix insured £900m and £460m, respectively, of the liabilities of Marks & Spencer's UK pension scheme.
- In June, Rolls Royce executed the biggest buy-out to date – at £4.6bn – with L&G, covering the benefits of 33,000 pensioners. As part of the deal, a longevity swap originally with Deutsche Bank was transferred to L&G – the first time a swap has been novated between counterparties.
- In July, Scottish Widows completed buy-ins totalling £830m with Peugeot and QinetiQ
- In August, PIC executed a £3.4bn de-risking deal with the British American Tobacco UK Pension Fund covering both 8,300 pensioners and 2,300 deferred members. It is the biggest deal to date covering both retired and non-retired members.
- In August, PICA completed a £7bn longevity swap with banking group HSBC's UK pension scheme – making it the second largest swap in the UK after the £16bn swap for the British Telecom Pension Scheme in 2014, also arranged by PICA. The transaction – which covers half of the scheme's pensioner liabilities – was structured as an insurance contract with a Bermuda-based, HSBC-owned captive insurer, which reinsured the longevity risk with PICA. It was the first captive longevity reinsurance transaction for a pension scheme associated with a major bank. Amy Kessler, PICA's head of longevity risk transfer, said: 'The captive approach has become the strategy of choice for large pension schemes seeking to hedge longevity risk'.¹⁰¹
- In August, Phoenix Life completed a £1.1bn buy-in of its own DB pension scheme, the PGL Pension Scheme. In the same month, it executed a longevity reinsurance arrangement with PICA.¹⁰²
- In August, Rothesay Life executed a £520m buy-in with the Cadbury Mondelēz Pension Fund, covering 1,900 pensioner members.
- In August, L&G announced it had completed a buy-in transaction for the UK hybrid pension scheme of data and technology company Hitachi Vantara. The deal was described as 'innovative' since it also took into account the DC elements of the scheme. Each member's retirement benefit is based on the higher of the DB and DC pension over their career with Hitachi Vantara. The buy-in was structured to

¹⁰¹ Susanna Rust (2019) HSBC pension scheme strikes £7bn longevity risk transfer, *IPE*, 6 August.

¹⁰² <https://www.artemis.bm/news/prudential-in-longevity-reinsurance-deal-for-pension-insurer-phoenix/>

maintain this arrangement, allowing deferred members to ‘consider their options’ prior to a full buy-out.¹⁰³

- In September, L&G arranged a £930m buy-in with the Tate & Lyle Pension Scheme, covering 4,800 members.
- In September, Rothesay Life executed an even larger buy-in than the Rolls Royce deal in June – at £4.7bn – with the GEC 1972 Plan, covering 39,000 members split 70-30 between pensioners and deferreds. There is an option for a buy-out at a later date. Hence this is known as a ‘buy-in to buy-out deal’. The parent company of GEC is Telent.
- Also in September, Rothesay Life insured £3.8bn of members’ benefits for the Allied Domecq Pension Fund in another buy-in covering around 27,000 pensioners and deferred members, split 63-37. The parent company of Allied Domecq is the Pernod Ricard Group.
- In October, Rothesay completed a £2.8bn buy-in with the National Grid Pension Scheme (Section A). The following month, L&G completed a £1.6bn buy-in with the National Grid Pension Scheme (Section B), covering 6,000 pensioner members.
- In October, Rothesay executed a full buy-in with retailer ASDA (owned by Walmart) for £3.8bn, covering 4,800 pensioners and 7,500 deferred members. This converted to a full buy-out in 2020-21 at an additional cost of £800m.
- In October, Aviva Life and Pensions UK completed a £1.7bn buy-in for the Aviva Staff Pension Scheme, covering 1,500 pensioners and 4,300 deferred members.
- In November, Phoenix completed a £144m buy-in with the Aegon UK Staff Retirement and Death Benefit Scheme.
- In December, Zurich and Hannover Re completed a £800m longevity swap with an unnamed FTSE100 company.

Other UK developments in 2019 included:

- In February, L&G launched Track My Apps, a tracking service provided by fintech company Origo, to enable advisers to track their clients pension transfers online.
- £936m of equity release deals in the first quarter with 20,000 households, taking out an average of £50,000 in housing wealth.
- In May, L&G announced the creation of a UK retirement housing business called Guild Living which plans to deliver 3,000 new homes over the next five years with a gross development value of £2bn.¹⁰⁴ The business will contribute the income it needs to pay the benefits on its longevity risk transfer business. In August, L&G announced it had acquired a site in Walton-on-Thames suitable for building 300 homes.
- In June, L&G launched the first pension risk transfer execution platform to be driven by blockchain technology. Known as ‘Estua-Re’, the technology provides a ‘single ecosystem capable of driving every stage of the PRT reinsurance value chain’, including pricing, claims handling, financial reporting, and collateral. It allows multiple parties to transact with each other without the need for an

¹⁰³ Nick Reeve (2019) L&G backs ‘innovative’ buy-in for Hitachi UK pension scheme, *IPE*, 14 August.

¹⁰⁴ <https://www.legalandgeneralgroup.com/media-centre/press-releases/legal-general-launches-guild-living-bringing-retirement-communities-to-uk-city-centres/>

intermediary and there will be greater transparency since all parties will have access to the latest version of the ledger database.¹⁰⁵

- In August, PICA and the Phoenix Group launched a reinsurance counterparty to provide longevity reinsurance for insurers in the UK pension risk transfer market, covering both their buy-out and buy-in transactions. Phoenix head of bulk annuities Justin Grainger said: 'Phoenix views longevity reinsurance as a key risk management tool. This transaction brings further depth to our reinsurer relationships and enhances our ability to offer competitive terms to pension schemes as we continue to develop our de-risking proposition'. Prudential Financial head of international transactions for longevity risk transfer Rohit Mathur said: '[PICA] has consistently focused on supporting the entire UK pension de-risking market. The addition of Phoenix is a culmination of our efforts over the past several years to do just that. We have invested in our pricing and transaction teams and ...and we are happy to be in a position to support the robust pipeline of pension buy-ins and buy-outs seeking to be completed while market conditions hold'. PICA was advised in this deal by Willkie Farr & Gallagher, while Phoenix was advised by CMS and Eversheds Sutherland.¹⁰⁶
- In September, Rothesay announced it would raise an additional £500m in shareholder capital to support its longevity risk transfer business – which in 2019 alone executed around £10bn in new deals.
- In November, L&G agreed to provide annuities to Prudential (UK) customers with guaranteed rates. As part of the deal, all guaranteed benefits will be honoured by Prudential (UK) and fulfilled by L&G. As mentioned above, Prudential (UK), while remaining a UK-registered company, is closing down its UK operations in order to grow its businesses in the Far East.
- In November, PIC converted a £800m longevity swap – originally executed in 2017 with L&G – for a £750m buy-in for Scottish & Southern Energy (SSE) on the back of improved funding for the pension scheme. This is the first example of a transfer of obligations between counterparties where the first counterparty (L&G) could have offered the buy-in itself. In novating the swap between counterparties, it is another important milestone in bringing an early form of liquidity to the longevity swaps market. The first conversion of a longevity swap to buy-in took place in 2016 (by Phoenix Life) and the SSE conversion is the fifth one to date. PIC said that a longevity swap provides a useful first step towards a buy-in.¹⁰⁷
- In November, Scottish Friendly bought the back book of Canada Life's 127,000 life and pensions policies, with assets under management increasing by £2.4bn as a result.
- There was a modest recovery in annuity sales following the big fall in sales after the 'Freedom and Choice' reforms of 2015. There were 74,000 (internal and open market) annuity purchases in 2018/19. Annuity rates for 65-year olds were 4%,

¹⁰⁵ <https://www.professionalspensions.com/news/3077264/-deploys-blockchain-technology-streamline-pension-reinsurance>

¹⁰⁶ Holly Roach (2019) PICA launches reinsurance counterparty to back UK bulk annuities, *Professional Pensions*, 5 August.

¹⁰⁷ Susanna Rust (2019) Energy scheme completes rare longevity swap to buy-in conversion, *IPE*, 13 November.

which although low by historical standards, exceeded the 3% that a lower-risk fund recommended as a sustainable withdrawal rate.¹⁰⁸

There were a number of reasons explaining the strength of the UK longevity risk transfer market in 2018 and 2019. First, funding levels had improved as a result of deficit reduction contributions and strong equity returns, which increased asset values, and lower liability values due to a combination of higher interest rates and lower mortality improvements since 2011;¹⁰⁹ UK funds exhibited the first surplus in aggregate since 2011.¹¹⁰ Second, there was an increase in capital and competition from insurers which had recruited heavily and so had more staff to model pension scheme mortality, provide price quotations and implement transactions. Third, was an associated increase in reinsurance capacity, which is important since most of the longevity risk assumed by insurers is reinsured with global reinsurers. Fourth, there had been increasing standardization of the frameworks used to execute transfers, with three dominant examples: intermediated, pass through, and captive. Fifth, insurers had been increasing their investment in high yielding illiquid matching assets, such as infrastructure, housing and urban regeneration, and equity release, and had passed on the additional yield (including illiquidity premium) to schemes in the form of lower prices. Sixth, greater certainty over how Solvency II reserving requirements operate had helped to reduce margins for prudence. Finally, once a scheme closes to new entrants, its maturity increases rapidly: the proportion of the scheme's liabilities due to pensioners increases and the average age of non-pensioners also increases. Mature schemes tend to attract more favourable pricing because: scheme data for pensioners tend to be more reliable than for other types of member, there is less uncertainty over the timing and size of future cash flows, and the risk of the actual mortality experience deviating from that which was assumed is lower. All this helped to reduce the capital an insurer is required to hold.¹¹¹ Mercer has estimated that by 2030 more than £600bn of longevity risk transfers will have taken place in the UK, which represents around one-third of UK pension fund assets.¹¹²

Outside the UK, some significant developments took place in 2019, including:

- A longevity swap by RGA Life Reinsurance Company of Canada, covering 45,000 Manulife Canadian annuitants (February).
- A longevity swap by PartnerRe, covering 25,000 Manulife annuitants (March and May).

¹⁰⁸ Greg Nielson (2019) Glimmers of an annuity market renaissance, *Retirement Planner*, 7 November.

¹⁰⁹ This is discussed later.

¹¹⁰ At the end of November 2018, aggregate pension assets were £1.58trn, while aggregate pension liabilities were £1.57trn on a section 179 basis, according to the Pension Protection Fund's *Purple Book*. Some 3,008 schemes had a combined deficit of £137.6bn, while 2,442 schemes had a combined surplus of £151.9bn. During the previous 10 years, FTE100 companies had paid £82bn into their DB schemes in order to reduce their deficits (which equals one-eighth of the £636bn they paid out in dividends). If companies doubled their annual pension contributions to £16.6bn, 30% of schemes could buy-out their pension liabilities in 5 years, and 70% in 10 years (Kim Keveh (2019) Half of FTSE100 DB schemes could buy-out within 10 years, finds Barnett Waddingham, *Professional Pensions*, 1 July).

¹¹¹ Attractive pricing opportunities for buy-in/buy-out, XPS Pensions, *Briefing Note No. 2*, June 2018.

¹¹² Mark Cobley (2019) Pension insurance deals to top £600bn by 2030, says Mercer, *Financial News*, 16 December.

- A €5.5bn longevity swap by Canada Life Re, covering 150,000 in-payment and deferred pensioners liabilities of Dutch firm VIVAT (March).
- A €12bn longevity swap by Canada Life Re, for Dutch insurer Aegon, covering 200,000 in-payment and deferred pensioners (December).¹¹³
- There were also some significant buy-outs and buy-ins, e.g., PICA's \$1.8bn buy-out of the Lockheed Martin pension scheme and a C\$200m buy-in with an unnamed Canadian scheme executed by Brookfield Annuity Company and reinsured by L&G; this was L&G's first transaction in Canada.
- LifeXcel, a trading platform for mortality-linked contracts (MLCs), such as life settlements, was established in the US for institutions and hedge funds only. LifeXcel is an alternative assets administration company, specializing in structuring, distributing, and managing portfolios of MLCs. In 2021, the platform opened to 'accredited investors' in the US.

The introduction of third-party capital

We had mentioned earlier the problem of capacity constraints in the insurance and reinsurance industries. Our conference series is explicitly about capital markets solutions to the problem of transferring longevity risk. When the modern form of the longevity risk transfer market started in 2006, investment banks, such as J.P.Morgan, with their links to capital market investors, became active in the market along with insurers. However, the Global Financial Crisis in 2007-08 and the 2010 US Dodd-Frank (Restoring American Financial Stability) Act which followed led to the majority of investment banks withdrawing from the market. A few banks with insurance subsidiaries – such as Goldman Sachs, owner of Rothesay Life, and Deutsche Bank, owner of Abbey Life – remained for a while before they too sold their life businesses. So for the past few years, the market has been dominated by insurers and reinsurers. However, they are beginning to see that the current growth rates in the market are not sustainable without new sources of external (or third-party) capital.

One new solution to this problem that has emerged recently is the reinsurance sidecar – which is a way to share risks with new investors when the latter are concerned about the ceding reinsurer having an informational advantage. Formally, a reinsurance sidecar is a financial structure established to allow external investors to take on the risk and benefit from the return of specific books of insurance or reinsurance business. It is typically set up by existing (re)insurers that are looking to either partner with another source of capital or set up an entity to enable them to accept capital from third-party investors (Bugler et al. (2021)).

It is established as a special purpose vehicle (SPV), with a maturity of 2-3 years. It is capitalized by specialist insurance funds, usually by preference shares, though sometimes in the form of debt instruments. It reinsures a defined pre-agreed book of business or category of risk. Liability is limited to the assets of the SPV and the vehicle is unrated. The

¹¹³ <https://www.artemis.bm/news/aegon-gets-e12bn-longevity-reinsurance-cover-from-canada-life-re/>

benefit to insurers is that sidecars can provide protection against exposure to peak longevity risks,¹¹⁴ help with capital management by providing additional capacity without the need for permanent capital, and can provide an additional source of income by leveraging underwriting expertise. The benefit to investors is that they enjoy targeted non-correlated returns relating to specific short-horizon risks and have an agreed procedure for exiting; investors can also take advantage of temporary price hikes, but without facing legacy issues that could affect an investment in a typical insurer.

There are a number of challenges to the use of sidecars in the longevity risk transfer market. There is the tension between the long-term nature of longevity risk and investor preference for a short-term investment horizon. There are also regulatory requirements on cedants, affecting their ability to generate a return. These include: the posting of prudent collateral, the underlying assets in the SPV must generate matching cash flows, the risk transfer must be genuine, and the custodian/trustee must be financially strong. There is also a risk to cedants of losing capital relief if regulatory requirements are not met or they change.

Three reinsurance sidecars were established at the end of 2017 and the beginning of 2018, with investment capital provided by private equity investors and hedge funds, in addition to insurers and pension funds.

In December 2017, Athene entered into a reinsurance agreement with Voya Financial, covering \$19bn of fixed, indexed and variable annuity liabilities. The matching assets will be managed by Athene Asset Management. By using an ‘enhanced asset management’ strategy and positioning itself for ‘incremental value creation in a more favorable credit spread environment’, the company hopes to generate ‘mid-teens returns’. The capital is supplied mainly by private equity investors, including Apollo, Athene’s parent company, Crestview Partners and Reverence Capital Partners.¹¹⁵

In January 2018, RGA Re and RenaissanceRe, announced a new start-up named Langhorne Re, which will target in-force life and annuity business. The new company has secured \$780m of equity capital from RGA, RenaissanceRe and third-party sidecar investors, including pension funds and other life companies.¹¹⁶

In February 2018, the \$400m Leo Re Ltd 2018-1 collateralized reinsurance sidecar was established between Dutch pension fund manager PGGM and Munich Re as a private ILS deal. The agreement allows PGGM, which manages the pension assets of the Dutch healthcare workers’ scheme, PFZW, to gain access to a share of Munich Re’s portfolio. PGGM will enter into direct ILS trades with counterparties, via quota share arrangements

¹¹⁴ That is, specific individual cashflows that give rise to the greatest uncertainty in value terms.

¹¹⁵ Athene & Apollo get long-term capital in \$19bn annuity reinsurance deal, by Artemis on December 21, 2017; <http://www.artemis.bm/blog/2017/12/21/athene-apollo-get-long-term-capital-in-19bn-annuity-reinsurance-deal/>

¹¹⁶ Steve Evans (2018) Langhorne Re launched by RGA and RenRe as in-force life and annuity reinsurer, *Reinsurance News*, 11 January,

with a reinsurer, for a proportion of the counterparties' underwriting book, thereby sharing in the cedents' risks and underwriting returns.¹¹⁷

By 2021, more than \$20bn in third-party capital from sidecar investors had been deployed to support around \$400bn worth of life and annuity book transfers. There are three categories of transactions. The first is standard spread business, like pension risk transfer, fixed annuities, and fixed indexed annuities. The second focus on mortality risk for inclusion in the same sidecar as annuity risk, thereby offsetting longevity and mortality risks in a capital-efficient way.¹¹⁸ The third is variable annuities which is a more specialist category. The first category is the most common, while the third is the least. Sidecar platforms which cover all three categories include: Atlas Merchant Capital, Berkshire Hathaway, J. C. Flowers & Co, and Varge Agam. Sidecar investors include pension funds (e.g., APG, Canada Pension Plan, Ontario Teachers Pension Plan, PGGM), asset managers (e.g., Blackstone, Invesco, PIMCO), sovereign wealth funds (e.g., Abu Dhabi Investment Authority, NZ Super Fund), private equity and hedge funds (e.g., D. E. Shaw & Co, KKR), ILS funds (e.g., Leadenhall Capital Partners, Securis Investment Partners), endowments and family offices.¹¹⁹

In July, the Channel Island of Guernsey announced it would develop a simplified structure for the ILS market via an all-in-one legal entity that would combine insurance/reinsurance and investment activity in one vehicle – described as a 'Fund of One'. This would create a more transparent vehicle for investors which would promote 'true convergence' in ILS. Investors would establish both an unregulated investment fund and a reinsurance transformer cell. This would remove the need for multiple vehicles and allow a sidecar to have both the risks and the assets held in a single vehicle. This would help to reduce the challenges often associated with multiple vehicles, such as doing business in various jurisdictions, regulation, time zones, account rules, audit, and multiple layers of administration expenses.¹²⁰

Another example of introducing new third-party capital is an initial public offer (IPO). This was the route Swiss Re considered in June 2019 when it proposed listing the shares of ReAssure – its UK closed book life consolidator business – on the London Stock Exchange. The idea was to provide working capital to put into new transactions and grow the UK life insurance book under the SwissRe brand. However, the idea was shelved due to weak demand and, in December 2019, ReAssure was sold to Phoenix for £3.2bn. In the process, Phoenix – which was valued at the time at £5.3bn – became Europe's biggest consolidator of life and pension businesses and justified the acquisition on the grounds that 'there are

¹¹⁷ PGGM's \$400m Leo Re is a private sidecar deal with Munich Re, by Artemis on February 5, 2018; <http://www.artemis.bm/blog/2018/01/02/pggm-secures-140m-leo-re-sidecar-tranche-takes-2018-issue-to-400m/>

¹¹⁸ That is, exploiting the natural hedge in the insurer's balance sheet.

¹¹⁹ Kessler (2021, Table 14).

¹²⁰ Guernsey targets "true convergence" via all in one ILS structure, by Artemis on July 24, 2018; <http://www.artemis.bm/blog/2018/07/24/guernsey-targets-true-convergence-via-all-in-one-ils-structure/>

too many insurance companies in a market which is consolidating..[and the acquisition will] give us the opportunity to capture significant cost and capital synergies'.¹²¹

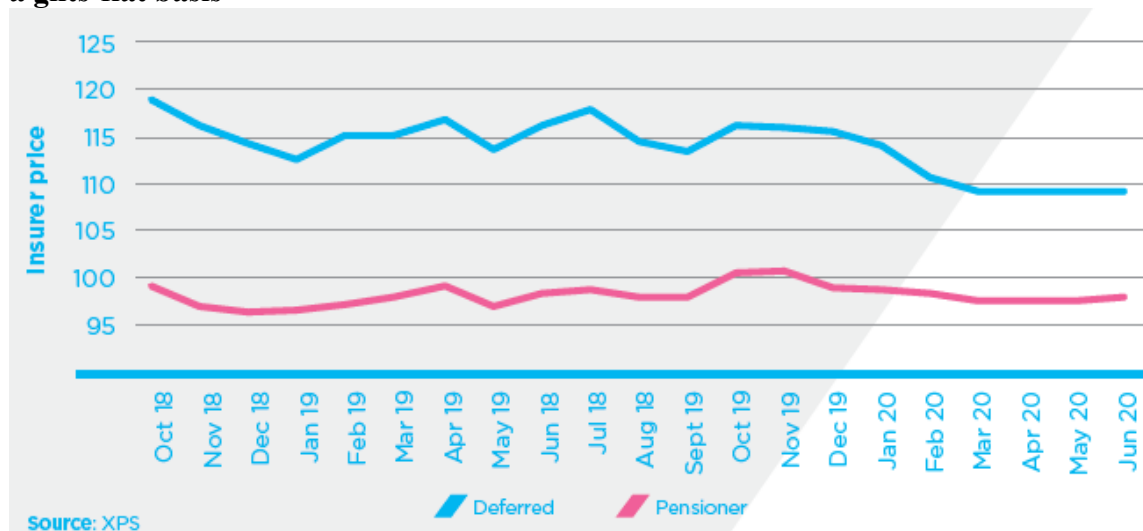
In September 2019, the European Life Settlement Association launched the ELSA Master Agreement for Tertiary Transactions (MATT). The aim was to develop an industry standard purchase and sale agreement to make tertiary transactions more cost and time efficient – in a similar manner as the ISDA Master Agreement.¹²²

2020

Longevity risk transfers

2020 was a near record year for the longevity risk transfer market in the UK at £55.8bn. LCP and Mercer reported that £31.7bn of buy-ins and buy-outs and £24.1bn of longevity swaps were completed during the year. L&G had a 24% market share, followed by Rothesay with 22%, Aviva and PIC both on 19%.¹²³

Figure 1: Bulk annuity pricing 2018-2020 – buy-out price relative to £100 liability on a gilts-flat basis



Source: XPS Risk Transfer News, 8/20

One explanation was that bulk annuity pricing fell slightly compared with 2019. Pensioner pricing was based on a ‘gilts + 0.2% p.a.’ discount rate to value liabilities (instead of ‘gilts + 0.3% p.a.’), while the pricing of deferred pensioner liabilities was based on a ‘gilts –

¹²¹ Matt Sheehan (2019) Swiss Re confirms ReAssure IPO is set for July, *Reinsurance News*, 14 June; <https://www.reinsurancene.ws/swiss-re-confirms-reassure-ipo-is-set-for-july/>. Louis Ashworth and Michael O’Dwyer (2019) Phoenix boss bows out with £3.2bn takeover of insurance rival ReAssure, *Daily Telegraph*, 7 December.

¹²² <https://www.derivsdocu.com/services/consultancy/What-is-an-ISDA-Master-Agreement/>

¹²³ UK. Pension longevity risk transfers reach record-breaking £55.8bn in 2020, *Pension Policy International*, 19 March 2021.

0.35% p.a.’ liability (instead of ‘gilts – 0.5% p.a.’). This implied that a buy-out for pensioners was cheaper than using gilts for pensioners in payment (equivalent to valuing liabilities on a gilts-flat basis) – see Figure 1.¹²⁴

Highlights for 2020 in the UK included:

- In January, Securis Investment Partners announced that they had completed a capital market derisking deal – a longevity swaption – with a ‘large well-known life risk carrier’: ‘we have taken structured longevity risk on a specific block of business. The transaction was structured as an indemnity derisking tool, i.e., without the use of any longevity indices, as a way to optimize the impact for our counterparty even further.. [It involved] a direct risk transfer to a Securis fund with no intermediary involved,...and was a first in terms of regulatory approval’.¹²⁵
- In January, PIC said it would raise £750m in additional capital from existing investors to continue expanding its buy-out business. At the time, it managed £40.9bn on behalf of 225,000 pension scheme members.¹²⁶
- Also in January, Pacific Life Re executed a £10bn longevity swap with three Lloyds Banking Group pension schemes – the second largest on record. The deal covers pensioner liabilities in the Lloyds Bank Pension Schemes No.1 and No.2 and the HBOS Final Salary Pension Scheme. The deal was structured as an insurance contract with Scottish Widows as the insurer and Pacific Life Re as the reinsurer.¹²⁷
- In February, PIC agreed a £1.6bn buy-in with the Merchant Navy Officers’ Pension Fund covering 14,000 members, in the process taking over a longevity swap that the fund initially executed with Pacific Life Re in 2014, using a Guernsey captive cell insurance company arrangement offered by Willis Towers Watson. This is another example of the novation of a swap to an annuity.¹²⁸
- In February, Aviva and PIC each completed a £1bn buy-in with the Co-operative Pension Scheme. The deal was completed using a pre-agreed ‘umbrella contract’ designed to support a quick and efficient continuous process, each one covering 7,000 members. In May, Aviva completed a £350m buy-in transaction with the Co-operative Scheme covering an additional 2,300 members.¹²⁹
- In February, PICA executed a \$6bn reinsurance transaction with Rothesay Life.¹³⁰

¹²⁴ Nick Reeve (2020), Longevity and risk transfer: A booming market, *IPE*, February; *XPS Risk Transfer News*, 8/20.

¹²⁵ Email announcement from Luca Tres, 8 January 2020. See also Paul Fulcher and Luca Tres (2019) A capital management toolkit for life re/insurers, *InsuranceERM*, 14 March; <https://www.insuranceerm.com/analysis/a-capital-management-toolkit-for-life-reinsurers.html>

¹²⁶ Emily Horton (2020) Pension Insurance Corporation to raise £750m from backers, *Financial News*, 28 January.

¹²⁷ James Phillips (2020) Lloyds schemes agree £10bn longevity swap with Pacific Life Re, *Professional Pensions*, 29 January; Lloyds Banking Group pension schemes strike £10bn longevity swap, *IPE*, 29 January 2020.

¹²⁸ Susanna Rust (2020) Merchant navy fund converts longevity swap to £1bn buy-in, *IPE*, 19 February.

¹²⁹ Susanna Rust (2020) Co-op pension scheme insures more liabilities as PIC deal disclosed, *IPE*, 19 February. Aviva in £350m bulk annuity deal with Co-operative Pension Scheme, *Reinsurance News*, 14 May 2020.

¹³⁰ Ditto.

- In February, the AIB Group UK Pension Scheme completed a £1.1bn de-risking transaction with L&G, comprising a £850m buy-in combined with a £250m assured payment policy (APP).¹³¹ The APP hedges the scheme's investment risk by protecting against changes in asset yields, interest rates and inflation, giving the scheme increased surety of being able to reach a full buy-out over a planned timeframe.¹³²
- In March, the Xylem UK Pension Plan completed a £255m bulk annuity transaction with Rothesay Life, covering around 2,500 final salary section members.¹³³
- In March, L&G announced that it executed eight PRT deals worth £261m, ranging in size between £2.2m and £80m.¹³⁴
- In March, the General Healthcare Group (GHG) Pension & Life Assurance Plan secured a £150m buy-in contract with Aviva to cover all 700 of its defined benefit members.
- In May, L&G completed a £650m buy-in with the 3i Group Pension Plan.¹³⁵

¹³¹ An assured payment policy is an insurance policy that provides the pension scheme with protection against investment-related risks, such as changes in asset returns, interest rates and inflation. It was developed by L&G. APPs:

- Provide a pre-agreed series of future payments, which may be fixed or inflation-linked.
- Similar in nature to a buy-in, with the crucial difference being that APPs do not vary with longevity risk or other demographic experience. Compared with bulk annuities, they will be cheaper by around 15-20% for deferred pensioner members, but will be more expensive for pensioner members.
- Held as a pension scheme asset.
- Can apply to any sub-set of a pension scheme's liabilities.
- Can be used in combination with other de-risking solutions, such as pensioner buy-ins.

APPs can best be thought of as:

- Partial insurance: an APP locks down investment risk now, with a clear structure for adding the remaining pension-related risks in the future to 'complete the bulk annuity'; or
- An investment: an APP allows a pension scheme to 'build its own bond', with tailored inflation coverage and no exposure to market and reinvestment risk, while achieving a yield in excess of gilts.

APPs work as follows:

- An APP's fixed or inflation-linked pre-agreed payments are designed to match all or some of a pension scheme's liabilities.
- The trustees pay an upfront premium, as per a bulk annuity. In exchange, a payment schedule is agreed at outset, and payments are made by the provider to the trustees of the pension scheme as per that schedule.
- APPs can be structured to allow for conversion to buy-in or buy-out, including through a series of partial conversions over time. This flexibility, and the effective and transparent conversion mechanics, create a more certain de-risking journey.

Source: <https://www.legalandgeneral.com/institutional/pension-risk-transfer/what-we-offer/app/>

¹³² AIB UK scheme completes £1.1bn de-risking deal, *IPE*, 13 February 2020. In May 2021, £61m of the AIB Group's APP was converted into a buy-in policy, which L&G said shows 'how APPs facilitate the de-risking journey'.

¹³³ Xylem UK Pension Plan secures £255m bulk annuity deal, *Pensions Age*, 2 March 2020.

¹³⁴ L&G completes £261m of pension risk transfer deals in March, *Pension Policy International*, 3 April 2020.

¹³⁵ L&G agrees £650m buy-in with 3i scheme, *Professional Pensions*, 27 May 2020.

- Also in May, L&G completed a £70m buy-in for the ICI Pension Fund, the fund's 17th de-risking deal.¹³⁶
- In June, the pension scheme of the Willis Group, now part of Willis Towers Watson, entered into a longevity swap with Munich Re. The swap covered £1bn pensioner liabilities of around 3,500 members. The longevity risk was transferred to the reinsurer via a Guernsey-based captive insurance company fully owned by the trustee of the scheme. It was established under Willis Towers Watson Guernsey ICC Limited, which is part of Willis Towers Watson's Longevity Direct solution allowing pension schemes to use a 'ready-made' incorporated cell company to access the reinsurance market.¹³⁷
- In June, PIC executed a £280m longevity reinsurance deal with MetLife.¹³⁸
- In July, the UBS (UK) Pension and Life Assurance Scheme executed a £1.4bn longevity swap with Zurich Assurance, covering around half the longevity risk in its £3bn DB scheme. Mercer, which acted as the adviser to the trustees, said the deal was structured as an 'innovative "pass through"' insurance contract, with 100% of the longevity risk reinsured by Canada Life Re.¹³⁹
- In July, UBS executed a £1.4bn longevity swap with Zurich.¹⁴⁰
- In July, the LV= Employee Pension Scheme converted a longevity swap held with ReAssure into a £800m buy-in with Phoenix Life. The buy-in covered the 4,100 pensioners and 200 deferred members who had been covered by the longevity swap, which had been agreed in 2012 and reinsured by Swiss Re. Swiss Re will continue to cover the longevity risk by providing reinsurance to Phoenix Life.¹⁴¹
- In July, the DB pension fund of Premaberg Holdings Limited, a UK manufacturer, completed a £5m bulk annuity transaction covering 50 members, of which around 80% are pensioners in payment. The buy-in was executed with Just Group and completed using Mercer's streamlined quotation service, which monitors buy-in pricing, demonstrating that 'smaller schemes can and do achieve successful bulk annuity transactions, despite continued high demand from much larger schemes'.¹⁴²
- In July, the superannuation scheme for a farmers' cooperative secured the benefits of all its 120 members via a £13m buy-out with L&G.
- In July, the Countrywide Farmers Retirement Benefits Scheme agreed a £100m bulk annuity deal with L&G covering the benefits of 360 deferred members and 712 retirees. The scheme had entered the PPF assessment¹⁴³ in March 2018 following the insolvency of its sponsor, a rural retailer, livestock feed and energy supplier. However, it was overfunded on a PPF measure, and was therefore able to complete a so-called 'PPF+' transaction with L&G, which provided enhanced

¹³⁶ ICI fund teams up with Legal & General for 17th buy-in, *IPE*, 13 August 2020.

¹³⁷ Willis pension scheme strikes £1bn longevity hedge with Munich Re, *IPE*, 30 June 2020.

¹³⁸ <https://www.artemis.bm/news/metlife-enters-uk-longevity-reinsurance-market-with-pic-transaction/>

¹³⁹ UBS UK pension scheme enters into £1.4bn longevity hedge, *IPE*, 7 July 2020.

¹⁴⁰ *Aon's Risk Settlement Market Review 2020*.

¹⁴¹ <https://www.pensionsage.com/pa/LV-converts-longevity-swap-into-800m-Phoenix-Life-buy-in.php>

¹⁴² £5m deal shows small schemes' ability to access bulk annuity market, *IPE*, 22 July 2020.

¹⁴³ That is, being considered for inclusion in the PPF due to sponsor insolvency.

- benefits compared with those available from the PPF, but less than those available from a full buy-out.¹⁴⁴
- In August, the Littlewoods Pensions Scheme insured all its pension liabilities with a £930m buy-in covering deferred members with Rothesay Life, following a £880m buy-in covering pensioners with Scottish Widows in 2018.¹⁴⁵
 - Also in August, Hitachi UK agreed a £275m buy-in transaction for the remaining deferred and pensioner members of its DB pension scheme with L&G. Hitachi's first buy-in was with Scottish Widows in 2018.¹⁴⁶
 - In October, the Old British Steel Pension Scheme agreed a £2bn buy-in covering 30,000 members with PIC, with a buy-out expected at a later date.¹⁴⁷
 - In October, Rothesay executed a \$320m longevity reinsurance deal with MetLife.¹⁴⁸
 - In November, the Marks & Spencer Pension Scheme completed a third set of buy-ins with Aviva (for £390m) and Phoenix (for £360m), with 80% of the scheme's £3.7bn pensioner liabilities now insured. Both of the new transactions were carried out under 'umbrella contracts' entered into in 2018.¹⁴⁹
 - In November, the Prudential (UK) Staff Pension Scheme agreed a £3.7bn longevity swap covering 20,000 pensioners. The deal involved a Guernsey-based captive insurance company owned by the scheme trustees, which provided access to the reinsurance market. Artex Risk Solutions established the captive entity, with Pacific Life Re as the reinsurer.¹⁵⁰
 - In November, the £2.9bn Pearl Group Staff Pension Scheme, one of Phoenix Group's pension schemes, completed a £731m buy-in with the group's life assurance company, Phoenix Life.
 - Also in November, the £1.4bn Baker Hughes UK pension plan completed a £100m buy-in with Just Group.
 - Smiths Group completed a £290m buy-in with Aon as consultant in the August-December period.¹⁵¹
 - In December, the Barclays Bank UK Retirement Fund completed a £5bn longevity swap transaction with RGA. Aon advised on all aspects of the transaction, including risk analytics, design and structuring, reinsurance selection and operational establishment. Tom Scott, principal consultant in Aon's risk settlement team, said: 'This transaction...demonstrates the capacity and appetite of the global reinsurance market to take on pension fund longevity risk, even in these challenging times'.¹⁵²

¹⁴⁴ Pension scheme of collapsed rural retailer agrees £100m bulk annuity, *IPE*, 30 July 2020.

¹⁴⁵ Littlewoods scheme completes de-risking with £930m buy-in, *IPE*, 12 August 2020.

¹⁴⁶ Lounon Pratt (2020) Hitachi UK completes £275 million pensions buy-in transaction, *Employee Benefits*, 26 August; <https://employeebenefits.co.uk/hitachi-pensions-buy-in-transaction/>

¹⁴⁷ Pension Insurance Corporation buys British Steel pension fund in £2bn deal, *Financial News*, 22 October 2020.

¹⁴⁸ <https://www.artemis.bm/news/metlife-reinsures-320m-of-pension-longevity-risk-for-rothesay-life/>

¹⁴⁹ M&S tops up de-risked pensioner liabilities with £750m set of buy-ins, *IPE*, 4 November 2020.

¹⁵⁰ Prudential Staff Pension Scheme agrees £3.7bn longevity swap, *IPE*, 11 November 2020.

¹⁵¹ *Aon's Risk Settlement Market Review 2020*.

¹⁵² Barclays Bank UK scheme agrees £5bn longevity swap transaction, *IPE*, 14 December 2020.

- In December, the BBC Pension Scheme completed a longevity swap that covers more than £3bn of pensioner liabilities, Zurich Life was the insurer, while reinsurance was provided by Canada Life Re. The swap covers around one-third of the scheme's pensioner and dependant members.¹⁵³
- In December, L&G executed a \$2bn longevity reinsurance deal with MetLife.¹⁵⁴ It also completed a £400m APP with the L&G Group UK Senior Pension Scheme, covering 200 deferred members and 385 pensioner members.
- In December, the National Grid UK Pension Scheme completed an £800m buy-in with Rothesay.¹⁵⁵
- In December, Maersk agreed £1.1bn buy-in with L&G.
- Also in December, the Aon Retirement Plan completed a £510m pensioner buy-in with Scottish Widows.¹⁵⁶
- Finally, Willis Towers Watson completed a £3.3bn buy-in with an unnamed company, the market's largest bulk annuity to date.¹⁵⁷

A number of other key developments took place in the UK in 2020.

In June, Prudential Retirement, a subsidiary of PICA, introduced 'funded reinsurance' to the UK PRT market, with a deal involving UK insurer Aviva. Funded reinsurance allows an insurer to transfer both the asset risk and longevity risk associated with pension and annuity liabilities.¹⁵⁸ It therefore protects the insurer not only from the financial risk of an unexpected increase in life expectancy, but also from unexpected losses in the invested assets. In return for a single premium, the reinsurer pays monthly benefits to the insurer for as long as the insured members live.¹⁵⁹ Before this, Prudential Retirement only reinsured the longevity risk of other insurers. As a consequence of the huge growth in the UK PRT market, insurers have been looking for reinsurance partners to bring in additional capital and asset management expertise in order to help manage the asset and longevity risk they have assumed. Amy Kessler, now head of international reinsurance at PICA, said: 'Our entry into the funded reinsurance business is a natural place for us to expand. The presence of reinsurers like us, with both longevity capacity and asset management capabilities, will allow the UK market to continue to grow in new ways in the years to come. ...At least five

¹⁵³ <https://www.artemis.bm/news/bbc-pension-gets-3bn-longevity-swap-from-zurich-canada-life-re/>

¹⁵⁴ <https://www.artemis.bm/news/metlife-reinsured-2bn-of-longevity-risk-for-lg-in-2020/>

¹⁵⁵ National Grid completes £800m buy-in with Rothesay, *Professional Pensions*, 9 December 2020.

¹⁵⁶ BBC scheme strikes £3bn longevity swap, Aon plan in £510m buy-in, *IPE*, 15 December 2020.

¹⁵⁷ Willis Towers Watson, *De-risking Report 2021: Keep calm and carry on de-risking*; <https://www.willistowerswatson.com/en-GB/Insights/2021/01/keep-calm-and-carry-on-de-risking-de-risking-report-2021>

¹⁵⁸ It has been described as 'akin to a bulk annuity insurer doing its own buy-in behind the scenes. The insurer takes a portion of the buy-in/buy-out premium received from the pension scheme and passes it on to a reinsurer, often but not necessarily overseas. The reinsurer is then on the hook for providing monthly benefit payments to the insurer, and the insurer passes these payments on to the pension scheme or (following buy-out) the pensioners directly.' (Michael Abramson and Lara Desay (2023) The Insurance Regulator Takes a Look at Funded Reinsurance, *Life Risk News*, 2(8), 10 August, https://liferisk.news/the-insurance-regulator-takes-a-look-at-funded-reinsurance/?utm_campaign=life-risk-news-volume-2-issue-8-august-2023).

¹⁵⁹ <https://www.pacificlifere.com/content/dam/plre/GFS-deal-signing-press-release-Final.pdf>

reinsurers... closed funded reinsurance transactions, resulting in meaningful volume and capacity to support the growth in the UK'.¹⁶⁰

In June, PIC announced that it had invested £75m in debt issued by a UK housing association, Trident Housing Association. PIC said the maturity profile of the debt has been tailored to match PIC's pension liabilities in years where it is difficult to source low-risk, long-term, secure cashflows in the public bond markets. It will also meet Trident's borrowing needs to develop more social housing stock. The debt is secured on a pool of housing assets owned by the association.¹⁶¹ In November, PIC invested £65m in Welsh housing association Pobl in order to create 10,000 new homes over the next 10 years, with the debt secured on social housing assets. PIC said: 'This investment complements our portfolio providing low risk, long-term, secure cashflows that match our pension liabilities for decades into the future'.¹⁶²

In July, a report by L&G – *The Power of Pensions: How pension savings can help to build the UK's infrastructure and drive growth in all regions* – suggested that pension risk transfer providers, such as insurers, were willing to invest up to £190bn of pension assets in UK infrastructure over the next decade. According to the report, this would provide 20% of the investment needed to 'to support our society's needs', since investment in infrastructure was the 'key' to maintaining the long-term competitiveness of the UK economy and was 'vital' to delivering the government's 'industrial strategy' and would bring the economic stimulation and employment opportunities needed following the covid-19 pandemic. Long-term infrastructure investments are 'very attractive' to insurers because of their security and ability to generate steady cash flows for paying pensions as they fall due.¹⁶³

However, pension funds face barriers to infrastructure investing. There is a shortage of supply of suitable assets and those that are available face stiff competition from commercial fund managers and sovereign wealth funds which have significant amounts of capital to deploy and are often prepared to accept lower returns. Also while bigger schemes can acquire assets directly, smaller schemes have to invest via infrastructure funds which involve higher fees. Morten Nilsson, chief executive of the British Telecom Pension Scheme, argues that the government could help stimulate supply through the UK Infrastructure Bank which was set up in June 2021 to support infrastructure that drives local economic growth or helps tackle climate change through loans, credit enhancement and equity investments. It has a £22bn budget, split between £12bn of equity and debt capital, and the ability to issue £10bn of government guarantees.¹⁶⁴

¹⁶⁰ Prudential Retirement enters funded reinsurance business, 30 October 2020; <https://news.prudential.com/prudential-retirement-enters-funded-reinsurance-business.htm#.X5wS1QIIOSE>.linkedln; Kessler (2021).

¹⁶¹ UK housing association Trident secures £75m funding from PIC, *IPE*, 19 June 2020.

¹⁶² PIC invest a further £65m in Welsh housing association Pobl, *IPE*, 26 November 2020.

¹⁶³ PRTs could help plug UK infrastructure 'mega-gap' – L&G, *Pension Policy International*, 9 July 2020.

¹⁶⁴ Val Cipriani (2021) Pension funds 'outcompeted' on UK green infrastructure investments, *Pensions Expert*, 29 November 2021; <https://www.pensions-expert.com/Investment/Pension-funds-outcompeted-on-UK-green-infrastructure-investments>

The most significant pension event of 2020 was the introduction in June by TPR of an interim regulatory regime for the superfund pension consolidation market.¹⁶⁵ This is the market where pension schemes are consolidated into a larger fund, while remaining legally classified as pension schemes.¹⁶⁶ Consolidators must be able to demonstrate that they are well-governed, run by fit and proper people, and are backed by adequate capital, thereby reducing the chance that they later become insolvent and fall back on the PPF which bails out the pension schemes of insolvent sponsors.

Transferring to a consolidator might be a preferred option for a sponsoring company that wants to remove its pension liabilities, but cannot afford a full buy-out. The interim regime also explains how consolidators will be assessed and regulated. Capital adequacy is a key aspect of TPR's interim regime, since there will no longer be an employer covenant. TPR will require superfunds to hold sufficient assets to meet the promises to savers with a high degree of certainty. This will include the requirement for the scheme's liabilities (or technical provisions) to be calculated using specific assumptions set out in TPR's guidance and for additional assets to be held in a capital buffer. The interim regime sets a 1-in-100 risk of failure to pay benefits promised to scheme members in full, which is less stringent than the Solvency II regime for insurers which sets a 1-in-200 risk of failure. Superfunds must not extract any surplus from a scheme or its capital buffer until such time as either the pension liabilities are bought out with an insurer or final payments have been made. The interim regime will eventually be replaced by a legislative authorization and supervision framework.

Trustees need to be certain that a transfer to a superfund is in their members' interests. In October, TPR issued further guidance to trustees, setting out, three 'gateway principles' that transactions with superfunds must meet:

- A transfer to a superfund should only be considered if the scheme cannot afford to buy out now;
- A transfer to a superfund should only be considered if a scheme has no realistic prospect of buy-out in the foreseeable future, given potential employer cash contributions and the insolvency risk of the employer; and
- A transfer to the chosen superfund must improve the likelihood of members receiving full benefits.

TPR said: 'We expect ceding employers to apply for clearance in relation to a transfer from their scheme to a superfund, and for trustees to demonstrate they have done their due diligence in respect of the transfer'. Marc Hommel, senior pensions adviser at EY, said the guidance 'further signals that the government and pensions regulator are backing employers to access superfunds as more affordable solutions to discharge their pension obligations and, in distressed situations, for trustees to have better options for their

¹⁶⁵ <https://www.thepensionsregulator.gov.uk/en/media-hub/press-releases/2020-press-releases/tpr-launches-tough-new-interim-regime-for-emerging-superfund-pension-market>

¹⁶⁶ This contrasts with buy-outs where the liability for paying pensions is transferred to an insurance company.

members relative to the Pension Protection Fund. In the near term, superfund transactions are likely to take place only where the employer is distressed or insolvent'.¹⁶⁷

The introduction of the interim regime renewed the debate between the consolidators and insurers about which model of PRT was safer. Insurers complain that because superfunds operate as pension funds, there is no legislation which sets standards on their capital requirements or investment strategy. Hetty Hughes, policy adviser at the Association of British Insurers (ABI), argued: 'By underwriting superfunds with the PPF, you are potentially privatizing the gains and socializing the losses'.

However, superfunds counter that they must also hold a capital buffer, and, unlike insurers, they cannot distribute profits to investors for three years. Antony Barker of the Pension Superfund even argues that superfund capital requirements are more onerous than those of the insurers: 'If you do the maths on their one-year test versus our five year test, they have to hold less capital than us. For the schemes in PPF assessment, insurers can cut members' benefits unilaterally in securing them, but superfunds cannot'.

Nevertheless, Hughes believes that the interim guidance is insufficient. Her concern is that superfunds are targeting well-funded schemes: 'That is where the risk of regulatory arbitrage becomes more acute. The regime doesn't need to be Solvency II compliant as it is trying to serve a market that can't afford a buy-out, but that doesn't mean the regime doesn't need to have similar features to Solvency II. For example, the life insurance industry has undergone stress tests recently, where they have to measure the impact if half their assets' credit rating were downgraded. This was found to be manageable, whereas TPR guidance simply says that superfunds can do their own homework and come up with their own stress tests. The regulator imposing a three-year ban on passing profits to investors, is still insufficient. We might not see legislation for another five years and the guidance also says that the three-year rule is under review. What it doesn't say is that there are other ways of extracting value other than dividends. Performance fees and management fees are examples of the instructions private equity firms tend to put in place'. Andrew Bailey, the governor of the Bank of England, has also warned that the lack of firmer rules in TPR's interim guidance could pose a risk to financial stability.

It is certainly appears to be the case that superfunds have greater flexibility than insurers over investment strategy and can take on more investment risk. The Pension Superfund, for example, has a target allocation of 80% in a liability-driven investment (LDI) strategy,¹⁶⁸ with the rest in return-seeking assets. Barker accepts that, unlike insurers, superfunds have more freedom to adjust this target portfolio to the allocation that schemes already have in place: 'Our actual strategy will be driven to some extent by the schemes we inherit. One of our unique features is that we novate the schemes' existing portfolios. That ensures that our transaction costs are lower. So, if people already have private equity, we don't need them to sell it to provide us with cash and government bonds. The return-

¹⁶⁷ UK regulator delivers superfund guidance for trustees, sponsors, *IPE*, 21 October 2020.

¹⁶⁸ Huw Jones and Sinead Cruise (2022) What is LDI? Liability-Driven Investment strategy explained, Reuters, 12 October 2022; <https://www.reuters.com/markets/europe/what-is-ldi-liability-driven-investment-strategy-explained-2022-10-04/>.

seeking assets are going to be drawn from public and private markets, but will probably allow us to focus more on private markets and illiquid assets because we expect that our peak cash-flows are going to be in the late 2030s to early 2040s so that gives us a lot of time to invest in illiquids. We can look at infrastructure, private equity, insurance-linked securities, land, property and other real assets’.

Chris Clark, DB policy lead at TPR, says: ‘We don’t see superfunds as a replacement for insurance, they are not targeting an insurance level of guarantee, but there are many schemes out there that can’t afford that level of guarantee. For trustees considering a transfer, it is vital that they are doing so because it is in the best interest of scheme members’. Yet, David Weeks, co-chair of the Association for Member Nominated Trustees, points out that currently superfunds do not allow for member nominated trustees with any say in scheme governance.¹⁶⁹

In October, a third superfund consolidator, Stoneport, joined the market. It was established by actuarial consultant Punter Southall with the aim of targeting the 4,350 DB schemes with fewer than 1,000 members. Punter Southall’s own small DB scheme has joined up. Stoneport has the following aims: ‘To address the growing number of problems facing trustees and sponsoring employers of small schemes, Stoneport [aims] to target running cost, investment management and end-game efficiencies, as well as improving governance standards’. Small schemes have running costs of £1,000 per member per year, compared with less than £100 for the largest schemes, leading to potential long-term savings of £40bn, comprising savings in lifetime running costs of £10bn, reduced investment management costs, the dividend from good governance, and the saving from joining together for an eventual buy-out.¹⁷⁰ In December 2021, Stoneport appointed Mobius Life as its investment platform provider. The platform will host Stoneport’s investment funds which small schemes will be able to access without having to do their own market research.¹⁷¹

Another innovation in 2020 was the introduction of ‘third-party capital solutions’ (TPCSs).¹⁷² These involve investors who provide a ‘helping hand’ to pensions schemes in the form of an additional capital buffer to schemes planning for a buy-out (or even just to achieve self-sufficiency) at a future target date if pre-agreed funding thresholds are not met. The link between the sponsor, the scheme and the trustees is maintained, so this model is different from the superfund model. It is also different from a buy-in which involves the bulk purchase of an annuity from an insurer. The model is most similar to the reinsurance sidecar discussed earlier, although with differences.

With a TPCS, the investors have a bigger influence on the investment strategy of the scheme. Indeed, the scheme trustees need to agree an investment strategy with the investors

¹⁶⁹ Quoted in Mona Dohle (2020) Superfunds – New entrants to the DB consolidation market, *Portfolio Institutional*, 17 August.

¹⁷⁰ New DB consolidator targets UK’s small schemes, *IPE*, 20 October 2020.

¹⁷¹ <https://www.ipe.com/news/uk-db-consolidator-appoints-mobius-life/10056678.article>

¹⁷² Willis Towers Watson, *De-risking Report 2021: Keep calm and carry on de-risking*; <https://www.willistowerswatson.com/en-GB/Insights/2021/01/keep-calm-and-carry-on-de-risking-de-risking-report-2021>

which will incorporate a return on the capital provided. The investment strategy can target higher returns and possibly enable lower sponsor contributions, since the capital buffer gives greater downside risk protection. However, once the investment strategy has been agreed, it cannot be changed without the consent of the investors, and the downside protection is limited to the size of the capital buffer. On the target date, if the scheme is sufficiently well funded to achieve a full buy-out, both the scheme and capital structure are wound up, with investors getting back their capital in full; otherwise the scheme reverts to normal operations and the investors receive a partial return of capital. TPCS investors are looking at schemes with a strong sponsor covenant, with liabilities below £250m, which are at least 85% funded on a buy-out basis, and with a significant proportion of total liabilities in the form of deferred pensions.

International developments outside the UK in 2020 included:

- In May, NN Life, executed a €13.5bn longevity reinsurance and swap transaction covering a portfolio of annuity policies for over 200,000 pensioners and dependants. The deal was reinsured with Canada Life Re, Munich Re and Swiss Re, and NN Group said it would lower its required capital and strengthen its capital position, with a 25 percentage points increase to its Solvency II ratio, which at the end of April 2020 stood at 220%. There will be an immediate upfront capital benefit, as well as lower future operating capital generation of approximately €90m p.a., although the ongoing longevity reinsurance premiums will reduce the IFRS operating result before tax by approximately €30m p.a.¹⁷³
- In June, actuarial consultant Milliman released the results of its new Milliman Pension Buy-out Index (MPBI) for the US. The MPBI uses the FTSE Above Median AA Curve, along with annuity purchase composite interest rates from a number of insurers, to estimate the average cost of a PRT annuity de-risking strategy. During May, the estimated cost to transfer retiree pension risk to an insurer dropped from 105.5% to 103.9% of a scheme's pension liabilities, as measured by its accumulated benefit obligation (ABO). The explanation for the fall is that discount rates in May dropped 27 basis points compared to a 10 basis point drop for annuity purchase rates, resulting in the relative cost of annuities decreasing by 1.6 percentage points.¹⁷⁴
- The launch in August by Australian annuity provider Challenger – Australia's largest provider of annuities¹⁷⁵ – of a guaranteed floating rate lifetime annuity, with payments linked to the Reserve Bank of Australia (RBA) cash rate, so that annuitants would gain from any increase in interest rates.¹⁷⁶
- In September, Mercer's US pension buy-out index indicated that the buy-out cost was only 97.7% of a US DB plan's accounting obligations, making buy-outs

¹⁷³ <https://www.artemis.bm/news/nn-life-transfers-eur-13-5bn-of-pension-longevity-risk-to-reinsurers/>; Aon's Risk Settlement Market Review 2020.

¹⁷⁴ Milliman analysis: Estimated cost of retiree pension risk transfer drops significantly, from 105.5% to 103.9% in May, *Pension Policy International*, 24 June 2020.

¹⁷⁵ <https://www.challenger.com.au/about-us/challenger-group>

¹⁷⁶ Australia. Challenger launches floating rate annuity, *Pension Policy International*, 24 August; <https://pensionpolicyinternational.com/challenger-launches-floating-rate-annuity/>

increasingly attractive. This followed a number of amendments to the US index which was originally launched in 2013 in response to changing to market conditions, including:

- competition – the number of insurers who compete for annuity and buy-out transactions has doubled since 2012;
- investments – insurer pricing is generally driven by the ability of insurers to source higher yielding, less liquid assets, such as private credit and commercial mortgages, which provide a good match for illiquid annuity buy-out liabilities; and
- mortality – insurers have evolved their mortality underwriting techniques to better assess mortality risk at the individual participant level. This may often lead to lower pricing especially for transactions with smaller benefits and/or where benefit accruals have been frozen for many years.

By contrast, the estimated long-term costs of maintaining pension liabilities on sponsor balance sheets was 105.2%, which reflects costs not included in accounting liabilities (i.e., ABOs), such as Pension Benefit Guaranty Corporation (PBGC)¹⁷⁷ premiums, investment management and administration fees, and the risk associated with fixed-income defaults and downgrades.¹⁷⁸

- In November, Milliman’s US Pension Buy-out Index was modified to reflect the impact of competitive pricing on estimated buy-out cost and two new insurers were added to the index: Massachusetts Mutual Life Insurance Co. and Banner Life Insurance Company (Legal & General America). During September, the average estimated cost to transfer retiree pension risk to an insurer decreased by 60 basis points, from 102.9% of a plan’s total liabilities to 102.3% of those liabilities, measured on a retiree ABO basis. Annuity purchase costs were even lower at 100.2% (down from 101.0% in August).¹⁷⁹
- L& G completed its first two cross-country PRT transactions in 2020. The first, in May, covered IHS Markit’s UK and US pension plans. The UK deal was for £37.8m and covered 150 members in the IHS (Global) Ltd. Pension and Life Assurance Scheme. The US deal was for \$97.2m and covered 1,200 members in the IHS Retirement Income Plan.¹⁸⁰ In December, US chemicals company Evonik agreed a £544m full buy-in with L&G for its four UK pension schemes. This built on a \$93m ‘lift-out’ completed by L&G for the US Evonik Corporation Retirement Plan in September. In a lift-out, a subset of pension scheme members are lifted out and

¹⁷⁷ The PBGC is a mandatory US federally-chartered insurance plan that pays pensions to members of private defined benefit pension plans when the sponsor has become insolvent; <https://www.pbgc.gov/>

¹⁷⁸ Revised Mercer U.S. Pension Buyout Index Methodology Shows That Costs of Annuity Buyouts Could Be Less Than Accounting Liability, *Pension Policy International*, 18 September 2020; <https://pensionpolicyinternational.com/revised-mercero-u-s-pension-buyout-index-methodology-shows-that-costs-of-annuity-buyouts-could-be-less-than-accounting-liability/>

¹⁷⁹ Milliman expands Pension Buyout Index to include competitive pricing rate, which drops to 100.2% in September, *Pension Policy International*, 4 November 2020; <https://pensionpolicyinternational.com/milliman-expands-pension-buyout-index-to-include-competitive-pricing-rate-which-drops-to-100-2-in-september/>

¹⁸⁰ <https://www.ipe.com/news/uk-roundup-tpr-pipes-up-over-inter-dc-transfers-cross-country-prt-deal/10045567.article>

transferred to an insurance company.¹⁸¹ The main reason for a lift-out are to reduce administrative costs and, especially, the PBGC fixed-rate premiums of around \$83 per participant.¹⁸²

For many PRT providers, 2020 was a record year with L&G, for example, completing more than 60 deals worth over £8bn across its US and UK businesses.¹⁸³ Actuarial consultant Hymans Robertson has pointed out that since the PRT market took off in 2007, UK buy-ins/buy-outs (£180bn) and longevity swaps (£110bn) have insured £300bn of risk from DB pension schemes and expects an additional £700bn by the end of 2031, resulting in £1trn of DB pension scheme risk – around 50% of the total – being insured by then.¹⁸⁴

The Covid-19 pandemic

The most significant global event of 2020 was, of course, the Covid-19 pandemic.¹⁸⁵ There was no longevity conference in 2020 as a result. Here we discuss the implications of the pandemic for pension schemes and the PRT market.

A study in May 2020 by Cairns et al (2020) of the UK predicted that if total Covid-19 deaths were capped at around 80,000, then this would have little overall effect on pension liabilities. By June 2022, total UK Covid-19 deaths were 200,000.¹⁸⁶ Liabilities fell since some pensioners would die, especially those in care homes, and that would be offset by a small increase in the average life expectancy of survivors. The UK government announced that it would save around £600m in state pension payments in 2020 as a result of an increase in excess deaths among the elderly. Given state spending on pensions of £100bn, this amounts to a reduction of 0.6%.¹⁸⁷ Given that pension scheme members are typically from higher socio-economic groups than the average, we should expect the liabilities of pension schemes to fall by less than this.

LCP's 2020 *Longevity Report* predicted that the value of a typical UK defined benefit scheme's net liabilities might fall by less than 0.25% as a direct result of the deaths of pensioners arising from Covid-19 in 2020. Since, total UK DB liabilities are around £2.2trn, excess deaths in 2020 due to Covid-19 could reduce liabilities by less than £5bn. However, this is dwarfed by the increase in liability values of over £50bn in 2020 as a result of falling stock markets and ultra low interest rates. The report concluded: 'The ultimate impact of deaths due to the coronavirus on the funding of DB pensions will be

¹⁸¹ <https://www.ipe.com/news/evonik-legal-and-general-add-544m-buy-in-to-us-de-risking-transaction/10050112.article>

¹⁸² <https://www.pbpc.gov/prac/prem/premium-rates>

¹⁸³ *Insurance Asset Management*, 3 February 2021.

¹⁸⁴ <https://www.pensionpolicy.net/uk-roundup-1trn-of-db-pension-risk-to-be-insured-by-2031-says-hymans/>

¹⁸⁵ XPS COVID-19 Tracker for UK: <https://www.xpsgroup.com/what-we-do/technology-and-trackers/xps-covid-19-tracker/>

¹⁸⁶ <https://ourworldindata.org/explorers/coronavirus-data-explorer?facet=none&Metric=Confirmed+deaths&Interval=7-day+rolling+average&Relative+to+Population=true&Color+by+test+positivity=false&country=~GBR> (29 June 2022).

¹⁸⁷ *Daily Telegraph*, 25 November 2020; <https://www.statista.com/statistics/283917/uk-state-pension-costs/>

driven more by the economic and social consequences of the pandemic following 2020, in particular, a severe recession.’ The report also found that longevity insurers and reinsurers are making very little – if any – allowance for Covid-19 in their longevity assumptions at the moment: ‘Any impact on the affordability of longevity hedging has therefore been dwarfed by the impact of changes to the financial markets due to the pandemic’.¹⁸⁸ XPS Pensions estimated a larger fall in UK pension liabilities of between 1.5% and 3.5%, equivalent to £25bn-£60bn.¹⁸⁹

Willis Towers Watson found that the UK bulk annuities and longevity swaps markets remained active all throughout the lockdown, implying that insurers’ operating and financial models were robust enough to withstand the instability. Indeed, the widening of credit spreads created some exceptional pricing opportunities, which were taken advantage of by schemes already in the process of de-risking as well as schemes that had previously transacted and hence were in a position to execute a ‘repeat deal’ relatively quickly. WTW said it was involved in 20 buy-ins for 19 schemes, covering £8.6bn of liabilities, with most of these taking place during lockdown. It was also involved in five longevity swaps covering £14.7bn of liabilities. It noted: ‘There is a significant appetite for reinsurers to take on new longevity swaps and this is producing very attractive pricing, and in several cases, schemes have been able to hedge at little or no cost, relative to their technical provisions’.¹⁹⁰

WTW’s *Emerging Trends in DB Pensions Survey 2020*¹⁹¹ found that Covid-19 and the consequences for the wider economy are placing sponsors and schemes under strain, weakening the sponsor covenant: 1 in 3 say the sponsor’s ability to support the scheme has weakened in the short term; 1 in 6 say it has in the long term. There is a trade-off between scheme security and business recovery: trustees aim to shorten the time to meet schemes’ long term funding targets, while corporates expect to extend it. In the next 3 years, 4 in 10 schemes are looking to complete a bulk annuity transaction or longevity swap.

The economic impact of the Covid-19 pandemic following the lockdowns that most countries introduced to stop the virus spreading has affected the ability of workers and employers to contribute to private-sector pension schemes, according to the OECD’s *Pensions Outlook 2020*.¹⁹² It also points out that the liabilities of DB schemes are likely to grow. Although government wage support schemes meant that workers did not lose their

¹⁸⁸ UK roundup: LCP on COVID-19’s direct, indirect liabilities hit, *IPE*, 23 June 2020,

<https://www.ipe.com/news/uk-roundup-lcp-on-covid-19s-direct-indirect-liabilities-hit/10046384.article>

¹⁸⁹ <https://www.professionaladviser.com/news/4028930/covid-19-leaves-schemes-overestimating-pension-liabilities-research>

¹⁹⁰ Willis Towers Watson, *De-risking Report 2021: Keep calm and carry on de-risking*;

<https://www.willistowerswatson.com/en-GB/Insights/2021/01/keep-calm-and-carry-on-de-risking-de-risking-report-2021>

¹⁹¹ <https://www.willistowerswatson.com/en-GB/Insights/2020/10/emerging-trends-in-db-pensions-survey-2020>; October 26, 2020.

¹⁹² Published 7 December 2020; https://www.oecd-ilibrary.org/finance-and-investment/oecd-pensions-outlook-2020_67ede41b-en

entitlement to a state pension while they were furloughed, the huge cost of those schemes will inevitably impact the ability of governments to fund state pensions in the future.

Conducting an international comparison of mortality rates during 2020-21, Club Vita found that Canada's excess mortality rates versus the underlying trend were 6.3% and 2.9% in 2020 and 2021, while the US's were 14.3% and 14.4% and the UK's were 13.5% and 8.6%. Club Vita said 'Whether these levels of increased deaths continue and for how long will be vitally important for pension plans and insurers trying to understand future longevity trends in the UK, US and Canada'.¹⁹³

Longevity 16: 2021

The sixteenth conference (*L16*) was held in Helsingør near Copenhagen on 13-14 August 2021. It was hosted by PerCent at Copenhagen Business School and the Pensions Institute.¹⁹⁴

In 2021, UK DB schemes completed £44.8bn worth of PRT transactions covering buy-ins, buy-outs, longevity swaps and assured payment policies. Excluding APPS (which do not hedge longevity risk), bulk annuity transactions were £27.7bn. Five longevity swaps were executed worth £17.1bn.¹⁹⁵ There were four bulk annuity deals of £1bn or more, compared with seven such jumbo deals in 2020, reflecting fewer multi-billion pound opportunities. However, buy-ins/outs between £100m and £1bn have trebled since 2015 and comprised one-third of all deals in 2021, while the number of deals below £100m fell by a third over the same period. The market was dominated by five insurers: Aviva (£6.2bn in deals, 22% market share), Standard Life (part of Phoenix Group, £5.5bn, 20%), L&G (£5.3bn, 19%), PIC (£4.7bn, 17%) and Rothesay Life (£3.0bn, 11%). Helped by rising yields on corporate bonds (a key investment vehicle in de-risking strategies), competition between insurers was intense and this was reflected in keen pricing.¹⁹⁶

In March 2020, the UK Institute and Faculty of Actuaries' Continuous Mortality Investigation (CMI) released the CMI_2020 Mortality Projections Model.¹⁹⁷ This is used by most DB schemes in the UK and it requires schemes to choose what allowance to make for the pandemic. By 2021, there was enough information for schemes to form a best estimate. For most schemes, an appropriate pandemic allowance was a reduction of 1.5% to 3.5% in liabilities. For a scheme that is 90% funded, this could mean a 25% reduction in the deficit.¹⁹⁸

¹⁹³ <https://www.clubvita.us/news-and-insights/top-charts-22-03-2021-excess-deaths>

¹⁹⁴ The conference proceedings for *L16* were published in September 2023 in the *Journal of Demographic Economics*, 89(Special Issue 3: International Longevity Risk and Capital Markets Solutions): 299-312; <https://doi.org/10.1017/dem.2023.2>

¹⁹⁵ <https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/>

¹⁹⁶ <https://www.ipe.com/news/2021-uk-pension-risk-transfer-volumes-hit-439bn-with-record-core/10058708.article>, <https://www.pensions-expert.com/Investment/Derisking-activity-ramps-up-in-Q3>

¹⁹⁷ <https://www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation/cmi-investigations/mortality-projections>

¹⁹⁸ Updating life expectancy assumptions for the new CMI_2020 model, *XPS Express for Employers*, March 2021.

Highlights for 2021 in the UK included:

- In February, L&G agreed a £570m pensioner buy-in deal with Deutsche Bank's UK pension scheme; it was the £4.5bn scheme's first de-risking strategy.¹⁹⁹
- In March, the AXA (UK) Pension Scheme executed a £3bn longevity swap with Hannover Re, covering a significant number of deferred members who comprise around 95% of the 16,000 members. This was helpful for the scheme's investment strategy as it provided increased cashflow certainty.²⁰⁰
- Also in March, an unnamed UK pension scheme executed a £6bn longevity swap with PICA and Zurich Assurance acting as an intermediary on a pass-through basis. The pass-through deal was the first used by PICA with a UK-based insurer, having previously used Guernsey- and Bermuda-based captive solutions. Rohit Mathur, the new head of international reinsurance at PICA, said 'We see the use of a third-party onshore UK-regulated insurer as a limited recourse intermediary as the logical next step in the de-risking solutions we can offer for clients in our evolving business model'.²⁰¹
- In April, PIC made a £37.5m debt investment in Welsh housing association Wales and West Housing which will fund the building of 2,500 new homes over the next five years. PIC said: 'Sourcing long-dated, secure cash flows is important to PIC. The investment backs our long-term pension liabilities, while having the beneficial outcome of putting PIC's capital to use in parts of the economy where funds are vitally needed'.²⁰²
- In May, the AIB Group UK Pension Scheme agreed a £61m transaction with L&G to convert a tranche of its existing APP into a buy-in policy. Covering both deferred members and new retirees, the transaction is the first example of a APP being partially converted into a new buy-in policy. The conversion builds on the original £250m APP transaction with the AIB Group scheme, and follows a £400m APP transaction with the L&G Group UK Senior Pension Scheme.
- In May, the Wyeth Group Pension and Life Assurance Scheme, a Pfizer Group subsidiary, completed a £190m bulk purchase annuity buy-in, covering 2,000 members.²⁰³
- Also in May, the ICL Group Pension Plan (whose sponsor is Fujitsu) completed a £3.7bn longevity swap with Swiss Re.²⁰⁴

¹⁹⁹ <https://www.pensionpolicy.net/deutsche-bank-inks-buy-in-deal-for-u-k-pension-fund-with-lg/>

²⁰⁰ <https://www.ipe.com/news/axa-uk-scheme-signs-3bn-longevity-swap-for-mostly-deferred-liabilities/10051692.article>

²⁰¹ <https://www.professionalpensions.com/news/4030529/pica-reinsures-gbp6bn-longevity-risk-unnamed-scheme>

²⁰² <https://realassets.ipe.com/news/pension-insurance-corporation-lends-to-welsh-housing-association/10052418.article>

²⁰³ <https://www.ipe.com/news/251m-in-de-risking-deals-as-aib-converts-app-wyeth-seals-buy-in/10053116.article>

²⁰⁴ <https://www.ipe.com/news/icl-group-scheme-strikes-37bn-longevity-hedge/10052771.article>

- In June, the pension scheme of travel agency company TUI agreed two buy-ins for £794m with L&G.²⁰⁵
- In June, PIC announced it was investing £200m in the development and operation of 10 new retirement living communities comprising around 2,000 older residents, via a partnership with Octopus Real Estate. PIC's aim is again to generate index-linked cash flows.²⁰⁶ In the same month, it invested £175m in the senior secured debt funding of 18 Spanish solar parks owned by Q-Energy which in turn receives payments from the Spanish electricity system and so can guarantee an agreed level of return and predictable cashflows for PIC.²⁰⁷
- In July, L&G completed its third APP, another deal (valued at £925m) with its own DB pension scheme, covering 2,000 retired and 2,800 deferred members.²⁰⁸
- In July, the Pearl Group Staff Pension Scheme completed a second £998m buy-in with Phoenix Life.²⁰⁹
- In July, the Kingfisher Pension Scheme completed a £900m bulk purchase annuity transaction with Aviva, covering 8,000 of the £3.7bn scheme's members.²¹⁰
- In September, Aviva completed a £320m bulk purchase annuity transaction with the John Laing Pension Fund, covering 1,850 pensioners.²¹¹
- In September, Just Group introduced medical underwriting for its equity release mortgage range, by taking account of the client's medical conditions and lifestyle factors in determining the borrowing rate and limit.²¹²
- In September, Standard Life entered the equity release market with a range of lifetime mortgage products launched in partnership with Key Group, under the brand Standard Life Home Finance. Earlier in the month, Phoenix Group bought a portfolio of equity release mortgages worth £300m from Just Retirement. In 2020, the equity release market totalled £3.89bn, while £1.17bn of property wealth was unlocked by over-55 homeowners in the second quarter of this year, according to the Equity Release Council.²¹³
- In October, the Metal Box Pension Scheme agreed a £2.2bn buy-in, covering 10,300 pensioners and 2,200 non-pensioner members, with PIC as a step towards a full buy-out in November.²¹⁴

²⁰⁵ <https://www.ipe.com/news/uk-roundup-tui-trust-strikes-800m-buy-in-pair-lothian-names-new-ceo/10053151.article>

²⁰⁶ <https://realassets.ipe.com/news/pic-to-invest-up-to-200m-in-uk-retirement-communities-via-octopus-jv/10060819.article>

²⁰⁷ <https://realassets.ipe.com/news/pic-increases-investment-in-renewable-energy/10053393.article>

²⁰⁸ <https://www.ipe.com/news/legal-and-general-completes-925m-assured-payment-policy-transaction/10054195.article>

²⁰⁹ <https://www.pensions-expert.com/DB-Derisking/Pearl-Group-pension-fund-completes-further-buy-in>

²¹⁰ <https://www.ipe.com/news/kingfisher-pension-scheme-inks-900m-bulk-annuity-with-aviva/10054147.article>

²¹¹ <https://www.pensionpolicyinternational.com/aviva-announces-320m-bulk-annuity-deal-with-the-john-laing-pension-fund/>

²¹² <https://www.professionaladviser.com/news/4037321/group-launches-medical-underwriting-equity-release>

²¹³ <https://www.professionaladviser.com/news/4037061/standard-life-launches-lifetime-mortgage-range-key-group>

²¹⁴ <https://www.ipe.com/news/metal-box-scheme-in-wind-up-mode-after-striking-22bn-buyout/10055419.article>

- In October, the Sanofi Pension Scheme has signed a £760m buy-in policy with L&G, covering 2,900 retirees.²¹⁵
- In December, the Imperial Tobacco Pension Fund completed a £1.8bn bulk purchase annuity transaction, covering 6,600 pensioner members, with Standard Life.²¹⁶
- In December, the Gallaher Pension Scheme completed a £1.7bn bulk purchase annuity (BPA),²¹⁷ covering 7,600 members, with Standard Life. Standard Life said the assets underlying the deal will be used to continue its investment into UK infrastructure and socially responsible projects that are vital to the UK's post-pandemic recovery.²¹⁸
- In December, an unnamed pension scheme executed a £2.6bn longevity swap with Zurich and Metlife. It was MetLife's first pension scheme longevity swap transaction.²¹⁹
- In December, the Phoenix Group completed a £1.8bn longevity swap covering its UK pension liabilities with Metlife.
- In December, the pension scheme of biochemical and food company CSM Limited completed a £86m buy-in with Just Group. The scheme received pricing from multiple insurers in three weeks using the PwC Insure service.²²⁰
- In December, Just Group also completed £345m buy-in transaction with the UK pension scheme of an unnamed global distribution company. The deal covered 1,000 deferred members and 900 pensioner members.²²¹
- Also in December, the benefits in the pension plan of metal flow engineering company Vesuvius were fully insured with PIC following a seventh buy-in. The first buy-in with PIC was in 2012. With the latest deal, valued at £305m, over £600m of liabilities were insured with PIC.²²²

International developments outside the UK in 2021 included:

- Athora Netherlands executed two longevity swaps: the first was valued at €4.7bn with Canada Life Re in March and the second was valued at €3.3bn with RGA in September.
- Aegon executed a €7bn longevity swap with RGA in December. It had now reinsured 40% of the longevity risk of its Dutch pension insurance book. The deal improved the solvency ratio of Aegon's life business by 15 percentage points, releasing capital for new business growth.²²³
- NN Life executed a €4bn longevity swap with RGA also in December.²²⁴

²¹⁵ <https://www.ipe.com/news/sanofi-uk-pension-scheme-agrees-760m-buy-in-with-landg/10055597.article>

²¹⁶ <https://www.ipe.com/news/uk-roundup-tobacco-scheme-strikes-18bn-buy-in-deal/10057343.article>

²¹⁷ Alternative name for a buy-in.

²¹⁸ <https://www.ipe.com/news/de-risking-roundup-gallaher-pensions-17bn-buy-in-deal-with-standard-life/10057512.article>

²¹⁹ <https://www.ipe.com/news/metlife-zurich-complete-35bn-longevity-swap/10057535.article>

²²⁰ <https://www.ipe.com/news/csm-limited-scheme-completes-86m-deferred-heavy-buy-in/10058660.article>

²²¹ <https://www.ipe.com/news/metlife-zurich-complete-35bn-longevity-swap/10057535.article>

²²² <https://www.ipe.com/news/vesuvius-seals-seventh-final-buy-in-with-pic/10057145.article>

²²³ <https://www.ipe.com/news/aegon-reinsures-dutch-longevity-risk/10057149.article>

²²⁴ <https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/>

- These transactions all involved Dutch insurers, but the larger Dutch pension plans have also been considering buy-outs as funding ratios have improved as a result of strong equity markets and higher interest rates. With funding ratios above 120%, accrued pension benefits can be transferred to an insurer with guaranteed indexation. In 2021, 44 plans out of a total of 129 reached this threshold (e.g., ING and ABN AMRO Bank) compared with 15 in 2020. Competition from insurers has also increased, with NN Group, previously the only provider, joined by Aegon, Zwitserleven and Lifetri. It is however possible, under new Dutch legislation, for accrued DB benefits to be transferred to a DC plan and the Dutch regulator expected up to 70% of plans to do this.²²⁵
- In December, the Amsterdam School of Economics and Nationale-Nederlanden opened the Research Centre for Longevity Risk.²²⁶ The research centre ‘will study developments in survival rates and life expectancy and how these developments are affected by a variety of factors. This includes studying demographic trends and medical developments, as well as the impact of local socioeconomic conditions and the quality of our living environment. The research findings pertaining to expected developments in life expectancy will also provide a foundation for studying the financial and social impact of these trends’.
- US corporate pension plan buy-out sales totaled \$38bn in 2021, beating the previous record of \$36bn set in 2012.²²⁷ There were a number of large PRTs. For example, in August, Lockheed Martin Corp purchased group annuity contracts from Athene Holding to transfer \$4.9bn pension plan liabilities, covering 18,000 retirees and beneficiaries.²²⁸ In September, HP Inc agreed to purchase a group annuity contract from PICA to transfer \$5.2bn in liabilities, covering 41,000 retirees and beneficiaries in the HP Pension Plan.²²⁹
- In November, State Street Global Advisors launched a deferred lifetime income annuity within the University of California’s retirement plan. The deferred annuities are linked to target-date asset-allocation funds, which invest a portion of the plan member’s assets in annuity contracts as the member approaches retirement age.²³⁰
- Canada introduced longevity funds which are mutual funds with mortality credits as a middle ground between pension funds and annuities. Purpose Investments launched the Longevity Pension Fund in 2021, while Guardian Capital launched GuardPath Longevity Solutions in 2022.²³¹

²²⁵ <https://www.ipe.com/news/higher-funding-ratios-and-dc-transition-fuel-dutch-demand-for-buyouts/10056974.article>

²²⁶ <https://rclr.nl>

²²⁷ <https://www.pensionpolicyinternational.com/us-pension-risk-transfer-market-posts-record-breaking-2021/>

²²⁸ <https://www.pionline.com/pension-risk-transfer/lockheed-martin-offloads-another-43-billion-pension-liabilities-insurer>

²²⁹ <https://www.pensionpolicyinternational.com/hp-ships-off-5-2-billion-in-pension-liabilities/>

²³⁰ <https://www.pensionpolicyinternational.com/us-new-lifetime-annuities-in-401k-plans-could-cut-advisors-out-of-the-picture/>

²³¹ <https://www.pensionpolicyinternational.com/canada-are-longevity-fund-solutions-going-to-change-the-retirement-income-game/>

The effects of long Covid began to be observed in the UK in 2022. According to a study by the Institute for Fiscal Studies, there were 2m people with long Covid who have taken some time out of work, with 110,000 unable to work at any one time. Sufferers typically report long Covid for up to six months after they are first infected. Given that total unemployment and total vacancies both equal 1.3m, this implies 110,000 people had a ‘meaningful effect’ on the jobs market and the wider economy. The Office for National Statistics estimated that 8.75m people of working age were ‘economically inactive’, implying they were not in work or looking for work. This has risen by around 400,000 since the pandemic began. Of these, 2.3m were long-term sick (absent for more than four weeks), up by more than 200,000 since February 2020. Not only was this damaging for the economy, it also badly affected the finances of long Covid sufferers who experienced a reduction of income of around £1,100 per month on average.²³²

Douglas Anderson, Founder of Club Vita, reported that UK mortality rates for 2022 were below pre-Covid-19 levels. As social distancing measures were gradually relaxed at the start of 2022, Covid-19 cases increased, but the strain was less dangerous than at the beginning of the pandemic: ‘Statistics show that there are many people in hospital *with Covid*, but *not because of Covid*. What we are seeing is the Covid has completed its journey ...to now being a largely manageable endemic. When Covid first struck, the disease was materially more dangerous (a death rate of something like 10x flu). With vaccinations,²³³ changes to the way we live our lives, better treatments and the emergence of less deadly dominant variants, the risk of death has thankfully reduced. ...The patterns in North America are following a similar trajectory to the UK. But the picture in China is very different with Shanghai in lockdown [in May 2022]. It’s a good reminder that despite the improvement, we have not reached “herd immunity”, and some experts argue that we probably never will’.

Looking to the long-term and the implications for projecting pension liabilities, Anderson identified four trends for the UK:

1. Waiting times for health treatments have lengthened: Since 2018 the number of people in England on a waiting list has risen from 4m to 6m, and the average wait time has almost doubled from 7 weeks to 13 weeks.²³⁴

²³² <https://www.telegraph.co.uk/business/2022/07/27/long-covid-shrinks-workforce-110000/>

²³³ The World Health Organization estimated that Covid-19 vaccinations saved more than 1.4 million lives across Europe between December 2020, when the vaccine rollouts began, and March 2023; <https://www.medrxiv.org/content/10.1101/2024.01.12.24301206v1>. Further, undervaccination (receiving fewer than the recommended number of SARS-CoV-2 vaccine doses) could be associated with increased risk of severe COVID-19 outcomes (i.e., COVID-19 hospitalisation or death) compared with full vaccination (receiving the recommended number of SARS-CoV-2 vaccine doses), according to a meta-analysis of UK data published in *The Lancet*; [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(23\)02467-4/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(23)02467-4/fulltext)

²³⁴ In the UK at the height of the pandemic in 2020, most cancer deaths occurred at home as hospitals prioritized Covid patients; <https://www.telegraph.co.uk/news/2021/05/07/majority-cancer-deaths-occurred-home-last-year-hospitals-prioritised>

2. More public money going into the UK National Health Service (NHS): To deal with this waiting list, in 2022, the government introduced a health and social care levy which will raise £12bn a year. Given that the NHS budget is around £150bn, ‘that’s useful money at the margin, but could be quickly used up by the continued aging of the population’.
3. Labour shortages are encouraging employers to prioritize employee well-being: ‘Covid continues to cause a big shake out in working practices. Trade unions highlight the loss of 200,000 older workers, reversing a previously healthy trend in employment levels in older people. Further, workers show little appetite to return to a daily commute to the office, after showing that the job can be done perfectly well from home: “hybrid working” – part office-based, part home-based looks like it will be the “new normal” for those whose jobs are suitable. Employers are increasingly appreciating that they will need to invest more in health and wellbeing to attract and retain older employees. This emphasis on prevention in middle aged workers is very welcome. By focussing on slowing down aging by improving lifestyle, it is possible to soften the demands of the aging population on future treatment in the NHS system’.
4. More private money going into genetic research: ‘Covid showcased the first mass benefit of the genetics research industry (mRNA²³⁵ vaccines), leading to sharp share price gains for the visionary investors. This stunning success is encouraging other investors to back the biotechnology sector. The increase in research capacity bodes well for the volume of future advances. Take a look at the Deep Knowledge Group to see the growing coalition of researchers and investors’.

Anderson concludes: ‘My personal sample of emerging themes offers three positive, but slow, improvements from three different stakeholder groups: government, employers and investors. Collectively, these may turn out to be more significant for pensioner longevity – when the inevitable peaks and troughs from year to year are smoothed out – than today’s spike in waiting lists for treatments’.²³⁶

In 2022, for the first time, all eight insurers in the UK market were in a position to offer full-scheme buy-outs with member-facing administration services, ‘a reaction to the increasing maturity of final salary schemes and a growing conviction over targeting buy-out’.²³⁷

The funding position of UK defined benefit schemes increased by 20% during 2022 to 104% of liabilities (with assets of £1,456bn and liabilities of £1,394bn). This was largely explained by gilt yields rising by 3 percentage points and a corresponding 35% reduction

²³⁵ Messenger RNA (mRNA) is a type of single-stranded RNA involved in protein synthesis; <https://www.genome.gov/genetics-glossary/messenger-rna>

²³⁶ Douglas Anderson (2022) UK deaths now below pre COVID levels: what’s the long-term COVID legacy for pensioner longevity?, Club Vita, 11 May; <https://www.clubvita.co.uk/news-and-insights/uk-deaths-now-below-pre-covid-levels-whats-the-long-term-covid-legacy-for-pensioner-longevity>

²³⁷ <https://www.ipe.com/news/2021-uk-pension-risk-transfer-volumes-hit-439bn-with-record-core/10058708.article>

in the value of liabilities, moving many UK schemes into a surplus position for the first time for many years.²³⁸

WTW reported that 2022 was the biggest on record for pension scheme de-risking in the UK, with £60bn of bulk annuity and longevity swap transactions completed, comprising £40bn in buy-ins and buy-outs and £20bn in longevity swaps. A key reason was higher gilt yields and widening corporate bond spreads which increased pension scheme funding levels and lowered buy-out prices significantly. Around 30% of pension schemes anticipate de-risking their liabilities in the next three years.²³⁹

There was increasing automation of the pricing process which removed manual input and made use of interpretable machine learning, ensuring greater accuracy. This has improved workflows by making them more consistent, cost effective and reliable, which, in turn, has increased pricing agility and speed to market.

Despite this, some insurers were struggling to keep up with the current levels of demand, according to a report by Aon, especially the teams responsible for pricing transactions. This has made it harder for smaller schemes to attract the attention of insurance companies. Although transactions under £100m have increased in recent years due to insurer innovation, small schemes were now ‘having to compete harder for insurer engagement and potentially show flexibility over their auction timing and form’.²⁴⁰

Legal & General Investment Management’s (LGIM’s) DB Health Tracker found that a typical DB scheme could meet 98.8% of accrued pension benefits as of 30 June 2022: ‘The increase in both nominal and real interest rates benefited a typical scheme due to underhedged liabilities. This was largely offset by poor performance of growth assets relative to expectations. Overall, however, our Expected Proportion of Benefits Met (EPBM) measure managed to ...reach a new high’.²⁴¹ A PwC survey of UK DB pension plans in July 2022 found that 80% expected to reach their long-term funding target (of ensuring pensions are paid in full) within the next nine years: 85% of both the smallest plans with assets of less than £300m and the largest plans with assets above £5bn said they could achieve this, whereas only 75% of medium-size plans felt they could. Asset returns were a key component of the strategy, with 92% of plans saying that they would rely in whole or in part on assets returns and 41% relying solely on asset returns; 8% had hedged their investment risk and were relying on sponsor contributions to reach their long-term funding target. PwC said that pension funding levels had improved dramatically over the

²³⁸ <https://www.professionaladviser.com/news/4062207/defined-benefit-pensions-gbp400bn-funding-improvement-2022>

²³⁹ Willis Towers Watson (2023) Shifting up a Gear – De-risking Report 2023; <https://www.ipe.com/news/bulk-annuity-longevity-hedging-deals-set-to-reach-60bn-says-wtw/10064524.article>

²⁴⁰ <https://www.ipe.com/news/insurers-stretched-as-uk-pension-de-risking-demand-rises/10061581.article>

²⁴¹ <https://www.ipe.com/news/uk-roundup-db-schemes-health-reaches-new-high/10061802.article?> By 31 August 2022, the average UK pension fund was 100.2% funded on a long-term target basis for the first time since aggregated records began, according to XPS Pensions Group’s DB: UK funding tracker; <https://www.ipe.com/news/uk-roundup-pension-funds-achieve-100-funding-on-long-term-targets/10061950.article?>

last couple of years, with many schemes moving into a surplus position.²⁴² This will clearly increase the demand for buy-outs in the UK over the next decade.

In order to ensure they could meet their targets for buying out, pension funds were also increasing the inflation sensitivity of their portfolio in response to the increase in inflation following governments' pandemic quantitative easing programs and the increase in commodity prices following the Russian invasion of Ukraine on 24 February 2022. A poll of global pension funds by investment consultancy bfinance indicated that the funds were planning to increase their exposure to infrastructure (48%), private debt (39%) and real estate (36%). Alternatives were more popular as an inflation hedge than equities (18%), inflation-linked bonds (12%) and commodities (8%).²⁴³

In the light of the UK's departure from the EU, the UK government announced revisions to Solvency II on 17 November 2022. According to Pelkiewicz et al. (2019), the reason for this was as follows: 'Following the implementation of Solvency II, the risk margin²⁴⁴ came under considerable criticism for being too large and too sensitive to interest rate movements. These criticisms are particularly valid for annuity business in the United Kingdom. ...A further criticism is that mitigation of the impact of the risk margin has led to an increase of reinsurance of longevity risks, particularly to overseas reinsurers'.

The new regime for UK insurers is known as 'Solvency UK' and involves:

- a reduction in the 'risk margin', including a cut of 65% for long-term life insurers;²⁴⁵
- more sensitive treatment of credit risk in the 'matching adjustment',²⁴⁶ such as allowing insurers to invest in assets with 'highly predictable' (rather than strictly 'fixed') cashflows and assets with prepayment risk, such as callable bonds;
- a significant increase in flexibility allowing insurers to invest in long-term assets such as infrastructure and other assets with a construction phase;

²⁴² <https://www.ipe.com/news/uk-db-schemes-expected-to-reach-long-term-funding-target/10061323.article>

²⁴³ <https://www.ipe.com/news/pension-funds-turn-to-alternatives-for-inflation-protection/10059146.article>

²⁴⁴ The risk margin represents the potential costs of transferring insurance obligations to a third party should an insurer fail. It is the difference between the technical provisions (the transfer value) and the Best Estimate Liabilities (BELs). It is calculated in Solvency II using the 'cost-of-capital method' as an insurer's baseline solvency capital requirement (SCR) for unhedgeable risks multiplied by the cost of capital at 6% and discounted at current interest rates. Unhedgeable risks are risks that cannot be hedged or easily transferred to a third party, due to the absence of a deep and liquid market. A current example is longevity risk. The risk margin does not include credit and market risks as compensation for uncertainty arising from those risks is considered to be already adequately reflected in the BELs;

<https://www.risk.net/definition/risk-margin>

²⁴⁵ 30% for non-life insurers.

²⁴⁶ The matching adjustment give insurers capital relief for holding specific long-term assets which match the cash flows of a designated portfolio of life or annuity insurance and reinsurance obligations. It permits insurers to discount their liability cash flows at a higher rate than the risk-free rate, resulting in a lower liability value and hence lower regulatory capital. The higher rate is intended to reflect the illiquidity premium in the return on the long-term assets held and is calculated as the difference between the spread on these assets above the risk-free rate and the 'fundamental spread' or credit risk premium (i.e., the expected cost of default and downgrade of these assets); <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/publication/2022/solvency-ii-review-matching-adjustment-and-reforms-to-the-fundamental-spread>

- a meaningful reduction in the current reporting and administrative burden on firms; and
- a new regime for start-up insurers, with adjusted entry requirements such as a lower capital floor, lower expectations for key personnel and governance structures, and exemptions from some reporting requirements, which is also aimed at developing the UK insurtech sector.²⁴⁷

The combined effect of these reforms is expected to release 10-15% of the capital currently held by life insurers.²⁴⁸ They have been welcomed by UK insurers and are likely to lead to greater insurer capacity for schemes looking to de-risk through buy-ins and buy-outs. John Baines, partner at Aon and head of its bulk purchase annuity team, said the reforms struck a good balance between capital relief and policyholder protection, with the PRA likely to be reassured that the level of capital requirement would still be a ‘gold standard approach to ensuring insurers had a high chance of meeting pension benefit obligations.’²⁴⁹ Chris Anderson, head of BPA consulting at EY, said: ‘Risk margin rules at the moment drive insurers to transact a huge amount of longevity reinsurance when they complete a PRT deal. Two potential consequences of the proposed changes are that first, it may encourage insurance companies to carry out slightly less reinsurance, which could be beneficial on price for pension schemes, and secondly the risk margin on what remains will be lower, which also should be beneficial on price’. A key problem which slows down the pace of transactions is a shortage of qualified staff. According to Anderson: ‘Everyone is trying to find people. Insurance companies need people to run the quotation process and to onboard schemes. Employee benefit consultants also need additional staff – everyone is resource constrained’.²⁵⁰

A report from PIC entitled *Investment Unleashed*²⁵¹ argued that appropriate reform to Solvency II could unlock ‘tens of billions of pounds’ to invest in infrastructure and social assets in the UK, including renewable energy and social housing. PIC estimated its planned investment of £30bn in productive finance by 2030 could increase to £50bn. According to the report, the ideal reform of Solvency II would:

- preserve insurer balance sheet resilience throughout the cycle – protecting policyholder pensions – whilst discouraging investment in relatively riskier assets in overvalued markets;
- encourage investment into productive finance throughout the cycle;
- ensure a competitive UK insurance industry – especially when compared to insurers operating under the EU Solvency II regime.²⁵²

²⁴⁷ <https://www.skadden.com/insights/publications/2022/11/from-solvency-ii-to-solvency-uk>

²⁴⁸ <https://ukfinancialservicesinsights.deloitte.com/post/102hnw5/the-uk-governments-consultation-on-solvency-ii-part-1-risk-margin-and-matchin>

²⁴⁹ <https://www.ipe.com/news/analysis-uk-solvency-ii-reforms-and-the-pensions-buyout-market/10058506.article>

²⁵⁰ Quoted in Greg Winterton (2022) Solvency II Reform Proposals Could Drive Increased Pension Risk Transfer Activity, *Life Risk News*, Volume 1, Issue 8, December; <https://liferisk.news/solvency-ii-reform-proposals-could-drive-increased-pension-risk-transfer-activity/>

²⁵¹ <https://www.pensioncorporation.com/media/200562/investment-unleashed-2021-211223v1.pdf>

²⁵² <https://www.ipe.com/news/solvency-ii-reform-could-free-up-tens-of-billions-of-pounds-for-uk-infra-says-pic/10057177.article>

However, Michael Luo, associate director at fiduciary manager Cardano, pointed out that in 2022 life insurers were facing geopolitical risks and a macroeconomic climate that had not been experienced in over 40 years, with the prospect that they could see the quality of their investments deteriorate through increased credit downgrades and defaults. In addition, any insurers looking to raise hybrid debt capital in the near-future may experience higher borrowing costs than in recent years, whilst any increase in volatility in interest rates and credit markets could create pressure on liquidity management. This implies that trustees and sponsors will need to put more focus on understanding insurers' financial strength, risk management and capital resilience when undergoing an insurer-led risk transfer exercise, to ensure the most appropriate insurer is selected to deliver benefits to their scheme members.²⁵³

In response to this, some pension plan trustees had become concerned about post-transaction protection. According to Alan Pickering, President of BESTrustees: 'If the trustees do not realize until the eleventh hour that once the scheme has no money, they will be depending on insurance or internal indemnities to guarantee that they will sleep at night for the rest of their lives, because ambulance chasing lawyers will not come after them claiming the benefit payments are wrong. You do not want to double bank external insurance and internal indemnities, but it is important to send trustees into retirement with peace of mind'.²⁵⁴

One of the most significant events of the year was the impact on UK pension funds' liability-driven investment (LDI) strategies – used by 73% of DB schemes according to Mercer²⁵⁵ – following UK government's 'mini-Budget' of 23 September. The financial markets responded unfavourably to the unfunded tax cuts announced, predicting that the UK's national debt would increase substantially. The prices of gilts fell sharply and pension funds faced huge increases in collateral requirements as their hedging contracts for protecting against lower interest rates (principally in the form of interest rate swaps and gilt repurchase agreements²⁵⁶) moved out of the money. Pension funds were forced to sell gilts in an illiquid market to meet cash margin calls and this reduced gilt prices even further. The Bank of England was forced to step in and stabilize the market by agreeing to purchase gilts directly from pension funds. Although pension funds faced a severe liquidity crisis at the time, their solvency position actually improved, since the rise in gilt yields helped to reduce the value of their liabilities.²⁵⁷

This experience is expected to provide a further boost to buy-outs and buy-ins. It was also expected to be disappointing news for pension scheme consolidator companies that rely on

²⁵³ <https://www.pensionsage.com/pa/Trustees-urged-to-consider-insurers-financial-strength-as-PRT-market-approaches-unique-juncture.php>

²⁵⁴ Quoted in Mark Dunne (2022, Editor) *Endgame investing - pi roundtable*, July; <https://www.portfolio-institutional.co.uk/roundtables/endgame-investing/>

²⁵⁵ *Portfolio Institutional*, October 2022 (p.44).

²⁵⁶ See, e.g., *An Introduction to Liability Driven Investment*, Insight Investment, November 2021.

²⁵⁷ Sarah Breedon (2022) *Risks from leverage: how did a small corner of the pensions industry threaten financial stability?* Bank of England, 7 November; <https://www.bankofengland.co.uk/-/media/boe/files/speech/2022/november/sarah-breedon-speech-at-isda-aima.pdf>.

LDI strategies to hedge their risks.²⁵⁸ A survey by Russell Investments found that the volatility following the UK government's 'mini-Budget' had influenced asset allocation decisions, with moves away from developed markets (32% of respondents) and emerging markets equities (12%), as well as property (17%) exposure. Instead, investment grade credit (25%) and high yield credit (13%) were the key beneficiaries of this trend, as was infrastructure (16%) and private credit (12%), 'reflecting the perceived attractiveness of the risk/return opportunities available in these asset classes'.²⁵⁹

Another issue was currency movements. Sterling fell significantly against the US dollar during 2022 from \$1.35 to \$1.21. This reduced the costs for both US sponsors of UK pension plans and US insurers offering PRT solutions to UK plans.

A total of £44.7bn in buy-outs, buy-ins and longevity swaps were executed in 2022, of which £28.7bn were buy-ins and £15.7bn were in five longevity swaps.²⁶⁰ The largest providers were Legal & General, Standard Life, Aviva, PIC and Rothesay, with Just Group having a record year with £2.6bn in transactions. Around 30% of buy-in and buy-out transactions were run on an exclusive basis in 2022 and did not go through an auction process.²⁶¹

Highlights for 2022 in the UK included:

- In February, the Lloyds Banking Group Pensions Scheme executed a second longevity swap, covering £5.5bn of liabilities. It was structured as an insurance contract with Scottish Widows as the insurer and SCOR as the reinsurer, taking over the longevity risk.²⁶²
- In February, L&G agreed a £370m buy-in with London Heathrow's BAA Pension Scheme, securing the benefits of more than 1,400 retirees.²⁶³
- In February, L&G announced it would invest £2.5bn of DB pension assets in UK build-to-rent (BTR) projects over the next five years, creating more than 7,000 new homes.²⁶⁴ This was followed up in April with an announcement that it would invest a further £2bn in affordable UK homes over the next five years, creating 10,000

²⁵⁸ <https://www.pensionpolicyinternational.com/uk-ldi-fallout-will-spur-pension-funds-to-look-for-life-sector-arrangements/>

²⁵⁹ <https://www.ipe.com/news/uk-mini-budget-accelerates-db-schemes-de-risking-says-russell-investments/10063686.article>

²⁶⁰ <https://www.ipe.com/news/bulk-annuity-volumes-reach-278bn-according-to-aon/10065718.article?;https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/>

²⁶¹ Estimates from Hymans Robertson; *Insurance Asset Management*, 6 October 2023.

²⁶² <https://www.professionalpensions.com/news/4044972/lloyds-scheme-completes-gbp-5bn-longevity-swap>

²⁶³ <https://group.legalandgeneral.com/en/newsroom/press-releases/legal-general-agrees-c-370m-buy-in-with-heathrow-s-baa-pension-scheme>

²⁶⁴ <https://realassets.ipe.com/news/landg-to-inject-25bn-of-pension-money-into-uk-build-to-rent-projects/10058092.article>

- new homes.²⁶⁵ In August, it invested £500m in ‘later living’ residential homes in a joint venture with the NatWest Bank pension fund.²⁶⁶
- In March, the Air Canada (UK) Pension Trust Fund completed a £380m buy-in deal with PIC, covering 1,400 members.²⁶⁷
 - In March, the Royal Mencap Society completed a £61m bulk annuity transaction for its pension scheme, covering 710 members. Following a one-round appointment process, the scheme was able to benefit from Canada Life and Aon’s streamlined internal legal process. These efficiencies secured competitive pricing for the scheme.²⁶⁸
 - In March, the Newell Rubbermaid UK Pension Scheme has agreed to a £225m buy-in with L&G, covering 800 retirees and 900 deferred members.²⁶⁹
 - In May, the £10.3bn British Steel Pension Scheme II agreed a second buy-in with L&G, insuring around 25% of its liabilities. The first buy-in was completed at the end of 2021 and covered 5% of the liabilities.²⁷⁰ In December, the scheme completed a further £2bn buy-in with L&G. This covered 30% of its liabilities, and brought the total liabilities insured to 60%.²⁷¹
 - In May, PIC made a £130m debt investment in UK social housing provider Raven Housing Trust to help fund the development of 630 homes by 2026.²⁷² In September, PIC invested £105m to forward fund a new ‘net-zero in-operation office’ in Manchester to be let to the Government Property Agency for 25 years. In October, it invested £55m in Northern Ireland-based Clanmil Housing Association which will be used to build 1,400 new homes by 2026²⁷³ and provided £102m of debt financing to Corelink Rail Infrastructure, a UK rolling-stock lessor.²⁷⁴ Also in October, it invested £40m in the secured debt of UK social housing provider, Mhs, to fund the development of 600 new properties.²⁷⁵ In November, it financed the construction of a £200m residential skyscraper in the West Midlands region of England.²⁷⁶ Also in November, it created Senior Living Investment Partners with Octopus Real Estate which made its first £115m investment in a retirement

²⁶⁵ <https://realassets.ipe.com/news/landg-to-invest-2bn-of-pension-money-into-affordable-uk-homes/10059125.article>

²⁶⁶ <https://realassets.ipe.com/news/landg-and-natwest-pension-fund-to-invest-500m-in-uk-later-living-villages/10054341.article>

²⁶⁷ <https://www.ipe.com/news/uk-pension-schemes-sign-buy-in-deals-with-pic-just-group/10058758.article>

²⁶⁸ <https://www.ipe.com/news/uk-roundup-charity-completes-61m-bulk-annuity-transaction/10058643.article>

²⁶⁹ <https://www.ipe.com/news/uk-roundup-rubbermaid-scheme-completes-buy-in-with-legal-and-general/10058607.article>

²⁷⁰ <https://www.pensionsage.com/pa/BSPS-II-secures-two-buy-ins-with-L-G.php>

²⁷¹ <https://www.ipe.com/news/british-steel-pension-scheme-completes-2bn-buy-in-with-legal-and-general/10064456.article>

²⁷² <https://realassets.ipe.com/news/uk-social-housing-provider-raven-secures-130m-funding-from-pic/10059795.article>

²⁷³ <https://realassets.ipe.com/news/pic-invests-55m-in-clanmil-housing-association/10062602.article>

²⁷⁴ <https://realassets.ipe.com/news/uk-rolling-stock-lessor-corelink-gets-102m-pic-loan/10062627.article>

²⁷⁵ <https://realassets.ipe.com/news/pic-invests-in-secured-debt-issued-by-uk-housing-association-mhs/10062935.article>

²⁷⁶ <https://realassets.ipe.com/news/pic-funds-200m-residential-skyscraper-project-in-birmingham/10063144.article>

- community in St Albans.²⁷⁷ In December, it invested £40m of debt in Housing Solutions, a housing association which owns and manages around 7,500 properties in the south-east of England.²⁷⁸ In each case, the aim was to secure long-dated index-linked cashflows for the purpose of paying the ‘pensions of our current and future policyholders over coming decades’.²⁷⁹
- In June, the House of Fraser’s Beatties & Jenners Pension Scheme insured £600m of liabilities via a buy-out with PIC, covering 3,850 deferred members and 5,050 pensioners.²⁸⁰
 - In June, the Phoenix Group provided £90m of long-term funding to regulated social housing provider, Alliance Homes, with the aim of generating index-linked cash flows.
 - In July, the UBS (UK) Pension and Life Assurance Scheme extended its July 2020 longevity hedge by £500m to include 50% of its deferred members, those over 60. The combined hedge covered two-thirds of its DB liabilities. The deal involved Zurich Assurance as the insurer and Canada Life Re acting as the reinsurer.²⁸¹
 - In July, the Whitbread Group executed a £680m bulk purchase annuity covering approximately 8,000 members of its pension fund with Standard Life. Standard Life said: ‘we receive a one-off premium from the scheme and then guarantee that member benefits will be paid into the future. This premium is invested across a broad range of assets to ensure we are able to meet the future liabilities. Given that member benefits will be paid out over decades we can afford to take a long-term view in the way we invest and make allocations to illiquid investments. We aim to invest 60% of our illiquid assets in sustainable investments including in areas like renewable energy, infrastructure, affordable housing and healthcare and education, ...supporting some of society’s most vulnerable people as well as ...projects with a positive environmental impact, such as the provision of renewable electricity’.²⁸²
 - In August, the Equity Release Council reported that 47,000 new and returning customers withdrew £3.13bn from their properties during the first half of 2022, an increase of 37% on the same period in 2021. The majority (54%) of the withdrawals were in the form of lump sum lifetime mortgages rather than drawdown lifetime mortgages. The Council believes that this is ‘influenced by customers’ continuing desire to gift money to younger family members and share their property wealth across generations’. Stephen Lowe, group communications director at Just Group, said the ‘demand for equity release has recovered strongly from the pandemic wobbles. ...Homeowners may be using equity release to generate lump sums, extra income or for estate-planning’.²⁸³

²⁷⁷ <https://realassets.ipe.com/news/pic-and-octopus-real-estates-uk-retirement-living-venture-makes-first-investment/10063332>

²⁷⁸ <https://realassets.ipe.com/news/pic-provides-40m-of-debt-for-uk-social-housing-provider/10063997.article>

²⁷⁹ <https://realassets.ipe.com/news/pic-invests-105m-to-forward-fund-gpa-hub-office-project/10062435.article>

²⁸⁰ <https://www.ipe.com/news/uk-roundup-house-of-fraser-plan-strikes-600m-buyout/10060379.article>

²⁸¹ <https://www.ipe.com/news/ubs-uk-scheme-extends-longevity-hedge-by-500m/10060899.article>

²⁸² <https://www.ipe.com/whitbread-group-pension-fund-completes-680m-buy-in-with-standard-life/10061094.article>

²⁸³ <https://www.professionaladviser.com/news/4054181/equity-release-activity-26?>

- In August, Phoenix Group announced it would acquire Sun Life Assurance Company of Canada (UK), a closed book UK life insurance company, from Sun Life Financial for £248m. The deal was expected to deliver £470m of incremental long-term cash generation, inclusive of cost and capital synergies. The insurer had about 480,000 in-force policies and £10bn of assets under administration, of which £2.5bn were annuities that would remain reinsured with Sun Life Financial.²⁸⁴
- In August, Standard Life completed a £1bn buy-in of the WH Smith Pension Trust, covering around 13,000 members. As with other insurers, the assets underlying the contract will be used to continue Standard Life's program of investing into UK infrastructure and socially responsible projects, such as renewable energy, infrastructure, and affordable homes.²⁸⁵
- In August, L&G agreed a £50m full scheme buy-in with the Boots Supplementary Pension Plan, covering the benefits of more than 110 members. Lisa Varley, a senior consultant in Aon's risk settlement group, which advised the trustees, said: 'The successful outcome illustrates that there are excellent opportunities for sub-£100m schemes, as long as insurers can see a clear line of sight to a successful transaction'.²⁸⁶
- In August, Railpen, the UK railways pension scheme, purchased a life-science business park in Oxford for £29m with plans to attract leading companies in scientific research as tenants and generate 'enhanced returns' for scheme members.²⁸⁷ In October, Railpen agreed to fund the redevelopment of a mental health facility in Northern England in exchange for a 30-year lease on the site which will deliver inflation-linked returns for the scheme.²⁸⁸
- In September, the Barloworld UK Pension Scheme completed a £484m full scheme buy-in with Just Group, insuring the benefits of around 3,000 pensioners and 1,800 deferred members.²⁸⁹
- In September, the Yell Pension Plan executed a full scheme buy-in with PIC, covering the remaining £370m of liabilities, having completed a £200m buy-in also with PIC in 2014. All 1,800 plan members became PIC policyholders.²⁹⁰
- In October, the Cobham Pension Plan has concluded a £530m buy-in with Standard Life, covering around 3,000 members.²⁹¹
- In November, the Balfour Beatty Pension Fund completed a £1.7bn longevity reinsurance transaction (i.e., swap) covering 15,000 members with Zurich UK as

²⁸⁴ <https://www.professionaladviser.com/news/4054283/phoenix-group-acquire-sun-life-uk-gbp248m>

²⁸⁵ <https://www.ipe.com/news/standard-life-completes-1bn-buy-in-of-the-wh-smith-pension-trust/10061476.article>

²⁸⁶ <https://www.ipe.com/news/boots-supplementary-agrees-50m-pension-buy-in-with-landg/10061569.article>

²⁸⁷ <https://realassets.ipe.com/news/railpen-buys-29m-life-science-business-park-from-aew/10061697.article>

²⁸⁸ <https://realassets.ipe.com/news/railpen-to-fund-monkwearmouth-hospital-redevelopment/10062796.article>

²⁸⁹ <https://www.ipe.com/news/barloworld-uk-scheme-completes-484m-buy-in-deal-with-just-group/10061961.article?>

²⁹⁰ <https://www.ipe.com/news/uk-roundup-yell-pension-plan-completes-370m-buy-in-deal-with-pic/10062218.article?>

²⁹¹ <https://www.ipe.com/news/uk-roundup-cobham-scheme-completes-530m-buy-in/10062986.article>

- the insurer and SCOR taking on 100% of the longevity risk using a ‘pass-through’ structure.²⁹²
- In November, an unnamed UK pension scheme sponsored by a Fortune 500 company completed a £1bn longevity swap with Zurich as insurer and PartnerRe as reinsurer. The deal covered both pensioner and non-pensioner members.²⁹³
 - In November, the TT Group scheme executed a £400m buy-in deal with L&G, covering 5,000 members.²⁹⁴
 - In December, the Barclays Bank UK Retirement Fund executed a £7bn reinsurance transaction, with reinsurance provided by PICA.²⁹⁵
 - In December, the Amey pension fund executed a £400m buy-in deal with PIC, covering 3,473 members, including 1,938 deferred members.²⁹⁶
 - In December, The Interserve Pension Scheme completed a £400m buy-in with Aviva, covering around 7,000 members.²⁹⁷
 - In December, the Tioxide Pension Fund agreed a £430m buy-in with L&G, securing the benefits of around 2,700 retirees and deferred members.²⁹⁸
 - In December, the Co-operative Pension Scheme’s £2.1bn Bank Section completed a full £1.2bn buy-in with Rothesay Life, covering all the liabilities of 2,474 pensioners and dependants and a further 6,531 deferred members.²⁹⁹
 - Also in December, Rothesay Life executed a £762m buy-in for the Morrisons Retirement Saver Plan, covering 2,650 pensioners and dependants and 5,500 deferred members.³⁰⁰

There were a number of significant international developments outside the UK in 2022.

The US PRT market had its most successful year to date, with 568 transactions valued at \$51.8bn, of which \$48.3bn was accounted for by 562 single premium buy-outs, while the remainder were buy-ins.³⁰¹ This was largely due to improved funding ratios rising from 87.9% in 2020 to 95.8% in 2021 and to 100.7% in 2022, on the back of strong equity market performance and higher interest rates. With rising levels of inflation, a potential

²⁹² <https://www.ipe.com/news/uk-roundup-balfour-beatty-in-17bn-longevity-transaction/10063743.article>

²⁹³ <https://www.professionalspensions.com/news/4060514/fortune-500-sponsored-scheme-completes-gbp1bn-longevity-swap>

²⁹⁴ <https://www.ipe.com/news/partnerre-in-1bn-longevity-swap-deal-with-uk-fortune-500-scheme/10063540.article>

²⁹⁵ <https://www.professionalspensions.com/news/4061710/barclays-uk-retirement-fund-seals-gbp7bn-longevity-deal>

²⁹⁶ <https://www.ipe.com/news/british-steel-pension-scheme-completes-2bn-buy-in-with-legal-and-general/10064456.article>

²⁹⁷ <https://www.pensionsage.com/pa/Interserve-Pension-Scheme-completes-400m-buy-in-with-Aviva.php>

²⁹⁸ <https://www.ipe.com/news/uk-roundup-tioxide-pension-fund-in-430m-buy-in-deal-with-landg/10064566.article>

²⁹⁹ <https://www.pensions-expert.com/DB-Derisking/Co-operative-Pension-Scheme-completes-1.2bn-full-section-buy-in>

³⁰⁰ <https://www.pensionsage.com/pa/Morrisons-agrees-762-m-buy-in-with-Rothesay.php>

³⁰¹ [https://www.pensionpolicyinternational.com/us-pension-risk-transfer-market-keeps-setting-records/;](https://www.pensionpolicyinternational.com/us-pension-risk-transfer-market-keeps-setting-records/)
[https://www.pensionpolicyinternational.com/u-s-pension-plan-buyouts-reach-record-volume-in-2022/;](https://www.pensionpolicyinternational.com/u-s-pension-plan-buyouts-reach-record-volume-in-2022/)
<https://www.pensionpolicyinternational.com/us-pension-risk-transfers-spiked-in-2022-due-to-higher-interest-rates-report-shows/>

recession, and geopolitical uncertainty, plan sponsors wanted to protect themselves from market downturns. Some of the PRTs were lift-outs, with plans transferring some of their pension risk to an insurance company, but most followed plan terminations – and a consequential increase in annuity purchases – by plans that were over 100% funded. The market was also very competitive with 21 active insurers, including newcomers Global Atlantic, RGA and American National, compared with 10 in 2012.³⁰² As a result of this competition, the Milliman Pension Buyout Index was 98.9% of plans' retiree ABO, while the average annuity purchase cost across all insurers was 103.7%. This meant that the competitive bidding process was estimated to save plan sponsors on average around 4.8% of PRT costs (as of February 28). By September 30, the cost savings had fallen to 3.0% of PRT costs due to 'insurers having less appetite for interest rate risk, or less assets available for transactions'.³⁰³ The average premium per transaction was \$90m in 2022, up from \$55m in 2018.³⁰⁴ Another development is the entry of reinsurers into the market, providing additional balance sheet capacity to insurers, but without being direct writers in the market. There is beginning to be some interest in buy-ins in the US market, but longevity-only transactions, such as longevity swaps, are still rare, because they will not reduce PBGC premiums.³⁰⁵ A prediction for 2023 will be artificial intelligence enhanced modelling of mortality and longevity risks which could lead to more longevity risk-transfer deals.³⁰⁶

One of the largest disclosed US transactions of the year was completed in June by Lockheed Martin Corp. which purchased group annuity contracts from Athene Holding valued at \$4.3bn.³⁰⁷ An even bigger one was completed in September, when PICA and MetLife each agreed to reinsure 50% of the pension benefit payments of 100,000 IBM (International Business Machines) plan members. The total value of the PRT transaction was \$16bn, making it the second-largest deal in the US market.³⁰⁸ In December, Western & Southern Financial Group executed a \$1.7bn longevity swap with RGA.³⁰⁹

In the Netherlands, there has been a movement away from longevity derivatives towards longevity swaps (or longevity reinsurance). According to Andre de Vries, vice president business development at RGA, longevity derivatives, which dominated the Dutch market between 2012 and 2017, 'are based on the mortality risk of the general Dutch population, as opposed to a specified portfolio of insured beneficiaries. In addition, these longevity derivatives are structured to transfer more remote (out-of-the-money) longevity risk over a

³⁰² <https://www.institutionalinvestor.com/article/blxzjngikysg4t/Companies-Race-to-Offload-Pension-Risk-as-Market-Volatility-Rises>

³⁰³ <https://www.pensionpolicyinternational.com/milliman-analysis-competitive-pension-risk-transfer-buyout-rate-rises-320-basis-points-to-100-1-during-september/>

³⁰⁴ <https://www.pensionpolicyinternational.com/global-pension-risk-transfer-monitor-record-h1-transaction-volumes-in-uk-and-us/>

³⁰⁵ <https://liferisk.news/still-plenty-of-capacity-for-growth-in-robust-us-prt-market/>

³⁰⁶ <https://www.ipe.com/north-america/us-sponsors-back-pension-buyouts/10064707.article?>

³⁰⁷ <https://www.pensionpolicyinternational.com/us-milliman-analysis-competitive-pension-risk-transfer-buyout-rate-hits-all-time-low-in-february-at-98-9/>; <https://www.pionline.com/pension-risk-transfer/us-corporate-pension-plan-buyouts-hit-record-123-billion-q2-limra-survey>

³⁰⁸ <https://www.pensionpolicyinternational.com/prudential-and-metlife-entrusted-to-fulfill-16b-in-pension-obligations-for-100000-ibm-retirement-plan-participants-and-beneficiaries/>

³⁰⁹ <https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/>

limited term and the benefit (claim) under these longevity derivatives is capped at a pre-defined amount. Compared to longevity reinsurance, longevity derivatives require only a limited set of data to be shared with the risk takers and impose less due diligence requirements on the ceding company compared to a reinsurance transaction. On the other hand, it is more challenging to determine the reduction in Solvency Capital Requirement under Solvency II (SII) resulting from these derivatives because there is no perfect fit between the longevity risk transferred and the longevity risk of the insurance company’.

In 2018, the Dutch market switched to longevity reinsurance because of the introduction of SII in the EU in January 2016: ‘As longevity swaps transfer all the longevity risk of a specified portfolio of pension obligations over their full remaining term (which can easily be more than a few decades), these transactions are more expensive than longevity derivatives. On the other hand, because these reinsurance transactions exactly match the underlying liabilities of the insurance companies, these instruments allow insurance companies to fully release the SCR for the corresponding longevity risk. ...SII has an explicit SCR for longevity risk which resulted in clear capital relief from longevity risk transfer transactions. This was not the case under the prior regulatory regime’.

Dutch longevity swaps have introduced a number of new features:

- Recouping (or rebalancing) longevity swaps. The objective of recouping is to provide additional protection to the party that is facing a positive value of the longevity swap at a future moment during the term of the transaction. Under this mechanism, the fixed leg (the premiums) of the longevity swap is adjusted in case its present value has become materially different (either higher or lower) compared to the prevailing present value of the floating leg (the claims).
- Accommodating a bail-in. This is one of the resolution tools included in the 2019 Recovery and Resolution Act for insurers which might allow pension obligations to be reduced so that an insurer can continue in business.
- Extending longevity reinsurance with asset performance risk or ‘asset intensive’ (AI) reinsurance. This is a longevity swap whereby the present value of the fixed leg is paid at inception. To mitigate the counterparty credit exposure of the insurer on the reinsurer resulting from this initial settlement, a collateral arrangement forms part of AI reinsurance. Under this collateral arrangement, the reinsurer is responsible for maintaining a portfolio of assets within pre-agreed investment guidelines and restrictions. As asset performance risk is very capital intensive, Dutch insurers that are actively managing their capital position, are considering to also reinsure (some of the) asset performance risk resulting from these pension buy-outs. Such an approach might give them the opportunity to also offer very large pension buy-outs that they might otherwise not be comfortable executing because of the substantial capital implications.³¹⁰

³¹⁰ Andre de Vries (2022) Update on Longevity Risk Transfer in the Netherlands, *de actuaris*, December, 18-20; <https://www.ag-ai.nl/view/51882-DA-30-2-art-deVries.pdf>

The Australian Prudential Regulation Authority (APRA) introduced a retirement income covenant in July 2022.³¹¹ Regulated superannuation funds (or other registrable superannuation entities (RSEs)) are required to formulate a retirement income strategy (the strategy) for their members' decumulation phase which will improve their retirement outcomes and be in their best financial interests. Although not stated explicitly, the aim is to encourage greater use of lifetime annuities where that is appropriate for members. The A\$220bn Australian Retirement Trust (ART) – formed from the merger of QSuper and Sunsuper in February 2022³¹² – has introduced a lifetime pension product which is like an annuity. It offers a market-based income for life in a set-and-forget product in which the super funds are pooled with other investment funds to cover fees and costs and only a proportion of the assets are used to provide the pension. Other providers include *Challenger* Life and Generation Life which in May 2022 introduced an investment-linked lifetime annuity.³¹³ Previously, most retirees switched to an account-based pension which keeps their pension pot invested in the same pool of assets as in accumulation. Income from the account is tax free, but there is a minimum drawdown of 5% every year which increases as members get older.³¹⁴

In July, AXA Germany announced the transfer of a portfolio of around 900,000 conventional life and annuity insurance contracts worth €19bn in assets under administration to Athora Germany for a purchase price of €610m. It will take five years to transfer the contracts, beginning in 2023.³¹⁵

In May, the Bermuda Monetary Authority proposed amending the Insurance Act 1978 to introduce a new innovative class for long-term insurers (Class IILT). The BMA said it believed that market developments in the next decade will lead to a conflux of insurance, capital markets, artificial intelligence, and distributed ledger technology: 'The Class IILT is intended for, but not limited to, innovative business models, such as those insurers that utilize digital assets for their operations... [which] would enhance liquidity and risk transfer efficiency'.³¹⁶

One of the most significant events of 2022 was the opening of the Longitude Exchange – as the first digital marketplace for trading longevity risk in index-based format – in Bermuda which is regulated by the Bermuda Monetary Authority (BMA), Bermuda's financial regulator.³¹⁷ It describes itself as the Longevity Risk Marketplace for connecting hedgers and investors on a platform optimized for trading longevity risk. Its mission is to build an efficient and deep market for trading longevity risk, helping ensure the stability of individuals retirement income and the global financial system by: helping pension funds

³¹¹ <https://www.apra.gov.au/implementation-of-retirement-income-covenant>

³¹² <https://www.top1000funds.com/2022/03/super-and-sunsuper-merge-to-form-new-institutional-giant/>. ART is the second largest super fund after the A\$260bn AustralianSuper.

³¹³ <https://frsltd.com/latest-news/generation-life-launches-australias-first-investment-linked-lifetime-annuity-solution-on-investpro-from-frs/>

³¹⁴ <https://www.ipe.com/asia-pacific/letter-from-australia-superfunds-focus-on-retirement-income/10057677.article>

³¹⁵ <https://www.ipe.com/news/axa-germany-transfers-19bn-insurance-portfolio-to-athora/10061129.article>

³¹⁶ <https://www.reinsurancene.ws/bma-introduces-new-innovative-class-for-long-term-insurers-class-iilt/>

³¹⁷ <https://www.longitude.exchange/>

and insurers manage liabilities at a lower cost; providing investors better access to an uncorrelated asset class; enhancing the efficiency of trading longevity risk; and improving the security of the financial system.

The Longitude Exchange platform handles documentation, trade set-up, primary issuance, valuations, and secondary trading. Its tools streamline the process of hedging and investing in longevity risk. For hedgers, there are tools for: hedge construction – construct trades optimized for risk and capital objectives; hedge analysis – measure hedges’ impact on risk and capital positions; hedge placement – conduct auctions, negotiate terms and execute deals; hedge reporting – receive reporting, payment and collateral instructions; and hedge management – increase or decrease hedges through secondary trading. For investors, there are tools for: longevity modeling – models and datasets to generate longevity scenarios; investment analysis – price transactions using longevity scenarios; investment execution – place bids and negotiate terms with counterparties; on-going valuations – live quotes and historical trades to mark positions; and secondary trading – list positions, request bids, and buy listed transactions.³¹⁸

In May, the Longitude Exchange linked up with Dedomainia to advance the techniques and processes for monitoring, administering, and valuing index-based longevity risk hedges. In December 2016, Dedomainia had launched a web-based platform designed for longevity swap calculations called LISA (Longevity Insurance Servicing and Administration).³¹⁹ In September, the Longitude Exchange announced it had raised seed funding from the Deep Knowledge Group, a consortium of commercial and non-profit organizations active in several technological domains including Longevity, AI, FinTech, and InvestTech.

Dr Erik Pickett, Chief Content Officer at Club Vita, argues that the key to developing a successful life market is the:

commoditization of longevity risk, i.e., the development of fungible, tradable financial instruments linked to longevity risk that increase the efficiency of each step of the risk transfer chain and ultimately the creation of a deep liquid market for longevity risk. Commoditization should attract more, much needed, capacity in longevity risk takers. This is expected largely to come from capital markets investors entering the market, attracted by returns diversified against key financial risks, with some extra capacity also released from existing players due to standardization and automation.

It is often not economical for small pension funds to enter into complicated indemnity contracts to remove longevity risk. Streamlining of contracts such as those implemented by Mercer and Zurich have opened up this market to smaller players to a certain extent, but complete commoditization would open it up further. By simplifying the process and increasing the supply of risk takers, commoditization should create competitive pricing for longevity risk transfers. The

³¹⁸ https://www.bayes.city.ac.uk/data/assets/pdf_file/0012/701013/MICHAELSON-Avery.pdf

³¹⁹ <https://www.artemis.bm/news/efficient-management-of-longevity-transactions-key-for-counterparts/>

clearing price will of course be affected by any increase in demand, but price loadings due to market frictions should be reduced; a commoditized market could allow risks that have not traditionally attracted insurers or reinsurers, such as deferred annuity longevity risk contracts. A standardized risk classification system and index-based instruments will enable more efficient risk management solutions, in particular allowing more efficient balancing of longevity and mortality risk and reducing capital demands.

...For a commoditized market to develop, there needs to be a standardization of terms for the writing of financial instruments. Central to that will be the development of a set of widely accepted and accessible reference indices that would mimic the movements on the risk cedants' balance sheets. Index-linked instruments would be highly tradable and could protect cedants from extreme outcomes; they would also allow risk traders to act on their sentiment to future longevity risk. Innovative approaches to structuring financial instruments need to be developed that are attractive to both risk cedants and risk takers, in particular, instruments that reduce the time horizon of traditional indemnity swaps (such as those using commutation mechanisms) are needed to attract capital market investors. Shrinking the margins of dealers in a commoditized market could help to increase returns. Articulating the potential capital benefits of pairing longevity and mortality risk, or the diversification effect of longevity with key financial risks could help engage investors with the potential returns.

... Despite some previous false starts for the commoditized longevity market, it feels like the stars may finally be aligning. Over the last few years there has been real concern in the reinsurance community about a capacity crunch if the projected annual market demand materializes. Pension fund consolidators and the success of streamlined longevity swap contracts are bringing smaller pension funds into the de-risking market and new ideas about structuring financial instruments to address the key obstacle of shorter term contracts have now been developed. Players in the market such as Longitude Exchange and Club Vita are working to standardize models and index data to get everyone talking the same language.

For a market to develop, timing of many factors need to align. Maybe that is what's happening right now.³²⁰

An additional factor is the aligned understanding of longevity risk, especially in the UK. As Song et al (2023) point out: 'The UK actuarial community has relatively easy access to credible mortality data and mortality improvement studies (e.g., the UK CMI model). Accessibility to quality population mortality data is crucial to balancing the information asymmetry between insurers (who have relatively smaller, more volatile portfolios) and global reinsurers (who have the capability to perform credible longevity studies with their large data repository and carry significant volumes of offsetting mortality risk from group life, catastrophe and other business). This free flow of information has created an

³²⁰ Erik Pickett (2022) If Longevity Risk is an Asset Class, How Do We Make It More Tradeable?, *Life Risk News*, 13 July; <https://liferisk.news/if-longevity-risk-is-an-asset-class-how-do-we-make-it-more-tradeable/>

unprecedented level of alignment of views on longevity risk among all UK PRT market participants, which in turn has helped the industry in setting an effective “market price” for that risk via longevity swaps’.³²¹

Hedge funds (with assets of \$4.13trn³²² in June 2022) and private equity (with assets of \$7.97trn) could be attracted to this sector since the financial instruments being developed look like alternative fixed-income products with which they are already familiar. However, for them to commit capital, there needs to be much greater liquidity – which is where a trading platform like Longitude Exchange comes in.

Avery Michaelson, CEO of Longitude Exchange, argues that:³²³

In order for hedge funds and other institutional investors to get involved in the longevity market, they need a marketplace. Currently, transactions are brokered in an over-the-counter process using transaction formats that aren’t well suited to the investment criteria of these players. These investors benefit from a certain level of commoditization of transactions, something which can be addressed with index-based transaction formats. By basing transaction pay outs on general-population mortality data, information asymmetries can be removed along with much of the analytical complexity involved in pricing and risk analysis.

Rising interest rates have further accelerated pension de-risking, fuelling greater than ever demand for capital. Fortunately, there are already a number of ILS Funds with experienced life risk teams prepared to commit capital to this space. They will be joined by a much broader range of institutional investors as deal flow and liquidity materialize.

There are around \$100trn of longevity linked liabilities, globally. And every year of unanticipated life expectancy adds around 5% to liabilities. So, if estimates are off by three years, longevity risk could cause \$15trn of unfunded liabilities. The enormous quantum of this risk points to the need for capital markets participation. It’s only a matter of time before longevity risk is recognized as its own asset class.

2023

The year opened well for the financial strength of the UK’s remaining 5,000 pension schemes with the PwC Buyout Index showing a surplus of £245bn and the Low Reliance

³²¹ Paul Song, Patricia Nguyen, Rey Malile and Mark Spong (2023) Managing Longevity Risk: A Solution to Consider, *Reinsurance News*; <https://www.soa.org/sections/reinsurance/reinsurance-newsletter/2023/february/rsn-2023-02-spong/>

³²² According to data and analytics provider Preqin.

³²³ Quoted in Greg Winterton (2023) Is a Digital Exchange the Solution to the Investor Participation in Longevity Risk Transfer Conundrum?, *Life Risk News*, Volume 2, Issue 2, February; <https://liferisk.news/is-a-digital-exchange-the-solution-to-the-investor-participation-in-longevity-risk-transfer-conundrum/>

Index showing a surplus of £380bn.^{324, 325} This indicated another bumper year for the PRT market, with a record-breaking £21.2bn of buy-ins and buy-outs completed in the first half of 2023, and £50bn in total by the end of the year.³²⁶ It also attracted new entrants.³²⁷ For example, in May, M&G, the global asset manager, announced its intention to enter the bulk annuity market, via its wholly-owned subsidiary the Prudential Assurance Company Limited (UK),³²⁸ to focus on bespoke deals for larger schemes.³²⁹ Similarly, in October, Resolution Life announced that its Bermudian-based reinsurer, Resolution Re, would enter the market.³³⁰ Existing insurers were also scaling up by employing extra staff, enhancing technology, extending assets and streamlining internal processes. In August, a survey by Standard Life found that 90% of DB pension scheme trustees anticipated approaching an insurer in the next five years about a potential bulk annuity deal.³³¹ In October, LCP estimated that 1,000 schemes (20% of the total with assets of £275bn out of a total of £1.4trn for DB schemes) were fully-funded on a buy-out basis, while a further 1,250 schemes would reach full funding on a buy-out basis within the next five years. Transfers over the next five years were projected to be £360bn, compared with £155bn over the previous five years.³³²

Despite the new entrants and the increased efficiency of incumbents, there was concern that there would be insufficient capacity in the insurance industry to meet this increase in demand. A particular concern was the shortage of skilled people to meet the growth in the market. Andy McAleese, MVP, Longevity, Europe at Pacific Life Re argues: ‘The real

³²⁴ November data. The Low Reliance Index assumes schemes invest in low-risk, income-generating assets like bonds, implying a low risk of calling on the sponsor for further funding. The resilience of pension schemes to short term market shocks is something the Pensions Regulator has highlighted in its draft Code of Practice on scheme funding. As a minimum, TPR expects trustees to model and ‘stress test’ the impact of the kind of event that might occur once every six years on their scheme’s assets and liabilities. In contrast, insurance companies need to demonstrate that they can withstand at least a one-in-200 year stress scenario;

<https://www.pensionpolicyinternational.com/pension-scheme-consolidation-expected-to-continue-into-2024/>

³²⁵ The net buyout surplus to scheme sponsors increased by around £25bn as a result of a change to the surplus refund tax announced the UK Chancellor of the Exchequer in his Autumn Statement in November 2022; <https://www.pensionpolicyinternational.com/pension-scheme-consolidation-expected-to-continue-into-2024/>

³²⁶ <https://www.ipe.com/analysis/uk-pension-schemes-concerned-over-insurer-capacity-as-they-approach-endgame/10069778.article>; <https://www.pensionpolicyinternational.com/pension-risk-transfer-growth-fuels-uk-insurance-rating/>; <https://www.reinsurancene.ws/record-breaking-year-for-pension-risk-transfer-market-in-2023-legal-general/>

³²⁷ <https://www.ipe.com/news/uk-sees-record-212bn-transferred-to-insurers-in-first-half-of-2023/10069494.article>

³²⁸ Prudential (UK) for short.

³²⁹ M&G Prudential was set up as an asset manager in 2017 as one part of the restructuring of Prudential’s UK businesses. The other part included the transfer of £12bn worth of legacy annuity business to Rothsay Life by the end 2019, as previously discussed; <https://www.ipe.com/news/mandg-returns-to-uk-bulk-annuity-market/10069007.article>

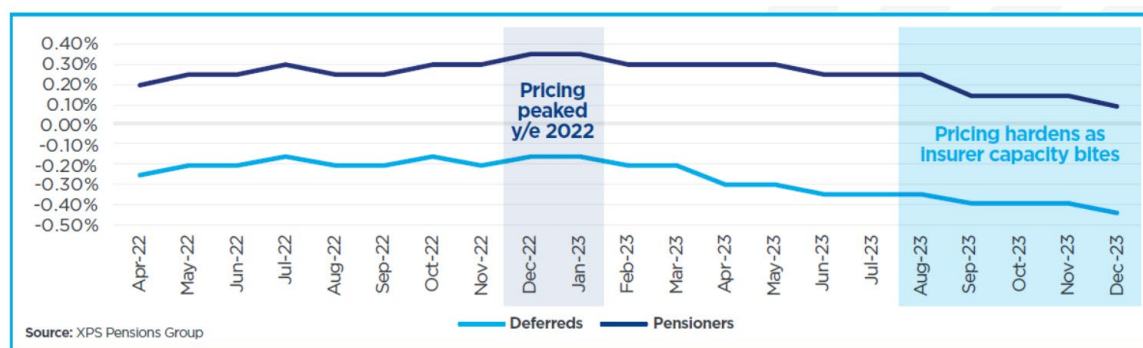
³³⁰ <https://www.ipe.com/news/resolution-life-enters-uk-buyout-market/10069742.article>

³³¹ <https://www.ipe.com/majority-of-db-schemes-expect-to-approach-an-insurer-about-de-risking-within-five-years/10068188.article>

³³² <https://www.ipe.com/news/uk-sees-record-212bn-transferred-to-insurers-in-first-half-of-2023/10069494.article>

constraint in terms of the amount of deals we can do is people. PRT is quite a complex world, transactions are quite challenging to price, structure and execute, they involve a lot of parties, and they are time consuming. There is quite a limited pool of specialist people that can do this, and we're all looking for the same people, and that's a real impediment to growth'.³³³ In October, a survey by Standard Life found that 20% of schemes were worried about a lack of insurer capacity or interest.³³⁴ LCP found that insurers were becoming more selective with a 20% reduction in the proportion of insurers that agreed to provide a quotation, while the market for sub-£100m transactions had tightened, with most insurers requiring exclusivity below £25m.³³⁵ Nevertheless, pricing remained competitive for well-prepared schemes and LCP felt that insurers were rising to the challenge, and despite short-term resourcing pressures, were confident about their capacity to meet the increase in demand in the coming years.³³⁶

Figure 2: Bulk annuity pricing January 2022-December 2023 – average pricing relative to gilt yields



Note: The pricing is based on observed market pricing and model points from bulk annuity insurers and is representative of a generic £100m liability. Source: Bulk annuity market: Q1 update for trustees and pension scheme sponsors, XPS Pensions Group, 23 January 2024; <https://www.xpsgroup.com/news-views/insights-briefings/bulk-annuity-market-q1-update-trustees-and-pension-scheme-sponsors>

Figure 2 shows that in December 2023, pensioner pricing was based on a ‘gilts + 0.10% p.a.’ discount rate to value liabilities; this is less than the best peak pricing rate of ‘gilts + 0.35% p.a.’ at the end of 2022, and reflects the hardening of prices as insurer capacity bites. Similarly, the pricing of deferred pensioner liabilities was based on a ‘gilts – 0.45% p.a.’, down from ‘gilts – 0.15% p.a.’ at the end of 2022. Both were also slightly more expensive than in 2019 (see Figure 1).

³³³ Quoted in Greg Winterton (2023) Change in approach a necessity to combat human capital challenges in uk pension risk transfer market, Life Risk News, 12 July 2023; https://liferisk.news/change-in-approach-a-necessity-to-combat-human-capital-challenges-in-uk-pension-risk-transfer-market/?utm_campaign=life-risk-news-volume-2-issue-7-july-2023

³³⁴ <https://www.ipe.com/analysis/uk-pension-schemes-concerned-over-insurer-capacity-as-they-approach-endgame/10069778.article>

³³⁵ <https://www.xpsgroup.com/news-views/insights-briefings/bulk-annuity-market-q4-update-trustees-and-pension-scheme-sponsors>

³³⁶ <https://www.ipe.com/news/uk-sees-record-212bn-transferred-to-insurers-in-first-half-of-2023/10069494.article>

In January 2023, the UK Prudential Regulation Authority wrote to UK insurance companies warning them that: ‘In light of the multiple external uncertainties facing insurers, it is important that firms take proactive steps to assess the adequacy of their risk management and control frameworks. Firms should be able to respond to market and credit risk conditions different from those that prevailed for a long time. Firms need to be prepared for novel risks, changes in risk correlations and increases in distressed assets. We expect firms to assess their credit and counterparty credit risk management capabilities in light of widening credit spreads, rating downgrades, and defaults. ... We are paying close attention to whether the continued high level of longevity reinsurance and the emergence of the more complex “funded reinsurance” in the UK life market reduce the protection UK policyholders should have, beyond the risk tolerance. In particular, we see the potential for offshored counterparty concentration risk to arise from rapidly growing levels of reinsurance. These concentrations can arise for firms individually and for the sector as a whole. We expect UK authorized firms to consider their compliance with the Prudent Person Principle (PPP) for the risks associated with their reinsurance activities. Insurers need to consider the reinsurer’s resilience over the whole duration of the exposures, as well as the potential impact from a mass recapture event where large concentrations to a small number of counterparties exist. Our own work on counterparty and concentration risk will examine the need for policy action on reinsurance structures and limits, to mitigate systemic risks to policyholders’.³³⁷ In June 2023, the PRA wrote again to UK insurers on the issue of funded reinsurance. It accepted the moderate use of funded reinsurance, but remained concerned about the possibility of too many UK DB assets and liabilities being moved out of the UK and hence outside of the jurisdiction of the UK Pensions Regulator or PRA.³³⁸

In April 2023, Charlotte Gerken, executive director for insurance supervision at the Bank of England, warned insurers not to overextend themselves in their efforts to win more business from pension schemes keen to offload risks, conjecturing that UK life insurers could take on more than £500bn of pension liabilities over the coming decade. She said: ‘As deals become larger and increasingly focused on buy-outs of complete schemes, we observe BPA writers expanding their risk appetite, sometimes outside their current core expertise. Insurers may be tempted to stretch their capabilities in the short term before leaner years arrive. This is a big structural change in the control of long-term investments in the UK, and the decisions that insurers make now will have long term consequences for the performance and development of the broader economy. Insurers will need to hedge their pension risks with interest rate, cross-currency and inflation swaps, increasing the sector’s links to the wider financial system. Insurers therefore need to understand, as they take on these vast sums of assets and liabilities, how they may become greater sources or amplifiers of liquidity risk’, reminding insurers of the LDI crisis faced by pension schemes

³³⁷ <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/letter/2023/insurance-supervision-2023-priorities.pdf>; Charlotte Gerken (2022) Who’s concentrating? Trends in the life insurance sector and the need for strong reinsurance and investment risk management, Bank of England, 20 September, <https://www.bis.org/review/r220921f.pdf>

³³⁸ <https://liferisk.news/the-insurance-regulator-takes-a-look-at-funded-reinsurance/>

in September 2022 when they struggled to find enough liquidity to pay collateral on their leveraged LDI strategies in response to rapidly rising gilt yields.³³⁹

The LCP *Longevity Report 2023*³⁴⁰ argued that ‘views on life expectancy need to be re-examined in light of the pandemic, recognizing newly emerging trends. ... We are moving into a new era for longevity risk’. The report’s key findings which are addressed to pension scheme sponsors and trustees, are:

- *We expect a material slowdown from the pre-pandemic expectation for longevity improvements, primarily due to the ramifications of the pandemic and the pressures on the healthcare system.*³⁴¹ *Compared to pre-pandemic levels, a fall in life expectancies of 1 to 2% may be a sensible starting point for most schemes.*
- *In this challenging environment, a robust longevity assessment is best achieved by sewing together actuarial modelling expertise with expert judgement from healthcare professionals. ... The gap between life expectancies for the most and least deprived sections of society is widening. This makes tailored analysis to suit your scheme’s membership critical for setting longevity assumptions.*
- *Longevity is a significant unhedged risk for many pension schemes. We estimate it is around 25% of the investment risks for a typical scheme. However, in many cases the tools trustees and sponsors use to analyse and manage this risk have not changed to reflect this.*
- *Insurers and reinsurers are now making allowances in their longevity pricing for the slowdown in improvements. An informed assessment of longevity is essential for negotiating with them effectively.*
- *Climate change was also expected to present mortality risks for DB schemes – comprising direct drivers such as air pollution and heat-related deaths, and indirect drivers such as increased transmission of diseases, damage to infrastructure, adverse economic consequences, and food supply issues.*³⁴²

In July 2023, the Continuous Mortality Investigation reported that deaths in the UK in June 2023 were 5% higher than in pre-pandemic June 2019. Across the UK, there have been 200,100 more deaths from all causes than expected from the start of the pandemic to 30 June 2023. Of these, 75,600 were in 2020, 56,600 in 2021, 39,400 in 2022 and 28,500 in the first half of 2023. Pension liabilities would be £8bn lower than three years previously anticipated for schemes going through their triennial valuation between September 2022 and September 2023, according to The Pensions Regulator. Stephen Caine, director of retirement at WTW, argued that the longevity slowdown when combined with the significant reductions in liabilities as a result of rising interest rates over the previous 12-18 months could result in the emergence of larger surpluses and bring forward planned de-

³³⁹ <https://www.pensionpolicyinternational.com/bank-of-england-tells-insurers-to-moderate-their-push-into-pensions/>

³⁴⁰ <https://indd.adobe.com/view/0fec53c5-dc7b-4171-bf9b-a5a7ec894328>

³⁴¹ Mortality rates in 2022 were around 4.5% higher than those in 2019, equivalent to around 30,000 additional deaths in the UK. As of January 2023, there were also more than seven million people on NHS England waiting lists, which LCP said was ‘worrying given that early consultation and diagnosis can have a significant impact on morbidity and are likely to affect mortality rates over the longer term’.

³⁴² This issue is discussed in more detail below.

risking strategies, such as switches from growth assets to matching assets to lock in gains made and insurance hedging solutions.³⁴³

In August 2023, TPR updated its guidance on pension superfunds. This included increasing the discount rate and lowering the minimum funding requirement to make pension scheme consolidations more attractive. However, some consultants thought this was ‘too little, too late’, since the TPR’s interim regulatory regime was introduced way back in June 2020, no superfund transactions had so far taken place and there remained continuing uncertainty around the ability of superfunds to extract profits prior to securing members’ benefits with an insurer. The updated guidance still favoured superfunds, such as Clara-Pensions, that provide a ‘bridge to buy-out’ solution with an insurer over those that intend to manage the assets and liabilities until full run-off, like the Pension Superfund.³⁴⁴

Just a month later, Edi Truell, the owner of the Pension Superfund, announced that he was closing the pension consolidator, after failing three times to get regulatory approval from TPR which, in turn, failed to produce guidance on how profits generated by superfund investments could be distributed to investors. This made the market ‘uninvestable’ according to Luke Webster, CEO of the Pension SuperFund, since there is ‘no line of sight for an investor as to how they might get their money back’. Steve Webb, the former pensions minister and now partner at LCP, thought the ‘government has had long enough’ to agree on the regulatory framework.³⁴⁵

Despite the regulatory challenges, in November 2023, Clara-Pensions announced its first pension superfund transaction with the Sears Retail Pension Scheme and the transfer of 9,600 members and £590m in assets, together with the injection of £30m of ring-fenced capital from Clara. Clara said the deal is ‘an important stepping stone’ in providing the members with a managed journey to an insured buyout, which is expected to take place within the next decade. The £30m funding will act as a loss-absorbing buffer for the scheme on this journey. Isio will administer the scheme.³⁴⁶ LCP partner and head of endgame innovation Jonathan Griffith said ‘Clara represents one of a growing number of new endgame options for pension schemes to embrace as a way to secure benefits for pension scheme members, while also offering enhanced value for other stakeholders’. Matt Cooper, head of alternative pension solutions at PwC, said that superfunds offered schemes with weaker sponsors an alternative solution to enhance the security of members’ benefits, and that around 500 DB schemes with 750,000 members and total assets of £100bn may be suitable candidates for entering into a superfund.³⁴⁷ Andrew Griffith, economic secretary to HM Treasury, called the deal ‘an important innovation to British pension provision’ and

³⁴³ Pamela Kokoszka (2023) Schemes should stay on top of changing mortality rates, *IPE*, 17 July; <https://www.ipe.com/news/schemes-should-stay-on-top-of-changing-mortality-rates/10067876.article?>

³⁴⁴ <https://www.ipe.com/news/tprs-updated-guidance-opens-the-door-to-more-uk-superfund-activity/10068307.article?>; <https://www.thepensionsregulator.gov.uk/en/document-library/scheme-management-detailed-guidance/db-superfunds>

³⁴⁵ <https://www.ipe.com/news/uk-financier-pulls-plug-on-commercial-pension-consolidator/10069044.article>

³⁴⁶ <https://www.ipe.com/news/clara-pensions-announces-first-superfund-deal/10069874.article>

³⁴⁷ <https://www.ipe.com/news/claras-first-superfund-transaction-marks-significant-milestone-for-uk-pension-industry/10069886.article>

added ‘Economies of scale from superfunds can do wonders for pensions, making people's retirement more secure, whilst enabling a broader range of investments in productive finance’, in line with the Mansion House Reforms announced in July 2023.³⁴⁸

Some organizations have proposed solutions that exploit economies of scale but which go short of full consolidation between pension schemes. For example, Dalriada Trustees has launched an integrated streamlined consolidation service for UK pension schemes to deliver trusteeship, governance and administration, while the schemes retain control of their investments and scheme journey planning.³⁴⁹ Similarly, Brightwell, the former British Telecom Pension Scheme Management company, has begun offering investment and administrative services to other pension schemes, including the design of mandates and the selection and oversight of investment managers; but again there is no pooling of assets or sharing risks across schemes. Brightwell is seeking partners that share the BT scheme's strategic decision to run the scheme towards self-sufficiency, instead of targeting an insurance buyout.³⁵⁰

Other organizations have even argued that the return of pension fund surpluses allows schemes to delay either buying out or selling out to a superfund and instead continue to operate as independent schemes but change their asset allocation in order to enhance investment returns. Van Lanschot Kempen Investment Management estimates that a £1bn DB scheme could lose £200m in value by defaulting to buy-out over the next decade and a further £50m in missed returns. These could be used to benefit members and sponsors, and to ‘stimulate the UK economy and promote wider societal benefits’.³⁵¹

A variation on this is capital-backed funding arrangements (CBFA) proposed by the UK Institute and Faculty of Actuaries. The IFoA argues that, despite strong funding, some DB schemes might not believe that an insurance buy-out is best short-term option for a number of reasons, including: not able to buy out liabilities in full with an insurer, concerns around corporate accounting implications, and the potential loss of future surplus that might be used to pay for discretionary pension increases or a defined contribution (DC) section, or be refunded to the company. In comparison with a buy-out or superfund solution where there is a ‘step-change in a governance arrangement’, a CBFA is principally a time-limited

³⁴⁸ <https://www.professionaladviser.com/news/4142708/superfund-deal-paves-era-db-schemes>. The Mansion House Reforms ‘will enable [the UK] financial services sector to unlock capital for [the UK's] most promising industries and increase returns for savers, supporting growth across the wider economy. Firstly, the [UK] government is announcing a series of measures to boost outcomes for savers and increase funding liquidity for high-growth companies through reforms to the UK's pension market. Secondly, the government is setting out ways to incentivise companies to start and grow in the UK by strengthening [its] position as a listing destination. And finally, the government is seizing the opportunities of the future by reforming and simplifying [the] financial services rulebook to ensure [the UK has] the most growth-friendly regulation of any financial services centre, without compromising [the government's] commitment to stability’; <https://www.gov.uk/government/collections/mansion-house-2023>

³⁴⁹ <https://www.ipe.com/news/dalriada-trustees-launches-alternative-pension-consolidation-solution/10071057.article>

³⁵⁰ <https://www.ipe.com/pension-funds/benefits-of-travelling-together-in-pensions-wyn-franciss-journey-from-bt-to-brightwell/10070368.article>

³⁵¹ <https://www.ipe.com/news/ifo-highlights-benefits-of-capital-backed-funding-arrangements/10068493.article>

investment decision within the remit of the existing trustee board. CBFAs can potentially improve member outcomes by, e.g., reducing downside investment risk by underwriting the risk of poor investment returns, pay benefit cashflows with added security while retaining some investment upside and flexibility, and supplement the sponsoring employer's covenant.³⁵²

Mercer's Pensions Risk Survey in November 2023 predicted that companies with pension fund surpluses could be the subject of restructuring and merger and acquisitions (M&A) activity, with the pension scheme being perceived as a valuable addition to any deal. Mercer senior corporate consultant, Shane Tuohy, said: 'Some [potential company buyers] might be able to take the scheme off company books at little or no cost by securing the benefits with an insurer. Others might choose to run schemes on to extract value. They might offer enhanced security in exchange for an investment strategy which works harder or insure part of the risk associated with the DB scheme via the use of a captive vehicle'.^{353,354}

In December, the UK Financial Reporting Council (FRC)³⁵⁵ revised its 'Technical Actuarial Standard 300: Pensions (TAS 300)' to reflect developments in the pension industry, in particular increased buyout activity and pension superfunds. Practitioners providing advice to a scheme sponsor contemplating a bulk transfer must consider credible alternatives to the potential transaction, any material impact on the protection provided, material risks to the benefits and any changes to the sponsor's ability to make decisions which affect the level of members' benefits. They must also use models that are calibrated appropriately to reflect the time horizon of projections and have sufficient regard to extreme events. Further, communication on superfund capital adequacy must include an explanation of the uncertainty in the actuarial information.³⁵⁶ In January 2024, the FRC dropped plans to add explicit ESG requirements in the UK Corporate Governance Code in order to keep administrative burdens on businesses 'to the minimum necessary'. Instead, the Code sets out more generalized expectations for company boards to monitor and review annually their firm's risk management and internal control framework. The new approach is a 'targeted, proportionate and balanced response to meeting enhanced investor and stakeholder expectations for better governance reporting around risk management and internal controls', but would be less intrusive and prescriptive for company boards, and would help to support UK growth, competitiveness,

³⁵² <https://www.ipe.com/news/ifo-highlights-benefits-of-capital-backed-funding-arrangements/10068493.article?>

³⁵³ <https://www.pensionpolicyinternational.com/uk-opportunity-for-buyers-as-db-pension-surplus-growth-continues/>

³⁵⁴ In the November 2023 Autumn statement, the UK Chancellor of the Exchequer reduced the surplus refund tax from 35% to 25% with effect from 5 April 2024.

³⁵⁵ The FRC 'regulate[s] auditors, accountants and actuaries, and ...set[s] the UK's Corporate Governance and Stewardship Codes. [It promotes] transparency and integrity in business. [Its] work is aimed at investors and others who rely on company reports, audit and high-quality risk management'; <https://www.frc.org.uk/about-us/>

³⁵⁶ <https://www.ipe.com/news/frc-updates-actuarial-guidance-in-light-of-increased-buyout-activity-superfunds/10070576.article>

It has become increasingly popular for trustees of larger UK pension schemes to buy ‘residual risks’ insurance cover to protect them against the risk of future claims or disputes following a buy-out of the scheme.³⁵⁷ The cost of the insurance is typically in the region of 1% of the buy-out premium and typically covers:

- claims from missing beneficiaries;
- a beneficiary proving s/he has a right to a higher level of benefits than those insured;
- a future change in law which reveals that higher benefits should have been secured;
- errors in the data file provided to the insurer; and
- the method used for guaranteed minimum pension (GMP) equalization³⁵⁸ being found to be deficient.

In an article in *Life Risk News* in December entitled, ‘Reinsurance concentration risks point to inevitable future for longevity risk transfer market’,³⁵⁹ Greg Winterton interviewed Avery Michaelson and David Schrager, CEO and CFO, respectively, of Longitude Exchange. They, along with Douglas Anderson and Steven Baxter of Club Vita and Professor Andrew Cairns of Heriot Watt University and Professor David Blake of Bayes Business School, are co-founders of ILMAC (the Index Longevity Market Action Committee) which was set up in May. ILMAC’s aim is ‘to build a consensus on a framework, ideally a market standard (to be incorporated into regulations such as Solvency UK or Solvency II, and related guidance) for basis risk quantification, combined with a set of principles for the development of an internal model for institutions seeking to use their own approach to basis risk quantification. This is intended to provide clarity on the capital relief that a regulated (re)insurer would achieve from using an index-based hedging structure’.

Michaelson and Schrager discussed the weaknesses of existing hedging arrangements for insurers. Schrager pointed out that ‘What insurers are doing – in the UK, the Netherlands, and the US – to avoid being overly exposed to longevity risk is that they transfer it to reinsurers using longevity swaps. But all of these insurers are hedging their longevity risk with the same limited number of life reinsurers’. Michaelson added ‘For all life reinsurers, a natural hedge exists on their balance sheets. The problem is that, as a hedge, it’s not quite as effective as it might appear on the surface. When an extreme mortality event, such as Covid, occurs, it is almost certain to produce an offsetting move in a reinsurer’s longevity exposures in the form of reduced liabilities. However, in extreme longevity scenarios resulting from broad-based increases in life expectancy, it’s less certain to produce significant gains from a reinsurer’s mortality business as these are typically shorter duration contracts whose pricing can reset to current expectations about mortality’.

³⁵⁷ <https://www.pinsentmasons.com/en-gb/out-law/analysis/pensions-risk-transfer-risks-residual-risk-insurance?>

³⁵⁸ Guaranteed Minimum Pension (GMP) equalisation, House of Commons Library, 21 September 2023; <https://commonslibrary.parliament.uk/research-briefings/cbp-8427/>

³⁵⁹ Greg Winterton (2023) Reinsurance concentration risks point to inevitable future for longevity risk transfer market’, *Life Risk News*, 2(12), December; <https://liferisk.news/reinsurance-concentration-risks-point-to-inevitable-future-for-longevity-risk-transfer-market/>

The second problem according to Michaelson is that the scope of the offset is not unlimited: ‘The pension risk transfer market is growing at a blistering rate as higher interest rates have accelerated a structural change that’s been underway for over a decade. For those reinsurers that have been writing longevity swaps for that whole period, a good portion of the mortality offset has been used up, and the demand for longevity risk capacity is growing faster than for mortality’. Sources of capital outside the insurance industry are therefore needed to support the growth in the global PRT market.

ILMAC was set up in response to these issues and to promote the use of index-based longevity hedging as a way of persuading capital markets investors, such as asset managers and sovereign wealth funds, to take on longevity risk in a format, namely an index, with which they are familiar. With this approach, capital markets investors assume the longevity risk above a certain level based on a general population mortality index. By attracting a large and diversified set of new counterparties, this framework would help to reduce the concentration risk in the exiting market.

Nevertheless, involving the capital markets involves challenges, not least getting regulatory approval for an index-based longevity hedge. This provided part of the motivation for setting up ILMAC. At the time of writing, the committee was preparing a case study that calculates the capital relief a Solvency II insurer could take if it used an index-based hedge and took account of the basis risk that this involved compared with a full-indemnification solution that accounted for the specific mortality experience of the pension scheme being transferred.

Michaelson concluded that ‘There could be as much as \$500bn of longevity risk transfer demand annually, which is nearly the same size as the entire reinsurance industry. It’s not sustainable to move all of the longevity risk globally to just a few balance sheets [those of the small number of global reinsurers] – this could introduce a “too big to fail” situation that regulators are right to be concerned about. The natural solution is to encourage greater involvement from the capital markets’.

Highlights for 2023 in the UK included:

- In February, PIC executed the largest buy-in to date (£6.5bn) with two of the RSA Insurance Group schemes, covering 40,000 members.³⁶⁰
- In February, the GKN Group Pension Scheme completed a £513m full scheme buy-in with Just Group, insuring the benefits of some 2,262 pensioners and 1,963 deferred members.³⁶¹
- In March, PIC completed £142m buy-in with the Spirent Communications Staff Pension & Life Assurance Scheme.
- In March, Aviva completed a £34m buy-in with the Chapelthorpe Pension Fund, securing the benefits of the remaining 805 uninsured members in the scheme.

³⁶⁰ <https://www.professionalspensions.com/analysis/4077080/rsas-record-breaking-gbp-5bn-means-pensions-risking-market?>

³⁶¹ <https://www.ipe.com/news/uk-roundup-gkn-group-completes-513m-pensions-buy-in-deal-with-just-group/10065404.article?>

- In March, PIC invested £50m Portsmouth Water to help fund the construction of the Havant Thicket Reservoir, the first major new reservoir in the UK since the 1980s.³⁶²
- In March, the Shoe Zone Group Pension Scheme completed a £34m buy-in with Rothesay, covering 367 pensioners and 166 deferred members.³⁶³
- In March, PIC bought a £268m office in Croydon, South London, pre-let to the UK Government Property Agency.³⁶⁴
- In April, L&G agreed a £18m buy-in with the Sleepyhead Retirement Benefits Plan, securing the benefits of around 200 retired and deferred members.
- In April, Rothesay secured a £1.4bn buy-in with the Safeway pension scheme, covering 22,500 members.³⁶⁵
- In April, Just Group completed a £190m buy-in with the Ibstock Pension Scheme, adding to an existing £340m buy-in policy completing in 2020.
- In May, the Yorkshire and Clydesdale Bank Pension Scheme announced a £1.6bn longevity swap with Zurich Assurance covering 9,000 members, with the longevity risk passed through to Pacific Life Re.³⁶⁶
- In May, Aviva completed a £900m buy-in with the Thomas Cook Pension Plan, covering 12,500 members.³⁶⁷
- In May, the British Steel Pension Scheme completed a fourth and final buy-in deal worth £2.7bn with L&G, becoming the largest UK scheme to fully insure all its 67,000 retired and deferred members' benefits.³⁶⁸
- In May, Just Group announced a £40m buy-in with the BUT Retirement Benefits Scheme.
- In May, Mitchells & Butlers, the pub chain, agreed a £1.2bn bulk purchase annuity transaction with Standard Life covering around 20,200 deferred and retired members. This follows a £650m buy-in for the Mitchells & Butlers Executive Pension Plan with L&G at the end of 2021.³⁶⁹
- In June, the Aegon UK pension scheme completed a £160m buy-in with Scottish Widows, covering around 500 members.

³⁶² <https://realassets.ipe.com/news/pic-joins-investors-in-portsmouth-waters-uk-reservoir-project/10065631.article>

³⁶³ <https://www.professionalspensions.com/news/4087363/shoe-zone-scheme-completes-gbp34m-rothesay>

³⁶⁴ <https://realassets.ipe.com/news/pic-buys-268m-office-pre-let-to-uk-government-property-agency/10065818.article>

³⁶⁵ <https://www.ipe.com/news/buy-in-roundup-safeway-completes-14bn-deal-with-rothesay/10066289.article>

³⁶⁶ <https://www.ipe.com/news/uk-bank-pension-scheme-in-16bn-longevity-swap-deal/10066421.article>

³⁶⁷ <https://www.ipe.com/news/uk-travel-pension-fund-secures-900m-buy-in-deal-with-aviva/10066537.article>

³⁶⁸ <https://www.ipe.com/news/uk-roundup-british-steel-pension-scheme-in-27bn-buy-in-deal/10066690.article?>

³⁶⁹ <https://www.ipe.com/news/uk-roundup-mitchells-and-butlers-scheme-in-12bn-buy-in-with-standard-life/10068002.article>

- In June, the Harrods Group Pension Plan secured the pension benefit of around 1,900 pensioners and 2,100 deferred members with a £400m buy-in agreement with Scottish Widows.³⁷⁰
- In June, Standard Life completed a £80m buy-in with MGM Assurance Staff Pension Plan.
- In June, the Nationwide Pension Fund completed a £1.7bn longevity swap, covering around 7,000 pensioner members, with Zurich Assurance and PICA (as reinsurer of the longevity risk).³⁷¹
- In June, Just Group completed a £94m buy-in with the Mabey Pension Scheme in a record time of three months.
- In July, the Chubb Pension Plan and the Chubb Security Pension Fund, both of which are sponsored by subsidiaries of APi Group Corporation, completed a £1bn buy-in with Standard Life.
- In July, British Telecom (BT) announced that it was planning a £30bn buy-in for its pension scheme which has 60,000 members.³⁷²
- In July, United Utilities insured £1.8bn in pension liabilities through a buy-in with L&G.
- In July, the Hammerson Group Management Limited Pension and Life Assurance Scheme completed a £390m bulk annuity transaction with Just Group, covering all members of the scheme.
- In July, United Utilities executed a £1.8bn buy-in deal with L&G for its two pension schemes, covering two thirds of the schemes' liabilities.³⁷³
- In July, Aviva completed a £600,000 buy-out with the Singer & James pension scheme, one of the smallest deals of all time.
- In July, PIC completed a £40m buy-in with the Qantas Airways Limited (UK) Retirement Benefits Scheme.
- In July, Canada Life completed its first-ever deferred member buy-in worth £58m with an undisclosed pension scheme.
- In July, Just Group executed a £7m buy-in with the Rannoch Food Group Pension Scheme, covering 46 deferred members and 10 pensioners.
- In July, RGA agreed a £5bn longevity swap with the BT Pension Scheme, covering pensioner liabilities.³⁷⁴
- In August, Rothesay completed a £260m buy-in with the Smith & Nephew UK Pension Fund.
- In August, Rothesay also completed a £440m buy-in with the P&O Pension Scheme, covering the retirement benefits of 5,300 members.
- In August, the BT Pension Scheme agreed a £5bn longevity swap with RGA.³⁷⁵

³⁷⁰ <https://www.ipe.com/news/harrods-pension-scheme-completes-buy-in-deal-worth-400m/10067147.article?>

³⁷¹ <https://www.ipe.com/news/nationwide-pension-fund-completes-17bn-uk-longevity-risk-transaction/10067303.article?>

³⁷² <https://www.ft.com/content/78934baa-e97e-4cd1-b07c-b0957d945f7b>

³⁷³ <https://www.ipe.com/news/united-utilities-pension-funds-secure-18bn-buy-in-deal-with-legal-and-general/10067906.article?>

³⁷⁴ <https://www.ipe.com/news/bt-pension-scheme-signs-5bn-longevity-swap-deal/10068085.article?>

³⁷⁵ <https://www.ipe.com/bt-pension-scheme-signs-5bn-longevity-swap-deal/10068085.article>

- In August, Just Group executed a fifth and final buy-in with the ITB pension scheme (valued at £290m), implying that all of the scheme members' benefits had now been secured.
- In September, the Association of British Insurers (ABI) pension and assurance scheme completed a £18.4m buy-out with Just Group.
- In September, Just Group also completed a £4m buy-out with the KGM pension scheme, covering 14 deferred and 10 pensioner members.
- In September, L&G agreed a £340m buy-in with the Cable and Wireless pension scheme, covering around 1,800 retirees and deferred members.³⁷⁶
- In September, M&G executed a £331m buy-in with its own pension scheme, covering 1,414 pensioners and deferred members, together with the transfer of the scheme's illiquid assets to Prudential (UK) as part of the transaction.
- Also in September, M&G concluded a £286m buy-in with the Northern Bank Pension Scheme, covering 1,917 members.³⁷⁷
- In October, the London Stock Exchange (LSE) Group Pension Scheme agreed a £335m buy-in with Standard Life, covering 1,740 members across the LSE and London Clearing House sections of the scheme.³⁷⁸
- In October, Canada Life executed a £30m buy-in with the Andrew Sykes Group Pension Scheme, covering around 440 members, including 160 deferred members.
- In October, the British Red Cross pension schemes agreed a £30m buy-in with Aviva, covering 360 members.
- In October, the Bayer Group Pension Plan executed a £280m buy-in with Canada Life, covering the benefits of around 1,300 retirees.³⁷⁹
- In November, Aviva agreed a £80m buy-in with the Rotork pension scheme, securing the benefits of 406 pensioners and dependants.
- In November, Just Group completed a £32m buy-in with the Air France (UK) Pension Scheme, covering around 200 members.
- In November, PIC invested £50m to develop 125 affordable and shared ownership homes in partnership with residential developer London Square, in order to generate secure low-risk, inflation-linked cashflows to pay its pensioner policyholders. PIC has invested around £4bn in this sector since 2012.³⁸⁰
- In November, Just Group invested £350m in UK real estate and social infrastructure, including around 100 healthcare facilities that provide specialist care for patients with high acuity caring needs and childcare centres. These assets also generate long-dated, inflation-linked cashflows.³⁸¹

³⁷⁶ C&W had previously executed buy-ins with Prudential in 2008 and with L&G in 2017 and 2019; <https://www.ipe.com/news/cable-and-wireless-superannuation-fund-complete-340m-buy-in-deal/10069038.article>

³⁷⁷ <https://www.ipe.com/news/northern-bank-pension-scheme-secures-benefits-of-nearly-2k-members/10069079.article>

³⁷⁸ <https://www.ipe.com/news/london-stock-exchange-pension-scheme-in-335m-buy-in-with-standard-life/10069419.article>

³⁷⁹ <https://www.ipe.com/news/bayer-group-pension-plan-in-280m-buy-in-with-canada-life/10069715.article>

³⁸⁰ <https://realassets.ipe.com/news/pic-invests-50m-in-uk-affordable-and-shared-ownership-homes-project/10069995.article>

³⁸¹ <https://realassets.ipe.com/news/just-group-invests-350m-in-uk-real-estate-with-focus-on-social-infrastructure/10070026.article>

- In November, Deutsche Bank's UK pension scheme completed a £500m buy-in with L&G, covering 2,000 members, and taking the scheme's total buy-in to £1.5bn, around half of the total liabilities.³⁸²
- In November, the Marsh McLennan (MMC) UK Pension Fund executed a longevity swap covering £2bn of liabilities for around 14,500 pensioners. The longevity risk was insured via a captive Guernsey insurance cell and immediately reinsured with Munich Re through the same Mercer Marsh longevity captive solution used in 2017. This was the first longevity swap to include active members and was also the second largest UK pension fund swap to cover more non-pensioner members than pensioners. Virtually all the fund's DB section longevity risk had now been insured.³⁸³
- In November, the Co-operative Pension Scheme agreed a £4bn buy-in with Rothesay, covering around 50,000 members, including 17,655 pensioners and dependants as well as 31,896 deferred members.³⁸⁴
- In November, the Boots Pension Scheme completed a £4.8bn buy-in with L&G, covering all 53,000 retirees and deferred members. This is the UK's largest single transaction of its kind by premium size and, for L&G, the largest single transaction by number of members. Boots agreed to pay £670m in additional contributions.³⁸⁵
- In November, Askews Retirement Scheme completed £11m buy-in with L&G, covering the benefits of all 86 scheme members.
- In November, Rothesay agreed a £2.7bn full scheme buy-in with the Thales UK pension scheme, covering around 16,000 members, including 10,512 pensioners and dependants, and 5,915 deferred members.³⁸⁶
- In December, the Superior Pension Fund executed a £10m bulk annuity deal with Just, insuring the pension liabilities of 78 members.
- In December, PIC announced it had provided a secured loan of £60m to enable the MHS Homes Group to increase its stock of social houses.³⁸⁷
- In December, PIC completed a £65m full buy-in of the Chemring Group Staff Pension Scheme.
- In December, Just Group and Macquarie Asset Management invested £400m in notes related to a portfolio of 55 commercial ground leases relating to Asda supermarket sites in exchange for a 'high-quality, long-term income stream from ground lease payments'.³⁸⁸
- In December, the Westminster Abbey pension scheme completed a £25m full-scheme buy-in with PIC.

³⁸² <https://www.ipe.com/news/deutsche-bank-uk-pension-scheme-completes-500m-buy-in-with-legal-and-general/10070007.article>

³⁸³ <https://www.ipe.com/news/mmc-uk-pension-fund-completes-first-active-member-longevity-swap/10070069.article>

³⁸⁴ <https://www.ipe.com/news/co-op-pension-fund-insures-remaining-4bn-of-liabilities/10070254.article>

³⁸⁵ <https://www.ipe.com/news/boots-pension-scheme-completes-largest-single-transaction-with-landg/10070257.article>

³⁸⁶ <https://www.ipe.com/news/thales-pension-scheme-secures-27bn-buy-in-with-rothesay/10070427.article>

³⁸⁷ <https://realassets.ipe.com/news/pic-expands-lending-in-uk-social-housing-sector-with-30m-investment/10070518.article>; *Insurance Asset Management*, 11 December 2023.

³⁸⁸ <https://realassets.ipe.com/news/macquarie-and-just-group-enter-400m-ground-lease-financing-with-asda/10070645.article>

- In December, the St Paul's Cathedral pension scheme agreed a £18m full scheme buy-in with Aviva.
- In December, the NICEIC (or Electrical Safety First) Pension Scheme did a £66m full buy-in with Just Group, securing the retirement benefits for 237 pensioners and 154 deferred members.
- In December, the Haag-Streit UK pension scheme completed a £18m full buy-in with Aviva.
- In December, the Hyde Housing Association pension scheme secured a £60m full buy-in with Just Group.
- During the year, Canada Life completed its first deferred member buy-in – the deal was valued at £58m and covered around 300 deferreds and a further 270 pensioners.³⁸⁹

There were a number of significant international developments outside the UK in 2023.

US corporate pension plans were on average fully funded for the first time in 15 years (103.5% in June 2023³⁹⁰). This was largely because the average discount rate used to value plan liabilities was 5.25%, well above the 2.88% rate used a year before. The increase is explained by the Federal Reserve's increase in the Federal Funds Rate to 5.25% to 5.50% in July in order to control inflation. This was expected to increase pension risk transfer transactions, whether a full termination or lift-out of a select population of retirees and beneficiaries. Corporations also benefited from lower buy-out premiums charged by insurance companies. According to Milliman, the estimated average premium was 99.3% as of March 31. Another contributing factor was the higher premium charged by the Pension Benefit Guaranty Corporation (increased by 9% in 2023 and 5% in 2024 to \$101 per participant³⁹¹) which can be avoided following PRT.³⁹² MetLife's 2023 Pension Risk Transfer Poll in October found that 90% of DB plans expected to fully transfer all their liabilities in an average of 4 years. The main reasons given were inflation (49%), increases in the volume of retirees, market volatility and rising interest rates (all 42%) and attractive annuity pricing (35%). The majority of respondents (55%) said they planned to divest of all their liabilities through multiple transactions, while the rest said they would use a single transaction.³⁹³ While they were waiting to divest, a large number of schemes (44%) were planning to amend their liability-driven investment strategies to improve downside risk protection, according to a survey sponsored by Franklin Templeton.³⁹⁴ During the first half of 2023, a record \$22.5bn in transactions were completed, with \$45bn for the whole year. There were a total of 773 transactions, of which 453 were terminations, 310 lift-outs

³⁸⁹ <https://www.xpsgroup.com/news-views/insights-briefings/bulk-annuity-market-q4-update-trustees-and-pension-scheme-sponsors>

³⁹⁰ <https://www.pensionpolicyinternational.com/global-pension-risk-transfer-monitor-record-h1-transaction-volumes-in-uk-and-us/>

³⁹¹ <https://www.pbpc.gov/prac/prem/premium-rates>

³⁹² <https://www.ai-cio.com/news/pension-risk-transfers-poised-for-2nd-strongest-year-ever>

³⁹³ <https://www.pensionpolicyinternational.com/90-of-u-s-companies-with-db-plans-looking-for-exits-via-prt-metlife/>

³⁹⁴ <https://www.pensionpolicyinternational.com/us-study-finds-healthier-funding-status-for-db-plans-raising-interest-in-ldi-strategy-reviews/>

and 10 buy-ins, valued at \$12.4bn, \$28.7bn and \$3.9bn, respectively.³⁹⁵ Pricing was competitive, close to the value of liabilities that plan sponsors are holding on their balance sheets.³⁹⁶

Highlights for 2023 in the US included:

- In May, AT&T Inc announced the third-largest US pension risk transfer to date via its purchase of group annuity contracts from two Athene Holding subsidiaries (Athene Annuity & Life Co. and Athene Annuity & Life Assurance Co. of New York) covering the \$8.1bn pension liabilities of 96,000 AT&T plan members and beneficiaries.³⁹⁷
- In June, Legal & General Retirement America (LGRA) and RGA agreed a \$309m pension risk transfer transaction with PPG, a Fortune 500 paint manufacturer.
- In June, Fidelity Investments registered Soteria Reinsurance in Bermuda in order to ‘focus on affiliated reinsurance of US Retail Fixed Annuities and Pension Risk Transfer Opportunities of existing and new Fidelity Investment Life Insurance Company (FILI) business’.³⁹⁸
- In August, Prudential Financial announced the transfer of around \$1bn in pension liabilities from PSEG, a utilities provider, for 2,000 participants. The deal is a ‘retiree only lift-out’, with only the liabilities of these retirees being annuitized.³⁹⁹
- In November, MetLife completed a risk transfer transaction with Global Atlantic Financial Group, a retirement and life insurance company. The deal contributed to the run-off of MetLife’s closed-block of US retail business, representing \$19bn of statutory reserves. MetLife will remain as administrator and service provider for the reinsured policies and MetLife Investment Management will also manage a significant amount of the assets for the next five years.⁴⁰⁰

One of the most significant events during the year was establishment in September of Prismic Life Re, a licensed Class E Bermuda-based life and annuity reinsurance company. Prismic is backed by \$1bn in equity capital, with the lead investors being Prudential Financial and Warburg Pincus, with equity holdings of 20% and 15%, respectively. Prudential plans to reinsure to Prismic a block of structured settlement annuity contracts⁴⁰¹ with reserves of approximately \$10bn. Prudential’s obligations to the holders of these

³⁹⁵ <https://www.pensionpolicyinternational.com/us-pension-risk-transfer-market-expected-to-see-10-billion-in-q3-deal-volume/>; <https://www.pensionpolicyinternational.com/u-s-prt-transactions-hit-all-time-high-in-2023-aon/>

³⁹⁶ <https://liferisk.news/still-plenty-of-capacity-for-growth-in-robust-us-prt-market/>

³⁹⁷ <https://www.pensionpolicyinternational.com/us-rising-interest-rates-put-corporate-pension-plans-on-end-game-pat/>; <https://www.pensionpolicyinternational.com/us-pension-risk-transfer-market-off-to-strong-start-this-year/>

³⁹⁸ <https://www.pensionpolicyinternational.com/fidelity-investments-forms-retail-annuities-and-pension-risk-transfer-focused-reinsurer/>

³⁹⁹ <https://www.ai-cio.com/news/prudential-closes-1-billion-prt-deal-with-pseg/>

⁴⁰⁰ <https://www.bloomberg.com/press-releases/2023-11-16/metlife-completes-risk-transfer-transaction-with-global-atlantic-financial-group>

⁴⁰¹ A structured settlement annuity provides regular tax-free payments and is used in cases of personal injury and legal settlements, such as workers’ compensation, medical malpractice and wrongful death; <https://www.annuity.org/structured-settlements/>

annuities will remain unchanged and Prudential will continue to administer the contracts. Prismic will be a strategic reinsurance partner for Prudential in the years ahead. PGIM (Prudential Global Investment Management) and Warburg Pincus will provide asset management services to Prismic: PGIM's expertise is in public fixed income, private credit and real estate, while Warburg Pincus specialises in private market investments. Prismic will become a client of PGIM Portfolio Advisory, a newly established affiliate within PGIM that combines asset-liability management expertise with portfolio strategy and asset allocation to deliver integrated solutions across public and private asset classes. Prismic's first CEO is Amy Kessler, who was the founding leader of Prudential's international reinsurance business.

Charles Lowrey, chairman and CEO of Prudential Financial, said: 'This unique reinsurance platform will play an important role in our vision to be a global leader in expanding access to investing, insurance, and retirement security for people around the world. Prismic will enhance our ability to address the evolving needs of our insurance customers and clients while continuing to meet our obligations to policyholders. It represents a formidable combination of industry-leading expertise, global capabilities, and the backing of two of the world's leading insurance and asset management firms'.⁴⁰² This event is significant because it is one of the first big attempts to bring third-party capital into reinsurance industry in order to sustain its extraordinary recent growth.

At the same time, the increasing involvement of private equity (or private capital) firms (sometimes in conjunction with other investors, such as sovereign-wealth funds) has attracted the attention of US politicians and regulators. McKinsey reported in 2022 that the five largest PE firms by assets have investments in life insurers with exposures ranging from 15 to 50% of their total assets under management and that private investors owned in excess of \$900bn of life and annuity assets in Europe and North America.⁴⁰³ In August 2023, Senator Sherrod Brown, Chair of the US Senate Committee on Banking, Housing, and Urban Affairs, started to question the role of PE in insuring pension payments.⁴⁰⁴ The Federal Insurance Office (FIO) pointed out in a response to Senator Sherrod Brown that 'As private markets have expanded over the last decade, far outpacing the growth of public markets, private equity firms have reshaped their business models and increased involvement in the life insurance sector. Previously, the focus of private equity was largely on buy-outs. Now, some private equity firms are increasingly pivoting their business objective to the private credit market'.

The McKinsey report points out that PE has been involved in the US insurance industry since at least 1967 when Berkshire Hathaway acquired National Indemnity. One of the key attractions is that ownership of a life insurer gives access to 'permanent capital', funds which do not have to be returned to investors on a specific timetable or at all. This

⁴⁰² <https://news.prudential.com/prudential-financial-inc-and-warburg-pincus-announce-launch-prismic-life-re.htm>

⁴⁰³ <https://www.mckinsey.com/industries/private-equity-and-principal-investors/our-insights/why-private-equity-sees-life-and-annuities-as-an-enticing-form-of-permanent-capital>

⁴⁰⁴ <https://www.brown.senate.gov/newsroom/press/release/sherrod-brown-continues-push-private-equity-firms-involvement-insurance-industry>

permanent capital therefore saves PE investors time and effort on fundraising and offers them the flexibility to invest ‘at times, like a crisis, when other forms of capital can become scarce’. Another attraction is that the returns on PE shareholders’ equity can be increased by between 4-7 percentage points annually (to between 10-14%) by applying their investment management capabilities to earn alpha on some asset classes, such as asset-backed securities (primarily collateralized loan obligations) and private loans. Further, the relatively high (ten times) asset-to-equity ratio typical of insurers amplifies the impact of strong investment performance. The report says that ‘The core attraction is straightforward. The balance sheets of life and annuities companies [are one form of permanent capital and] are well stocked with assets...but until payout, these assets need to be invested to generate returns. And in many cases, the cost of servicing the liabilities is significantly lower than the potential investment return. The spread represents an attractive margin’.

However, Charles Decker, a researcher at the Unite Here trade union, has argued that ‘The whole private debt sector has grown hand-in-hand with the low interest rate environment and there are reasons to be concerned about an asset class which has not been tested by either a period of prolonged high interest rates, or a major recession. But [our] greatest concern is just how opaque these assets are, it’s very difficult to find out exactly what these private equity-backed insurers are investing in’.⁴⁰⁵ There is also concern about the ‘maturity wall’ of low-grade corporate bonds that were issued during the period of ultra-low interest rates and which will mature over the next few years (\$38bn in the US in 2024 and increasing to \$235bn in 2028). These bonds will need to be rolled over in the world of much higher interest rates that central banks have introduced to control inflation. But according to the Federal Reserve, 10% of US companies have a so-called ‘zombie’ status and are unable to cover their interest expenses from operating income. A report by BCA (Bank Credit Analyst) Research found that ‘Zombie companies... are multiplying [and] are highly sensitive to surging borrowing costs’.⁴⁰⁶ Joe Engelhard, Senior Counsel, US Policy & Regulation at the Alternative Investment Management Association (AIMA), the global trade body for the private equity industry, responded to criticisms like this by arguing that ‘In the US, the pension risk transfer market is regulated at both the federal and state levels, and insurers have a great track record over many decades of providing benefits to annuitants’.⁴⁰⁷

The median solvency ratio of Canadian corporate DB pension plans was 119% at the end of June 2023, with 85% of the plans in surplus on a solvency basis. In order to protect these surpluses and de-risk their portfolios, plan managers were buying annuities from life insurance companies to transfer pension risk (around C\$8bn annually), increasing liability-driven investments, and swapping shorter-dated for longer-dated bonds to increase the maturity matching with liabilities.⁴⁰⁸

⁴⁰⁵ <https://liferisk.news/spotlight-falls-on-us-life-insurers-private-debt-investments>

⁴⁰⁶ <https://www.ai-cio.com/news/weak-companies-low-yielding-bonds-set-to-hit-maturity-wall/>

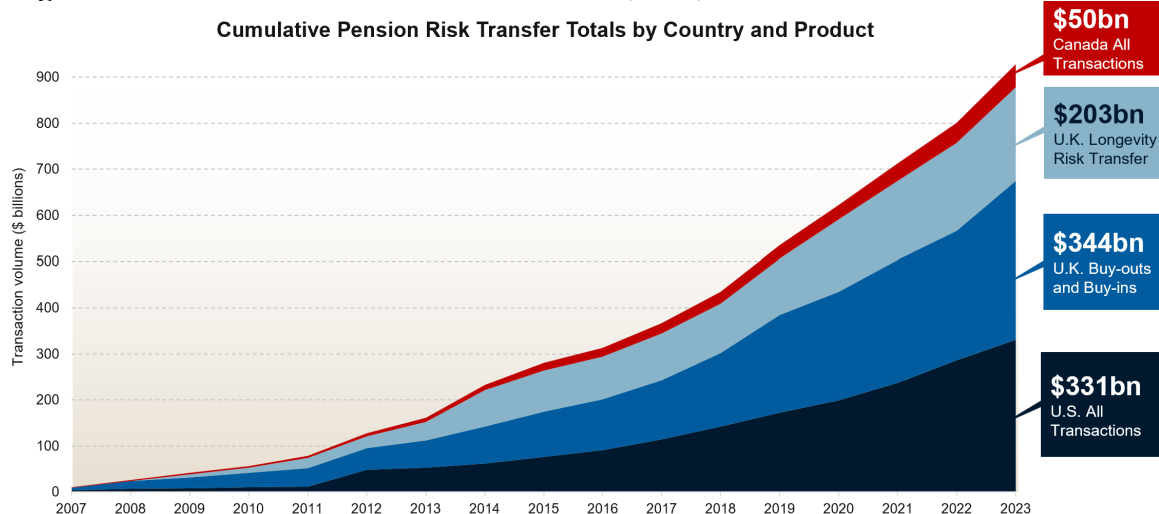
⁴⁰⁷ <https://liferisk.news/spotlight-falls-on-us-life-insurers-private-debt-investments>

⁴⁰⁸ <https://www.ai-cio.com/news/canadian-pension-plans-look-to-annuities-fixed-income-to-preserve-pension-surplus>

In March, Legal & General entered the Dutch buy-out market in partnership with Dutch insurer Lifetri to arrange future buy-outs with pension funds that do not want to make the transition to the new defined contribution system and would provide ‘insurance-based, capital-backed guarantees for members’. Lifetri had previously executed only one buy-out deal, namely a €850m buy-out of the pension benefits of Pensioenfondsen Allianz in 2020. To date, buy-outs have not been common in the Netherlands. In 2022, there was just one buy-out, with the closed Dutch pension fund of A.C. Nielsen executed by Zwitserleven.⁴⁰⁹

In December, NN Life (a subsidiary of NN Group) completed two transactions to transfer the full longevity risk associated with €13bn of pension liabilities across 300,000 policies in the Netherlands to Prudential Financial and Swiss Re.⁴¹⁰ The reinsurance agreements will continue until the portfolio has run off and do not impact the services and guarantees that NN provides to its policyholders. The aim of the agreements is to reduce NN’s exposure to longevity risk and hence strengthen NN’s capital position. David Knibbe, CEO of NN Group, said: ‘The capital uplift and economics from these transactions are very attractive compared to the limited impact on operating capital generation. It underscores our efforts to continually look for value creating opportunities, reduce longevity risk in the Dutch market, and actively manage our balance sheet’. Prior to the transaction, the Solvency II ratios for NN Group and NN Life were 205% and 187%, respectively. Following them, there will be an upfront capital benefit which will increase the Solvency II ratios for NN Group by 8 percentage points and for NN Life by 17 percentage points. The lower risk profile will lead to a limited decrease in operating capital generation for the first five years in the range of €30-35m per year. In the following years, the negative impact will decrease over time in line with the run-off of the portfolio.

Figure 3: Cumulative Pension Risk Transfers, \$bn, 2007-2023



Data in USD billions. Cumulative totals. Sources: LIMRA, Hymans Robertson, and WTW, 31 December 2023.

⁴⁰⁹ <https://www.ipe.com/news/landg-to-enter-dutch-buyout-market-with-lifetri-partnership/10065654.article?>

⁴¹⁰ <https://www.nn-group.com/news/nn-life-completes-two-longevity-transactions/>

Figure 3 shows the growth of the global market in longevity risk transfer between 2007 and 2023. A total of \$928bn in transactions have been completed during this period in the UK, the US and Canada (which comprises the vast majority of the global market).

Securitizing mortality risk

A number of insurers and reinsurers have used the capital markets to securitize some of the mortality risk on their book of business, in the form of what have become known as mortality-linked (or mortality catastrophe) bonds. Swiss Re has been the most active participant in the market, issuing the first security in 2003, known as Vita I.⁴¹¹ Vita I was a \$400m principal-at-risk variable rate note, where the investors' principal was at risk in certain extreme mortality risk scenarios in exchange for quarterly coupon payments of USD three-month LIBOR⁴¹² plus a spread of 135 basis points. The bond matured on 1 January 2007.

There has been some recent innovation in this market. An example of this is the La Vie Re Limited (Series 2020-1) mortality catastrophe bond issued by the Minnesota Life Insurance Company in October 2020. The bond covers the US and is the first indemnity 144A excess mortality bond that models the cedants' portfolio on a loss-ratio basis. The modelling was conducted by Risk Management Solutions which developed an indemnity trigger on loss ratios.⁴¹³

Guy Carpenter (GC), the global risk and reinsurance specialist, argues that risk transfer, reinsurance and insurance-linked securities sectors are well-placed to assist in dealing with climate change.⁴¹⁴ The company highlights catastrophe bonds as a key risk transfer and resilience financing tool for governments and public sector entities. Climate change increases the possibility of severe weather-related losses as well as demographic movements associated with rising sea levels, posing challenges to governments and entities exposed to these changes. GC calls for 'a rethink of how catastrophic events are funded and a greater use of public-private partnerships to manage risk'. According to the company, capital markets have the ability to absorb catastrophe and severe weather-related risks and diversify them away, allowing reinsurers and insurers to leverage its depth and liquidity and help make public sector entities more secure and better able to manage the financial exposure of climate-related risks.⁴¹⁵

⁴¹¹ Swiss Re obtains USD 400 million of extreme mortality risk coverage its first life securitization, news release, 8 December 2003;

https://www.swissre.com/dam/jcr:edf6b706-4c0b-4fc1-85bf-46a338e36208/pr_20031208_en.pdf

⁴¹² LIBOR, the London Interbank Offered Rate, was a benchmark interest rate at which major global banks lent to one another. It was replaced by the Secured Overnight Financing Rate (SOFR) on 30 June 2023; <https://www.investopedia.com/terms/l/libor.asp>

⁴¹³ <https://www.insurancebusinessmag.com/asia/news/breaking-news/rms-collaborates-on-new-mortality-catastrophe-bond-239994.aspx>

⁴¹⁴ Climate change is discussed in more detail below.

⁴¹⁵ Steve Evans (2020) Risk transfer, reinsurance key to address reality of climate change: Guy Carpenter, *Artemis*, 11 March; <https://www.artemis.bm/news/risk-transfer-reinsurance-key-to-address-reality-of-climate-change-guy-carpenter/>

Setbacks

As mentioned before, not all paths to progress are smooth. In recent years, this has been particularly true currently in the largest market dealing with micro-longevity risk, namely life settlements.⁴¹⁶ The life settlements market has been dogged by systematic underestimates of policy holders' life expectancies by certain medical underwriters, issues concerning premium financing, frauds, and ethical issues associated with 'profiting' from individuals dying and policies maturing. In December 2009, Goldman Sachs announced it was closing down its QxX.LS index. This was partly because of the reputational issues associated with life settlements, but mainly because of insufficient commercial activity in the index. While the ethical issues are no different in substance from those relating to the macro-longevity market (see, e.g., Blake and Harrison, 2008), the micro-longevity market needs to learn some important lessons from the macro-longevity (i.e., PRT) market. The macro-longevity market has been very successful at promoting good basic research on the analysis of the stochastic mortality forecasting models it uses and putting these models into the public domain and has also been much more transparent with the data it uses. This suggests a way forward for the life settlements micro-longevity market.

Another setback, this time to the macro-longevity market, occurred in April 2012 when a number of investment banks – Credit Suisse, Nomura and UBS – pulled out of the longevity risk transfer market as a result of additional capital requirements under Basel III. Investment banks had already been disadvantaged in this market by the Dodd-Frank Act which prevented US banks and their affiliates from entering longevity swaps and synthetic trades in life settlements. At around the same time, however, a number of insurers and reinsurers entered the market, e.g., PICA, SCOR and Munich Re. The following year witnessed the start of a process of consolidation in the insurance industry. In August 2013, Lucida was purchased by L&G for £150m; at the time, it had 31,000 pensioners on its books and £1.4bn in pension assets. In February 2014, the buy-out business of MetLife, which entered the market in 2007 and acquired the pension assets of 20,000 pensioners worth £3bn, was sold to Rothesay Life for an undisclosed sum, bringing its total assets to £10bn.

In December 2013, Goldman Sachs sold the majority of its stake in Rothesay Life to Blackstone (28.5%), the Government of Singapore Investment Corporation (GIC) (28.5%), and MassMutual (7%), due to the new regulatory capital requirements faced by banks and insurers.⁴¹⁷ In October 2020, Blackstone sold its 36% stake in Rothesay Life to GIC and

⁴¹⁶ The market for micro-longevity risk trades assets involving a small number of lives. In the case of life settlements, for example, the products involve individual lives and hence are subject to a significant degree of idiosyncratic mortality risk. This contrasts with the market for macro-longevity risk which deals with pension plans and annuity books and hence involves a large number of lives: here idiosyncratic mortality risk is much less important than systematic mortality risk which is essentially the trend risk of getting life expectancy projections wrong.

⁴¹⁷ In August 2017, Goldman Sachs sold its remaining stake in Rothesay Life to a consortium comprising US buy-out firm Blackstone, Singapore's sovereign wealth fund GIC, and US life insurer MassMutual in a deal valuing Rothesay Life at around £2bn; <http://www.cityam.com/269996/goldman-sachs-sells-final-stake-2bn-rothesay-life>

MassMutual for an undisclosed sum. This raised GIC and MassMutual's stakes to 49% each and values Rothesay Life at £5.8bn, with £56bn in assets under management.⁴¹⁸

Academic contributions

At the same time as these practical developments in the capital markets were taking place, academics were continuing to make progress on theoretical developments, building on the original idea of using longevity bonds to hedge longevity risk in the capital markets (Blake and Burrows (2001)). These included:

- Design and pricing of longevity bonds and other longevity-linked products (e.g., Blake et al. (2006a,b, 2014), Bauer (2006), Bauer and Ruß (2006), Antolin and Bloomestein (2007), Bauer and Kramer (2007), Denuit et al. (2007), Barbarin (2008), Bauer et al. (2010b), Chen and Cummins (2010), Kogure and Kurachi (2010), Bravo (2011), Dowd et al. (2011a), Mayhew and Smith (2011), Zhou et al. (2011, 2013, 2015), Chen et al. (2013), Shen and Siu (2013), Denuit et al. (2015), Hunt and Blake (2015), Milevsky and Salisbury (2015), Yang et al. (2015), Wang and Li (2016), Chen et al. (2017), Lin et al. (2017b), Blake (2018), D'Amato et al. (2018a), Leung et al. (2018), MacMinn and Richter (2018), Li and Tang (2019), Bahl and Sabanis (2021), Dagpunar (2021), Mayhew et al. (2021), Jevtić et al. (2021), Tang and Li (2021), Bozikas et al. (2022), Arik et al. (2023), Li et al. (2023))
- Design and pricing of longevity-linked derivatives (e.g., Shang et al. (2011), Lin et al. (2013), Wang and Yang (2013), Chuang and Brockett (2014), Bravo and Nunes (2021), Kung et al. (2021b)) and specifically survivor/longevity swaps (e.g., Dowd et al. (2006), Wang et al. (2013, 2015), Zhou and Li (2013), Li et al. (2019), Chen et al. (2022b)), survivor/longevity forwards and swaptions (e.g., Dawson et al. (2009, 2010), Zeddouk and Devolder (2020a)), q -forwards (e.g., Deng et al. (2012), Barrieu and Veraart (2016)), mortality options (e.g., Milevsky and Promislow (2001), Schmeck and Schmidli (2021), Zhou and Li (2021), Lin and Tsai (2023)), guaranteed annuity options (e.g., Gao et al. (2015)), longevity bond options (e.g., Xu et al. (2020)), and derivatives related to extreme mortality events (e.g., Huang et al. (2023b))
- Pricing longevity and mortality risk (e.g., Olivieri and Pitacco (2008), Bayraktar et al. (2009), Chen et al. (2010), Li (2010), Li et al. (2023))
- The pricing of longevity-related guarantees (e.g., Yang et al. (2008))
- The pricing and hedging of life settlements (e.g., Deng et al. (2011), Brockett et al. (2013), Zhu and Bauer (2013), MacMinn and Zhu (2017), Kung et al. (2021a))
- Longevity and mortality indices (e.g., Denuit (2009), Li et al. (2011), Chan et al. (2014), Tan et al. (2014), Ortiz et al. (2023))
- Securitization of longevity risk (e.g., Dahl (2004), Chen and Cox (2009), Cowley and Cummins (2005), Lin and Cox (2005), Cairns et al. (2006a), Cox and Lin

⁴¹⁸ Blackstone offloads stake in Rothesay Life, *Pionline*, 1 October; <https://www.pionline.com/money-management/blackstone-offloads-stake-rothesay-life>

- (2007), Biffis and Blake (2010, 2013, 2014), Wills and Sherris (2010), Lane (2011), Mazonas et al. (2011), Blake et al. (2013), Yang and Wang (2013), Michaelson and Mulholland (2014), Li et al. (2017c), MacMinn and Brockett (2017), Bugler et al. (2021), Börger et al. (2023), Zeddouk and Devolder (2023))
- Management and hedging of longevity risk (e.g., Dahl and Møller (2006), Friedberg and Webb (2007), Cocco and Gomes (2008), Tsai et al. (2010), Wang et al. (2010), Cairns (2011, 2013), Coughlan et al. (2011), Koijen et al. (2011), Li and Hardy (2011), and Tzeng et al. (2011), Wang et al. (2010, 2011b), Ngai and Sherris (2011), Barrieu et al. (2012), International Monetary Fund (2012), Li and Luo (2012), Cox et al. (2013a,b), Qiao and Sherris (2013), Cairns et al. (2014), Lin and Tsai (2014, 2020a,b), Zelenko (2014), Zhu and Bauer (2014), Liu and Li (2016, 2017, 2018, 2021), Blackburn et al. (2017), Li et al. (2017a), Wong et al. (2017), Zhou and Li (2017), D’Amato et al. (2018b), Li (2018), Tsai and Liang (2018), Hanbali et al. (2019), Zhou and Li (2019, 2020), Balasooriya et al. (2020), Sherris et al. (2020), Levantesi et al. (2020), Börger et al. (2021a), Broeders et al. (2021), Cairns and El Boukfaoui (2021), Hsieh et al. (2021), Kessler (2021), Li et al. (2021), MacMinn and Zhu (2021), Choulli et al. (2021), Siu and Liu (2021), Clemente et al. (2022), Feng et al. (2022), Tan et al. (2022), Chen et al. (2023a,b), Kallestrup-Lamb and Laursen (2023), Li et al. (2023), Yang and Zhou (2023))
 - Mortality data and modeling, mortality term structure⁴¹⁹ modeling, and mortality forecasting (e.g., Heligman and Pollard (1980), Hobcraft et al. (1982), Alho (1990), Lee and Carter (1992), Thatcher et al. (1998), Wilmoth and Horiuchi (1999), Booth et al. (2002a,b), Brouhns et al. (2002a,b, 2005), Renshaw and Haberman (2003a,b,c, 2006, 2008), Currie et al. (2004), Biffis (2005), Bongaarts (2005), Czado et al. (2005), Cairns et al. (2006b, 2008, 2009, 2011a), De Jong and Tickle (2006), Koissi et al (2006), Pedroza (2006), Schrager (2006), Delwarde et al. (2007), Bauer et al. (2008), Blake et al. (2008), Gourieroux and Monfort (2008), Hari et al. (2008), Kuang, et al. (2008), Haberman and Renshaw (2009, 2011, 2012, 2013), Hatzopoulos and Haberman (2009, 2011), Li et al. (2009, 2013, 2015a,b, 2017b), Plat (2009a,b), Wang and Preston (2009), Bauer et al. (2010a), Biffis and Blake (2010), Biffis et al. (2010), Cox et al. (2010), Debonneuil (2010), Dowd et al. (2010a,b, 2020), Lin and Tzeng (2010), Murphy (2010), Yang et al. (2010), Coelho and Nunes (2011), Currie (2011, 2016, 2020, 2023), D’Amato et al. (2011, 2012a,b), Ediev (2011, 2021), Gaille and Sherris (2011), Li and Chan (2011), Milidonis et al. (2011), Russo et al. (2011), Russolillo et al. (2011), Sweeting (2011), Wang et al. (2011a), Yue and Huang (2011), Zhu and Bauer (2011), Aleksic and Börger (2012), Hainaut (2012, 2018, 2023), O’Hare and Li (2012, 2017), Shang (2012, 2019), Wilmoth et al. (2012), Blackburn and Sherris (2013), Hyndman et al. (2013), Kleinow and Cairns (2013), Mitchell et al. (2013), Alai and Sherris (2014), Nielsen and Nielsen (2014), Hunt and Blake (2014, 2020a,b, 2021a,b,c,d), Villegas and Haberman (2014), Danesi et al. (2015), Tomas and Planchet (2015), Leng and Peng (2016), Li et al. (2016), Schinzingler et al. (2016), van Berkum et al. (2016), Beutner et al. (2017), Deprez et al. (2017), Gbari et al. (2017), Kleinow and Richards (2017), Li and Lu (2017), Li and O’Hare (2017), Mavros et al. (2017),

⁴¹⁹ The mortality term structure is the two-dimensional surface showing projected mortality rates at different ages for different future years.

Milidonis and Efthymiou (2017), Neves et al. (2017), Shang and Hyndman (2017), Tsai and Lin (2017a,b), Börger and Schupp (2018), Chen and Millossovich (2018), Debonneuil et al. (2018b), Ludkovski et al. (2018), McCarthy (2018), Salhi, and Thérond (2018), Shang and Haberman (2018), Venter and Şahin (2018), Villegas et al. (2018), Wong et al. (2018, 2023), Apicella et al. (2019), Guibert et al. (2019), Hilton et al. (2019), Liu et al. (2019), Pitacco (2019), Yang et al. (2019), Zhou (2019), Atance et al. (2020), Balland et al. (2020), Basellini et al. (2020, 2023), Li et al. (2020), Milevsky (2020), Njenga and Sherris (2020), Pascariu et al. (2020), Richards et al. (2020), Santolino (2020, 2023), Shang and Haberman (2020), Zeddouk and Devolder (2020b), Barigou et al. (2021, 2023), Börger et al. (2021b), Boumezoued (2021), Boumezoued and Elfassihi (2021), Diao et al. (2021), Guo and Bauer (2021), Gao and Shi (2021), Ghalehjooghi and Lyu (2021), He et al. (2021), Hilton et al. (2021), Li and Kogure (2021), Li and Lyu (2021), Li et al. (2021a), Lin et al. (2021), McCarthy and Wang (2021a), Medford (2021), Odhiambo et al. (2021), Pavía and Lledó (2021), Perla et al. (2021), Rabbi and Mazzuco (2021), Rizzi et al. (2021), Ševčíková and Raftery (2021), Shimizu et al. (2021), Su and Yue (2021), Tsai and Cheng (2021), Yue et al. (2021), Wang et al. (2021a,b), Yan et al. (2021), Zhou and Ji (2021), Albrecher et al. (2022), Awad et al. (2022), Beyaztas and Shang (2022), Bjerre (2022), Caraballo et al. (2022), Chandra and Abdullah (2022), Chen and Khaliq (2022), Djeundje et al. (2022), Huang et al. (2022), Jallbjørn and Jarner (2022), Kessy et al. (2022), Kularatne et al. (2022), Li and Chen (2022), Miyata and Matsuyama (2022), Odhiambo et al. (2022), Schnürch and Korn (2022), Scognamiglio (2022a,b), Scognamiglio and Marino (2022), Sliwka and Socha (2022), Spreeuw et al. (2022), SriDaran et al. (2022), Tang et al. (2022), Wang and Chan (2022), Zhou et al. (2022), Zhou and Li (2022), Zhu and Bauer (2022), Alonso-García (2023), Bégin et al. (2023b), Carannante et al. (2023a,b), Diao et al. (2023), Dyrting and Taylor (2023), Gowen et al. (2023), Haberman (2023), Hunt and Villegas (2023), Jena et al. (2023), Jones et al. (2023), Levantesi et al. (2023), Li (2023), Liu and Li (2023), Liu and Shi (2023), Lu and Zhu (2023), Marino et al. (2023), McCarthy and Wang (2023), Odhiambo (2023), Orwat-Acedańska (2023), Rakhmawan et al. (2023), Shimizu (2023), Ungolo et al. (2023), Wang et al. (2023b), Xiao et al. (2023), Zhu and Zhou (2023))

- Multi-population mortality modeling (e.g., Darkiewicz and Hoedemakers (2004), Li and Lee (2005), Cairns et al. (2011b), Dowd et al. (2011b), Jarner and Kryger (2011), Njenga and Sherris (2011), Torri and Vaupel (2012), Li (2013), D’Amato et al. (2014), Raftery et al. (2014), Zhou et al. (2014), Antonio et al. (2015), Chen et al. (2015), Kleinow (2015), Shang (2016), Yang et al. (2016), Antonio et al. (2017), Biffis et al. (2017), Li et al. (2015c, 2016, 2017d), De Jong et al. (2016, 2020), Enchev et al. (2017), van Berkum et al. (2017), Villegas et al. (2017), Zhu et al. (2017), Diaz et al. (2018), Hunt and Blake (2018), Kang et al. (2018), Pascariu et al. (2018), Pitt et al. (2018), Wang et al. (2018), Jevtić and Regis (2019), Jarner and Jallbjørn (2020, 2022), Shi et al. (2020), Wong et al. (2020), Chang et al. (2021), Li and Shi (2021a,b), Li et al. (2021b), Liu (2021), Lu et al. (2021), Richman and Wüthrich (2021), Schnürch et al. (2021), Shapovalov et al. (2021), Wen et al. (2021), Yang et al. (2021), Zhou and Ji (2021), Djeundje et al. (2022),

- Fokeer and Narsoo (2022), Gungah and Narsoo (2022), Jiao et al. (2022), Kung et al. (2022), Lin and Tsai (2022), Robben et al. (2022), Shang et al. (2022), Venter and Şahin (2022), Chang and Shi (2023), Debón et al. (2023), Jevtić et al. (2023), Perla and Scognamiglio (2023), Roshani et al. (2023), Shi et al. (2023), Wang et al. (2023c))
- Mortality modeling by cause-of-death, educational attainment, social class, special patterns, Covid-19 etc (e.g., Beard (1971), McNown and Rogers (1992), Christensen and Vaupel (1996), Hanewald (2011), Murphy and Di Cesare (2012), Arnold and Sherris (2013, 2015, 2016), Janssen et al. (2013), Alai et al. (2014a), Gourieroux and Lu (2015), Alai et al. (2018), Boumezoued et al. (2018), Yue et al. (2018), Li et al. (2019), Dutton et al. (2019), Cairns et al. (2020), Cupido et al. (2020), Kallestrup-Lamb et al. (2020), Lourés and Cairns (2020, 2021), Arnold and Glushko (2021), Lyu et al. (2021, 2023), Nusselder et al. (2022), Schnürch et al. (2022), Cadena and Denuit (2023), Huang et al. (2023a), Jallbjørn et al. (2023), Katsiferis et al. (2023), Navarro and Requena (2023), Pichler and Uhlig (2023), Wen et al. (2023), Zhang et al. (2023))
 - Population, births and deaths data – and modeling (e.g., Richards (2008), Cairns et al. (2016), Boumezoued et al. (2019, 2020), Boumezoued (2021), Boumezoued and Elfassihi (2021), Cheng et al. (2022), Hwang and Kim (2023), Tang et al. (2023))
 - Longevity inequality (e.g., Mayhew and Smith (2014, 2021), Debón et al. (2017), Mayhew et al. (2020), Álvarez et al. (2021), Li and Hyndman (2021), Sanzenbacher et al. (2021), Katsiferis et al. (2023), Mayhew (2023))
 - Longevity risk and financial innovation (improvements in the analysis and design of longevity-linked products) (e.g., Gong and Webb (2010), Stevens et al. (2010), Richter and Weber (2011), Cocco and Gomes (2012), Brown and Warshawsky (2013), Bernhardt and Donnelly (2019), Chen and Rach (2019), Chen et al. (2019), Weinert and Gründl (2021))
 - Reverse or equity release mortgages (e.g., Wang et al. (2008), Huang et al. (2011), Yang (2011), Alai et al. (2014b), Kogure et al. (2014), Shao et al. (2015), Lee et al. (2018), Dowd et al. (2019), Di Lorenzo et al. (2022))
 - Longevity risk in investment portfolios and asset-liability management (e.g., Milevsky and Young (2007), Menoncin (2008), Horneff et al. (2008, 2009, 2010, 2015), Maurer et al. (2013), Aro and Pennanen (2017), Gemmo et al. (2020), Maffra et al. (2021), Rogalla (2021), Lin et al. (2023))
 - Longevity risk in life insurance, pension plans, pension systems, annuities and long-term care, etc (e.g., Milevsky (2005), Huang et al. (2009, 2012, 2017), Richards et al. (2013, 2014), Aro (2014), Bisetti and Favero (2014), Donnelly (2014), Lin et al. (2014, 2015, 2017a), Ai et al. (2015), Wan and Bertschi (2015), Ai et al. (2017), Hunt and Blake (2017), Bravo and El Mekkaoui de Freitas (2018), Bruszas et al. (2018), Cox et al. (2018), Debonneuil et al. (2018a), Hsieh et al. (2018), Ignatieva et al. (2018), Kurtbegu (2018), Mayhew et al. (2018), Balter et al. (2020, 2021, 2023), Chen et al. (2020), Olivieri and Pitacco (2020, 2022), Wen et al. (2020), Ayuso et al. (2021), Balter et al. (2021), Cox et al. (2021), De Rosa et al. (2021), Dowd et al. (2021), Kogure et al. (2021), Lee et al. (2021), Leung et al. (2021), McCarthy and Wang (2021b), Richards (2021), van Berkum et al. (2021), Bakar and Büyükyazıcı (2022), Bernstein and Morales (2021), Bravo et al. (2021, 2023),

Bravo (2022), Cairns et al. (2022), Carannante et al. (2022), Chen et al. (2022a), Coppola et al. (2022), Feng et al. (2022), Li et al. (2022), Li and Kara (2022), Olivieri et al. (2022), Sharma et al. (2022), Rong et al. (2023), Agarwal et al. (2023), Bégin et al. (2023a), Bravo et al. (2023), Chen et al. (2023), Mrad et al. (2023), Lin et al. (2023), Lledó et al. (2023), Wang et al. (2023c)).

Looking into the future

There are a large number of factors that will influence the future of the PRT market. We now examine the key ones.

Peak cash flows

Pension funds not only need to have assets sufficient to meet liabilities (i.e., be fully funded), they need the cash flows on those assets to match pension payments as they fall due. Absent this, assets would have to be sold (possibly at unfavourable prices) in order to make the payments. It is especially significant for closed schemes which can no longer rely on contributions from active members to help to make pension payments. Further, once a scheme is closed, it matures rapidly and the duration of the liabilities falls. It is important therefore for such a scheme to work out the timing of peak cash flows and then insure that sufficient cash flow generating assets are in place during this period. In the UK, the Pensions Regulator requires schemes to set a long-term funding objective.

For a lot of UK schemes, research by TPR indicates that pension payments may already be close to their peak. Many of these schemes will have been preparing for this by switching out of growth assets, such as equities, into cash-flow generating assets, such as government (gilts) and high-quality high-yielding corporate bonds, as part of liability-driven investment strategy which might also have involved hedging the purchase of these bonds against falling interest rates. As the peak approaches, then more precise cashflow matching is required.

It has been estimated that around £1trn out of a total of £2.2trn UK pension liabilities are exposed to (i.e., were not hedged against) changes in interest rates and inflation. In addition, there will be between £250-£300bn of additional exposure as schemes deleverage their LDI portfolios in preparation for making cash payments.

Given the narrow range of suitable cash-flow generating assets, this is likely to drive up their prices. The total size of the sterling investment grade corporate bond market is only around £375bn. Although issuance has increased significantly with the fall the interest rates due to quantitative easing – £60bn of new sterling corporate bonds were issued in 2019, for example – quality and yields have also fallen. UK pension funds have been forced to increase their exposure to both BBB credit, the lowest class of investment grade bonds, and to sterling bonds issued by non-UK-based corporates (which account for around 50%

of sterling issuance). UK pension funds have also looked to source suitable bonds in the Eurozone and US corporate bond markets and then hedge the currency risk.⁴²⁰

In August 2020, LGIM launched a range of secure income asset funds aimed at small DB pension schemes following a cashflow-driven investment strategy. The funds have an open-ended pooled structure with a three-year lock-in period and target a return of gilts +2.5% per annum over a rolling three-year period. LGIM has also launched separate unit-linked life funds for senior real estate debt, investment grade infrastructure debt, investment grade private corporate debt, and sub-investment grade infrastructure debt and sub-investment grade private corporate debt, which are suitable for investment horizons of at least seven years.⁴²¹

The volatility of life expectancy trends

In 2016, the UK Office for National Statistics (ONS) reported that longevity improvements rates at very high ages have slowed down since 2011. A number of reasons were put forward to explain this: short-term reasons, such as lower increases in health service⁴²² and long-term care spending as part of the government's 'austerity' spending cuts following the Global Financial Crisis; and longer term reasons, such as increasing deaths from neurodegenerative disorders, such as dementia and Alzheimer's disease,⁴²³ and the fact that most of the improvement in life expectancy in the 1990s and 2000s was due to lower mortality from circulatory causes, such as heart disease, arising from the widespread use of statins and there was no longer scope for further improvement.⁴²⁴ In 2018, the UK ONS reported that healthy life expectancy – the average number of years lived in 'very good' or 'good' general health – fell for women and rose for men, comparing 2015-17 and 2009-11 data. For men, healthy life expectancy at birth increased by five months to 63.1 years, while it fell by three months to 63.6 years for women. At birth, UK men and women can expect to live with a disability for 16.5 and 20.9 years, respectively.⁴²⁵

⁴²⁰ Nikesh Patel and Arif Saad (2020) Viewpoint: The tipping point for UK pension schemes, *IPE*, 20 November; <https://www.ipe.com/viewpoint-the-tipping-point-for-uk-pension-schemes/>

⁴²¹ LGIM launches secure income range for DB plans, *IPE*, 3 August 2020.

⁴²² A University of York study published in 2021 estimated that for every 1% real increase in healthcare spending there was a 0.5% improvement in population mortality (cited in Murray et al. (2022); <https://bmjopen.bmj.com/content/bmjopen/11/10/e046417.full.pdf>).

⁴²³ Dementia is a syndrome, not a disease. A syndrome is a group of symptoms that does not have a definitive diagnosis. Dementia is a group of symptoms that affects mental cognitive tasks such as memory and reasoning. Dementia is an umbrella term that Alzheimer's disease can fall under. It can occur due to a variety of conditions, the most common of which, accounting for up to 70% of cases, is Alzheimer's disease. Other diseases which cause dementia are Parkinson's and Huntington's. See: Dementia and Alzheimer's: What Are the Differences?; <https://www.healthline.com/health/alzheimers-disease/difference-dementia-alzheimers>

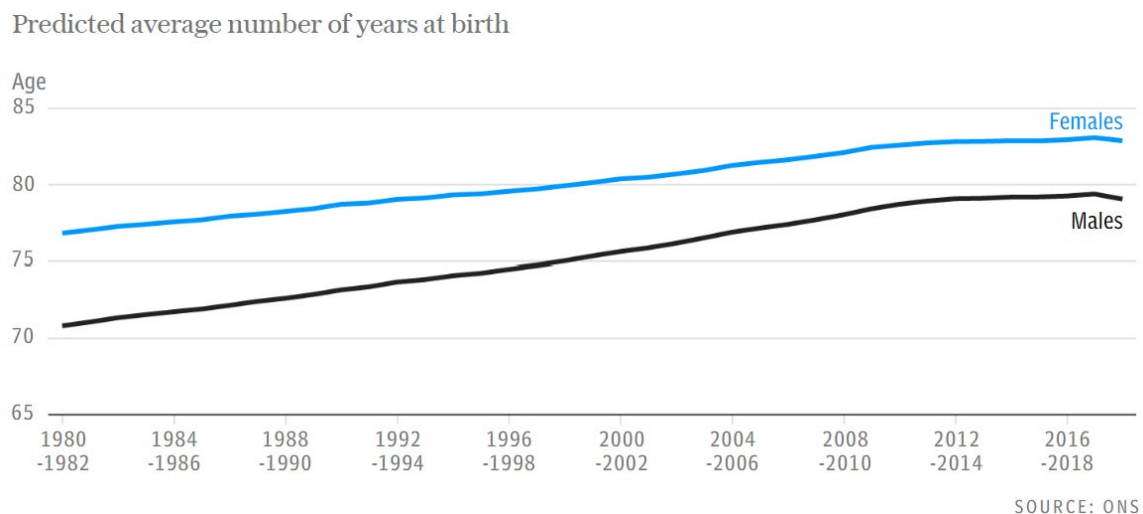
⁴²⁴ Anthony Hilton (2016) Life line, *Pensions World*, May; *Accounting for Pensions: Reflecting the cost of pension freedoms and life expectancy*, Xafinity Punter Southall, April 2018; page 12 of Willis Towers Watson *De-risking Report 2020*, January. See also www.bbc.com/news/health-4060825.

⁴²⁵ Stephanie Baxter (2018) 'Healthy' life expectancy falls for women, but improves for men, *Professional Adviser*, 13 December.

This prompted a debate in the UK about the volatility of life expectancy trends. Mortality improvements for England & Wales males aged 50-89 averaged 0.7% p.a. over the period 2011-16, compared with 3.1% p.a. between 2001-10, 1.8% between 1975-2000, and 0.7% between 1961-75.⁴²⁶ At the time, the UK actuarial profession took the view that the sharp reduction in the trend improvement was permanent. The Mortality Projections Model of the Institute and Faculty of Actuaries' Continuous Mortality Investigation – which covers England & Wales – published in March 2019 predicted that the average cohort life expectancy of a 65-year old man in 2018 was 19.8 years, down by five months (or 2.4%) compared with 2017; the corresponding figure for a 65-year old woman was 22.4 years, also down by 5 months (or 2.1%).⁴²⁷ The CMI's best estimate life expectancy growth for the next 40 years from 2022 is between 2.9 and 4.5 years, which is lower than the 6.8 years experienced over the previous 40 years.⁴²⁸

Figure 4 shows life expectancy from birth in the UK since 1980. The ONS found that between 2018 and 2020 there was 'virtually no improvement in life expectancy' for women which equalled 82.9 years in 2020. For men, life expectancy in 2020 was 79 years and had actually fallen back to 2012-14 levels. This is the first decline since the 1980s – and it could fall further following the pandemic.⁴²⁹

Figure 4: Life expectancy at birth in the UK



Source: <https://www.telegraph.co.uk/business/2022/12/03/why-state-pension-age-may-never-reach-70/>

Particularly, striking is what has been happening in the US where the life expectancy of the average American fell from 78.85 years in 2019 to 76.98 years in 2020 and 76.44 years

⁴²⁶ Page 6 of 'Mortality improvements in the next decade, Discussion hosted by SIAS and the CMI Mortality Projections Committee', 11 April 2017, Staple Inn Hall, London; <https://www.actuaries.org.uk/system/files/field/document/CMI%20SIAS%20meeting%202017-04-11%20-%20Mortality%20imps%20in%20the%20next%20decade%20v04.pdf>

⁴²⁷ Rachel Fixen (2019) UK schemes set for 2.5% fall in liabilities after CMI model revamp, *IPE*, 8 March.

⁴²⁸ Murray et al. (2022).

⁴²⁹ Szu Ping Chan (2023) Why the state pension age may never again reach 70, *Daily Telegraph*, 3 December; <https://www.telegraph.co.uk/business/2022/12/03/why-state-pension-age-may-never-reach-70/>

in 2021, a net reduction of 2.41 years, according to a study by Masters et al. (2022). The study said that most of the decline was due to the pandemic, with the rest explained by a rise in accidental deaths and deaths from drug overdoses, heart disease, chronic liver disease and cirrhosis. In contrast, 21 peer countries⁴³⁰ averaged a smaller decrease in life expectancy between 2019 and 2020 (0.55 years) and a 0.26-year *increase* between 2020 and 2021. This increased the gap in life expectancy between the US and the peer countries to around five years.⁴³¹

Time will tell if there has been a permanent change in trend in these countries or if the trend will again reverse in response to advances in applied biotechnology and in regenerative medicine, as discussed below. In December 2018, the CMI published a new version of its SAPS (Self-Administered Pension Scheme) data set. This covers UK members of DB pension schemes and the data has been collected since 2000. The S3 series mortality tables for the period 2009-16 showed that life expectancy in this select group was still increasing when compared with the S2 series mortality tables for the period 2004-11.⁴³² One year's increase in life expectancy can raise a pension scheme's liabilities by 4%,⁴³³ while if longevity risk is measured on a whole-of-life basis, the potential increase in pensions over 30-40 years could represent an increase in liabilities of 15-20%.⁴³⁴ In March 2020, the CMI reported that mortality rates in England and Wales were on average 3.8% lower in 2019 than in 2018, the highest year-on-year reduction since 2011. This shows that mortality rates are volatile and confirms the point that longevity trends can go both ways.⁴³⁵

The long-term impact of Covid also needs to be taken into account. The ONS estimated that there were 7.2% or 44,255 more deaths in the UK in 2022, compared with the previous five-year average (excluding 2020). There were 8.6% or 28,024 more deaths in the first six months of 2023 than expected. The causes of these excess deaths include the direct effects of Covid-19 infection, as well indirect consequences, such as late diagnosis and treatment of diseases, and the growing NHS backlog of operations.⁴³⁶ Analysis by consultancy Lane Clark & Peacock (LCP) predicted that, as a consequence, life expectancies could reduce by around nine months, which would equate to a £100m lower funding requirement for a £3bn pension scheme.⁴³⁷ Consultancy Hymans Robertson conjecture that if Covid

⁴³⁰ Australia, Austria, Belgium, Canada, Denmark, England and Wales, Finland, France, Germany, Israel, Italy, Netherlands, New Zealand, Northern Ireland, Norway, Portugal, Scotland, South Korea, Spain, Sweden, and Switzerland.

⁴³¹ <https://www.nytimes.com/2022/08/31/health/life-expectancy-covid-pandemic.html>

⁴³² XPS Pensions (2019), New 'SAPS3' mortality tables – a confusing message?, *Briefing Note No.3*, January.

⁴³³ Mark Dunne (2020) Breaking free: Bulk annuities, *Portfolio Institutional*, 24 January; <https://www.portfolio-institutional.co.uk/features/breaking-free/>

⁴³⁴ Willis Towers Watson *De-risking Report 2020*, January (p.9).

⁴³⁵ Susanna Rust (2020) Highest reduction in mortality rates in England and Wales since 2011, IPE, 2 March.

⁴³⁶ Pearson-Stuttard et al. (2024).

⁴³⁷ Jonathan Stapleton (2022) Mortality trend shift could cut funding requirements, *Professional Pensions*, 21 November; <https://www.professionalpensions.com/news/4060538/mortality-trend-shift-cut-funding-requirements>

becomes another endemic disease, with similar severity to the flu, this would mean an additional 20,000 – 30,000 death each year.⁴³⁸

All this makes it increasingly challenging for those operating in the PRT market to derive the best estimate of both the trend improvement in life expectancy and the volatility around the trend.

Population aging

There is an emerging global debate covering a wider set of demographic issues than just longevity risk. The debate has centred on population aging and its implications. One aspect of population aging is declining fertility which soon translates into an increase in the average age of the population. One key reason for declining fertility is the choice made by women in developed countries to have fewer children than previous generations.

This has been exacerbated by the Covid-19 pandemic, according to the United Nations. Birth rates have fallen due to ‘a postponement of childbearing in the face of the uncertainty regarding the disease and its economic impacts, disruptions in marriage patterns and family formation, and disruptions in the availability and access to sexual and reproductive health-care services, including family planning’.⁴³⁹ Edward Stanley, an analyst at Morgan Stanley, commented that ‘Prior financial crises suggest the suppressant on birth rates can last for three to four years. Moreover, using the 1917-20 Spanish Flu example as a loose proxy, the recovery in the birth rate in 2021 is unlikely to be linear. In 1917-20, with each new wave of virus came a renewed downturn in subsequent births’. The pandemic caused the fertility rate in the UK to plunge to a new low of 1.6 per woman in 2020. Stanley predicts that 70% of the world’s population will be below the replacement rate within five years, adding significantly to population aging.⁴⁴⁰

Another explanation for declining fertility is male sperm counts falling so fast across the world that the human race could be infertile within 50 years. There has been a 60% decline in the sperm count of Western men between 1973 and 2011, with 15% of young Western men with a sperm count low enough to impair fertility. A variety of explanations have been put forward to explain this: lifestyle factors, such as alcohol, smoking, stress, obesity, antidepressants, and high doses of ibuprofen; pesticides and industrial pollutants getting into the food chain; sunscreen, containing endocrine-disrupting UV filters; non-stick frying pans, containing poly- and perfluoroalkyl substances; tight underpants; oestrogen in the water supply from the female contraceptive pill; and electromagnetic radiation from wi-fi routers.⁴⁴¹

Figure 5 shows UN projections of fertility rates out to 2050. Prior to 1970, the average woman had five children. She now has 2.3 which is just above the ‘replacement rate’ of

⁴³⁸ Murray et al. (2022).

⁴³⁹ <https://www.telegraph.co.uk/business/2022/07/13/europe-faces-ageing-population-nightmare-absolute-collapse>

⁴⁴⁰ <https://www.telegraph.co.uk/business/2021/07/16/birth-rate-will-take-years-recover-covid-baby-bust/>

⁴⁴¹ India Sturgis (2018) Prepare for Spermageddon, *Daily Telegraph Magazine*, 27 January.

2.1, the level which stabilizes the population. Globally, fertility rates are expected to fall to the replacement rate by 2050. Fertility rates in Europe, North America, Australia and New Zealand have been below replacement since the mid-1970s.

Figure 5: Fertility rates are slowing down globally

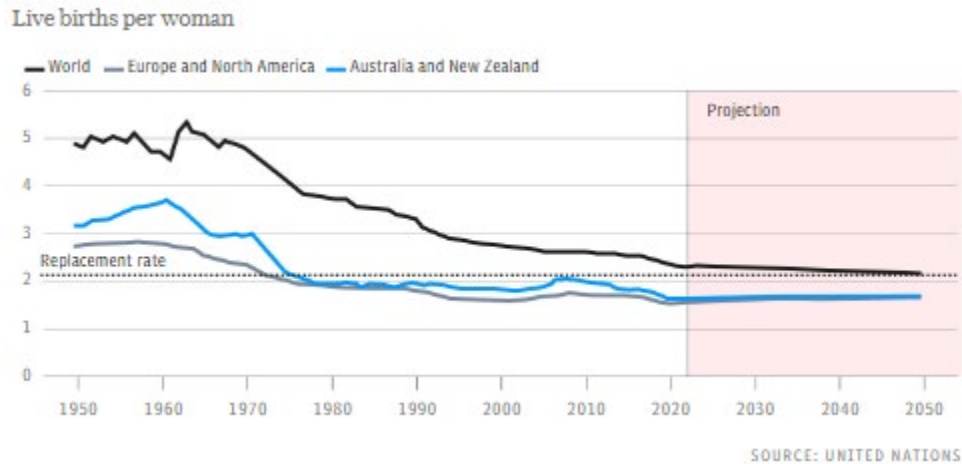


Figure 6 shows that global population growth has been on a downward trend since the mid-1960s from 2% to around 1% currently and is projected to be 0.5% by 2050. This is due mainly to the decline in fertility. The increase in deaths in 2020-21 caused by Covid-19 is also visible in the figure.

Figure 6: Global population growth is slowing

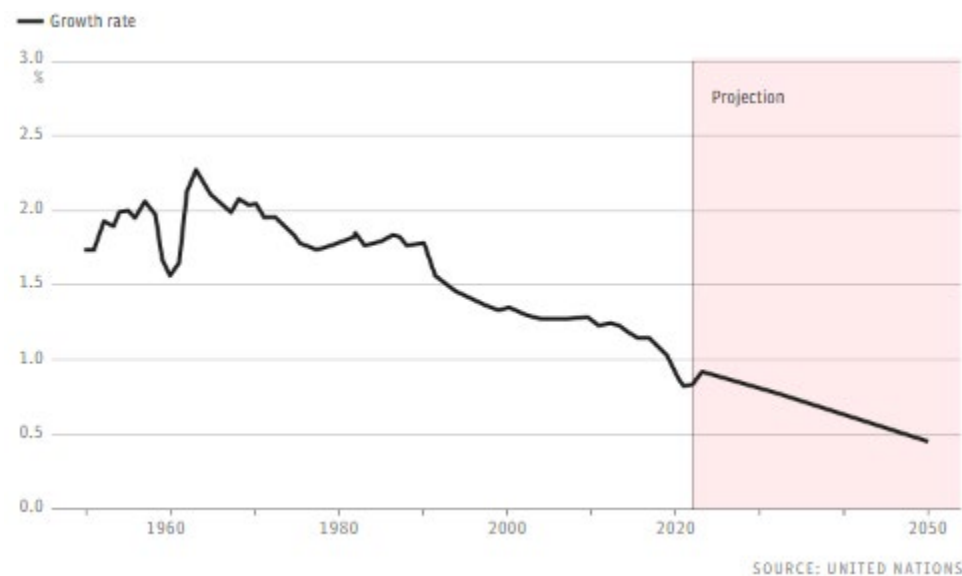
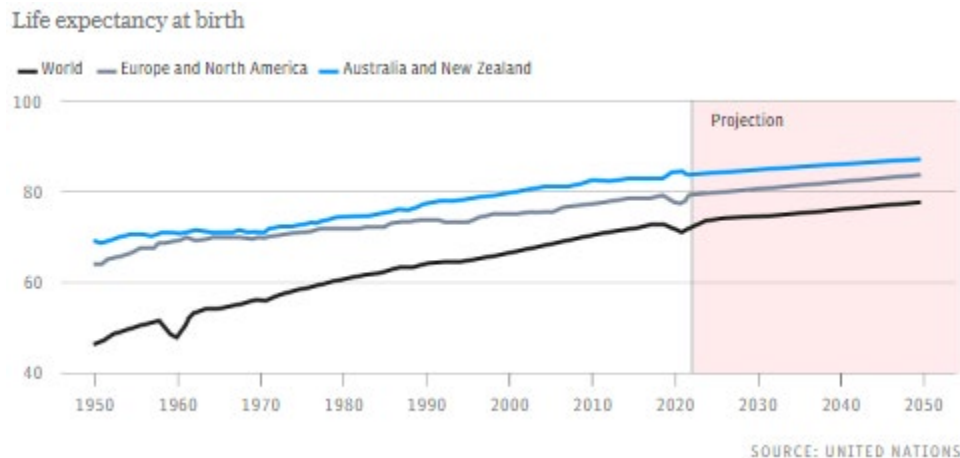


Figure 7 shows that, while life expectancy is expected to increase, the rate of increase is expected to slow down a little. By 2050, the global population aged 60 and over is projected

to exceed the population under 15. The global population – which reached 8bn on 15 November 2022 – is now expected to peak at 10.4bn in 2086 rather than in the 22nd Century as previously predicted.

Figure 7: The increase in life expectancy is expected to slow



In July 2022, the International Longevity Centre (UK) released five reports on aging in Australia, China, Japan, Indonesia and South Korea. The main findings were:

- Japan's population is aging rapidly. In 2017, 40% of Japan's workers were over 50 – predicted to rise to 47% by 2035. In 2022, Japan recorded the lowest number of births (799,728, a fertility rate of 1.3) and the highest number of deaths (1.58m) since the Second World War.⁴⁴²
- Over 50s made up 29% of Australia's workforce in 2017 – rising to 35% by 2035. Over 2 in 5 of Australian dollars were spent by older households in 2015, around 18% of GDP.
- By 2035, 42% of China's population will be over 50. In China, people over 65 spent 5 more hours a year volunteering than people at other ages.
- In 2018, 37% of South Korea's population was over 50 and by 2035, 51% of people will be over 50. By 2035, more than 6 in 10 South Korean employees could be aged 50 and over.
- In Indonesia in 2018, 72% of people aged 50-64 were in employment and a quarter of Indonesia's population was over 50 – this is set to increase to 28% by 2035.

In May 2021, China announced it was ending its policy of limiting couples to two children and would now allow them to have three.⁴⁴³ The government said the problem of an aging population was deepening and the change would help to improve the structure of China's population and maintain its advantage in human resources.⁴⁴⁴ The Chinese population aged

⁴⁴² <https://www.pensionpolicyinternational.com/japan-births-fall-to-record-low-as-population-crisis-deepens/>

⁴⁴³ China introduced a one-child policy in 1979 and a two-child policy in 2016.

⁴⁴⁴ <https://www.pensionpolicyinternational.com/china-introduces-three-child-policy-to-alleviate-problem-of-ageing-population/>

over 65 exceeded 14% of the total population in 2021.⁴⁴⁵ China's population fell by 850,000 in 2022 and by 2.08 million in 2023 to 1.409bn. The fertility rate is close to 1.0. President Xi Jinping wants to 'actively cultivate a new culture of marriage and childbearing'. In 2022, 17 government departments released guidelines on supporting policies in finance, tax, housing, employment, and education 'to create a fertility-friendly society and encourage families to have more children'.⁴⁴⁶ Jilin province in northeast China is offering up to 200,000 yuan (\$31,400) in 'marriage and birth consumer loans' to married couples to promote population growth; it has one of the fastest-shrinking populations in China.⁴⁴⁷ However, University of Michigan demographer Zhou Yun points out that fertility decline is often very difficult to reverse and no country with a fertility rate that has fallen below the 2.1 replacement rate has ever managed to raise it above the replacement rate again.⁴⁴⁸

The ILC(UK) reports, while highlighting the global nature of population aging, also emphasize the crucial role of older workers and consumers for post-pandemic recovery in these and other countries – which it calls the 'global longevity dividend'.⁴⁴⁹

The world is also trying to cope with supply shortages, insufficient workers and the financial burden of the rising proportion of pensioners – which will all worsen as the global population switches from boom to bust.

The UN predicts that in Italy, the population will fall from 59m to 55.3m by 2040, while Germany's population will fall over the same period from 83.4m to 81.2m. Holger Schmieding, an economist at Berenberg Bank, says Germany can do more to get people to join the workforce. Also 'There is room to increase the retirement age - it is going up to 67 already, it probably has to go up further'. Germany is also attractive to migrants which helps companies to keep growing despite the low domestic birth rate.⁴⁵⁰

The US Census Bureau projects that the US population will begin to decline by 2080, resulting in substantial risks for economic and social stability. Fewer young people are having children, so the population ages and there are more retired relative to working-age people. The proportion of Americans over the age of 65 was 9% in 1960, 17% in 2021, and is predicted to be 29% in 2100. As a result, companies will struggle to find workers – the Congressional Budget Office predicts that the size of the US labor force will grow by only 0.2% a year between 2024 and 2031– and Social Security, Medicare and Medicaid programs will become unsustainable. While immigration can help to ease the problem, the

⁴⁴⁵ <https://www.pensionpolicyinternational.com/china-may-see-negative-population-growth-in-2022-12-years-earlier-than-un-prediction-experts/>

⁴⁴⁶ <https://www.pensionpolicyinternational.com/chinas-population-drops-by-2-million-in-2023-due-to-record-low-birth-rate/>

⁴⁴⁷ <https://www.pensionpolicyinternational.com/chinese-province-offers-31000-baby-loans-to-counter-shrinking-population/>

⁴⁴⁸ <https://www.pensionpolicyinternational.com/chinas-population-drops-by-2-million-in-2023-due-to-record-low-birth-rate/>

⁴⁴⁹ <https://ilcuk.org.uk/global-longevity-dividend/>

⁴⁵⁰ <https://www.telegraph.co.uk/business/2022/07/13/europe-faces-ageing-population-nightmare-absolute-collapse>

natural population decline (population growth without immigration) may be too great. One of the explanations for having fewer children is cost, estimated at around \$240,000 over the first 18 years by LendingTree. Another is the preference for younger people (millennials and Gen-Z) to spend their money on leisure for themselves, such as travel, instead of saving for a future family. A 2021 study from the Pew Research Center found that 44% of young non-parents said they are unlikely to have children. A 2022 Harris Poll survey for Fortune found that 65% of non-parents agreed that the freedom that comes with not having children brings them happiness. While sectors of the economy favoured by younger consumers – travel, transport, retail, clothes and entertainment – could benefit, other sectors which are typically associated with higher productivity – such as IT, medicine and legal – or with supply chain security – such as certain types of manufacturing – could face challenges attracting young talented staff. Companies in these sectors will have to respond by offering more attractive benefits, such as remote flexibility, professional development opportunities, and student loan assistance. These companies will also need to make greater use of automation. Japan has led the way here by using industrial robots in its manufacturing and later life service sectors. Artificial intelligence applications, such as ChatGPT, will also help boost productivity.⁴⁵¹ Immigration could also alleviate labor shortages in certain sectors – such as agriculture, construction, leisure, hospitality and manufacturing – but since it has been the largest contributor to US population growth for decades, it would need to be significantly scaled-up to impact current population projections. However, countries that have traditionally supplied large numbers of immigrants to the US, namely China and India, are experiencing their own slowdowns in population growth.⁴⁵²

The UN predicts that, by 2050, the best-balanced work forces will be in South and Southeast Asia, Africa and the Middle East, potentially reshaping economic growth and geopolitical power balances. This will give these regions a ‘demographic dividend’, as a growing share of workers compared to dependants promotes economic growth.⁴⁵³

Figure 8 shows the UK’s population age structure according to calculations made by the Office for Budget Responsibility (OBR). In 1972, 60% of the population was aged between 16 and 64 and this rose to 62.2% in 2022, due to the large number of baby boomers who joined the workforce. Once they retire, the working age population will fall to 56.4% by 2072. By then, almost 30% of the British population will be over 65, more than double the proportion in 1972. The OBR predicts that age-related state spending will rise from 27% of GDP in 2023 to 36.1% in 2071. State pensions will rise from 4.8% to 8.1% of GDP or from £110bn⁴⁵⁴ in 2022 to £185bn in 2023 prices.

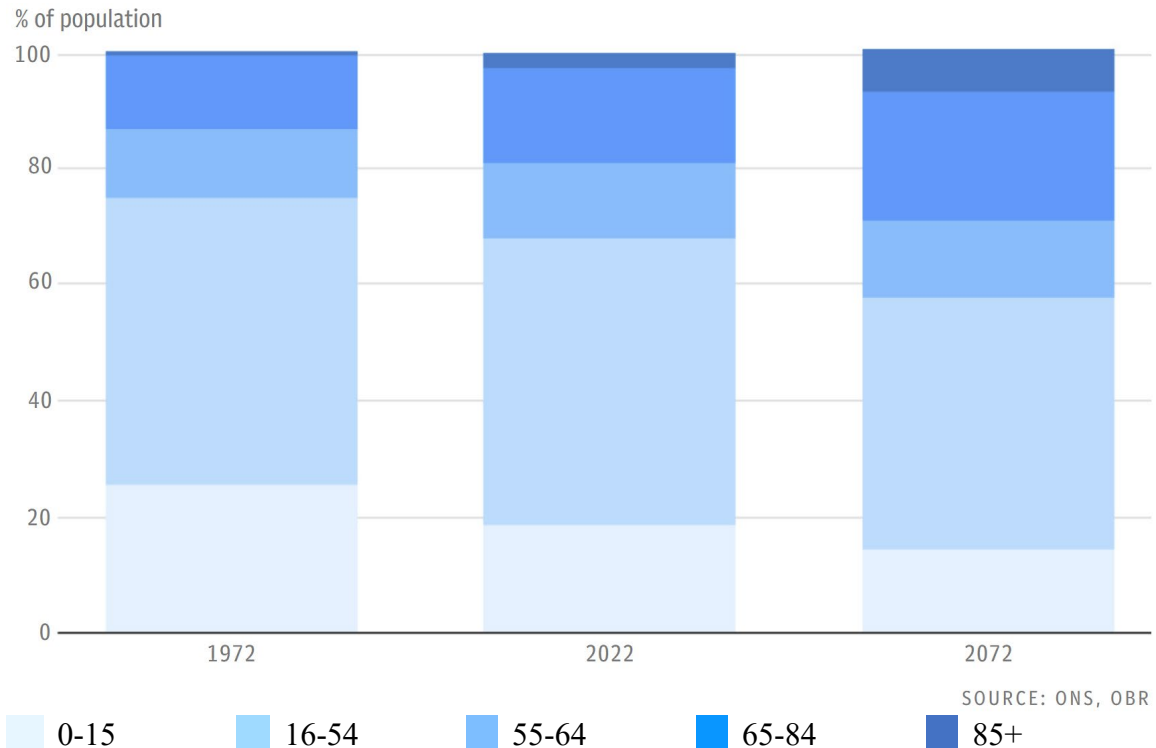
⁴⁵¹ AI and robotics are discussed in more detail below.

⁴⁵² <https://www.pensionpolicyinternational.com/anticipated-u-s-population-decline-and-the-risks-ahead/>

⁴⁵³ Lauren Leatherby (2023) How a vast demographic risk will reshape the world, New York Times, 16 July; <https://www.nytimes.com/interactive/2023/07/16/world/world-demographics.html>

⁴⁵⁴ <https://obr.uk/forecasts-in-depth/tax-by-tax-spend-by-spend/welfare-spending-pensioner-benefits/>

Figure 8: Population age structure in the UK



Source: <https://www.telegraph.co.uk/business/2022/12/03/why-state-pension-age-may-never-reach-70/>

This rising cost could be ameliorated by increasing the state pension age. In 2018, the UK state pension age was increased to 66 and is set to rise to 67 by 2028 and to 68 by 2046. The government is considering bringing this forward to 2039. Each year that the pension is not paid saves £10bn and, in addition, people pay in-work taxes for another year. The Institute for Fiscal Studies found the rise in state pension age from 65 to 66 resulted in 25,000 men and 30,000 women aged 65 working for an extra year.

However, John Cridland, who chaired the UK's first state pension age review in 2017, while accepting that the implications for the public finances is 'really concerning', argues that there could be an upper limit to the state pension age: 'while the government may be able to justify bringing forward an increase to 68, telling people to work until they're 69 or even 70 is a much more difficult prospect. The UK has got a lot of people who started work at 16. Many do manual work in hard physical jobs, and expecting them to wait till the age of 70 for a pension is not a reasonable balance. One might need to increase the state pension age beyond 68 in years to come, but I'm talking decades, and only if longevity increases take off again. There has to be a reasonable balance to deliver intergenerational fairness. [Further,] it's not obvious that the working population will have as much healthy life expectancy because of multiple morbidity, where more people suffer from multiple conditions like dementia, obesity, diabetes, that can actually affect the quality of people's lives'. His report recommended that those with poor health or caring responsibilities should

be able to access the state pension at 67.⁴⁵⁵ This suggests that there could be limits to the longevity dividend identified by the ILC(UK).

Another aspect of population aging is the differential impact on the rich and poor, i.e., health inequalities due to differences in wealth. A 2020 study by the Longevity Science Panel in the UK found that, while life expectancy had increased for all socio-economic groups between 2001 and 2015, it increased most for the richest cohort. The difference in life expectancy between rich and poor was 7.2 years in 2001, but this had increased to 8.4 years in 2015⁴⁵⁶ and to 9 years in 2020.⁴⁵⁷ Another study found that, while socio-economic status affects the incidence of multimorbidity (two or more of diabetes, coronary heart disease, stroke, chronic obstructive pulmonary disease (COPD), depression, arthritis, cancer, dementia, and Parkinson's disease), it did not affect the risk of mortality after the onset of these adverse health conditions, implying that primary prevention is key to reducing social inequalities in mortality (Dugravot et al (2019)). This is confirmed by a report written by the UK All-Party Parliamentary Group (APPG) for Longevity (*The Health of the Nation: A Strategy for Healthier Longer Lives*) which estimated that up to 75% of new cases of heart disease, stroke and type-2 diabetes, and 40% of cancer incidence and dementia risks could be reduced if individuals cut down on smoking and alcohol, increased physical activity and changed to a healthy diet. The report also found that a key reason for low productivity in certain parts of the country (e.g., the north of England) is that health is worse and reducing the health gap would keep people in work longer and hence increase national output.⁴⁵⁸

These findings will have implications for fairness between different cohorts of the same generation, for example, when governments raise the retirement age for all in line with increasing average life expectancy. In response to these inequalities, the UK government set up the UK Longevity Council to advise it on how best to use innovations in technology products and services to improve the lives of the older population. With the number of people in the UK over the age 65 to double to more than 20 million over the next half century, the government has set itself the Aging Society Grand Challenge which aims to ensure that people in the UK enjoy an extra 5 years of healthy and independent living by 2035, while narrowing the gap between the experience of the richest and poorest.⁴⁵⁹

Similar initiatives are happening in other parts of the world. For example, the Stanford Center on Longevity (SCL), recognizing that half of 5-year-olds in the US are likely to reach the age of 100, has a mission to ensure these 'century-long lives are healthy and rewarding'. It has developed a New Map of Life⁴⁶⁰ that seeks to change social institutions,

⁴⁵⁵ Szu Ping Chan (2022) Why the state pension age may never again reach 70, *Daily Telegraph*, 3 December; <https://www.telegraph.co.uk/business/2022/12/03/why-state-pension-age-may-never-reach-70>

⁴⁵⁶ Life expectancy gap between rich and poor widens, *BBC News*, 15 February 2018.

⁴⁵⁷ Amelia Hill (2020) Being wealthy adds nine years to life expectancy, says study, *Guardian*, 15 January. The same 9-year difference holds in the US. The UK results come from the English Longitudinal Study of Ageing, while the US results come from the US Health and Retirement Study.

⁴⁵⁸ Amelia Hill (2020) Health inequality greater than previously thought, report finds, *Guardian*, 12 February.

⁴⁵⁹ <https://www.gov.uk/government/news/experts-to-help-uk-champion-ageing-society-opportunities>

⁴⁶⁰ <https://longevity.stanford.edu/the-new-map-of-life-initiative/>

norms and policies that evolved when lives were only half as long, for example, the idea that people will retire and live off their savings at age 65. The SCL envisions a ‘future in which all people, regardless of socio-economic status, can make the most of the advantages afforded by increased lifespan—resulting in lives infused at every stage with a sense of belonging, purpose, and worth. We can meet challenges that longevity creates, and make the most of the 100-year opportunity if we act now, guided by these principles:

- Make use of age diversity
- Create longevity-ready communities
- Align health spans to life spans
- Build financial security from the start
- Invest in future centenarians to deliver big returns
- Support life transitions
- Learn throughout life
- Work more years, with greater flexibility
- Harness scientific and technological breakthroughs to transform the future of aging
- Ensure that advances are distributed to the entire population’.

Some of these issues – longer working lives, higher state pension ages, and narrowing the life expectancy gap – will clearly have consequences for the pricing of future PRT deals.

The aging process and anti-aging treatments

Life expectancy is strongly linked to the aging process.⁴⁶¹ Aging results in a progressive deterioration in physiological integrity, leading to impaired function and increased vulnerability to death. This deterioration is the primary risk factor for neurodegenerative diseases, cancer, diabetes, and cardiovascular disorders. López-Otín et al. (2013) show that there are nine candidate hallmarks of aging:⁴⁶² genomic instability,⁴⁶³ telomere attrition,⁴⁶⁴

⁴⁶¹ See, e.g., Andrew Steele (2020) *The New Science of Getting Older Without Getting Old*, Bloomsbury, London; <https://www.bloomsbury.com/uk/ageless-9781526608277/>

⁴⁶² Carlos López-Otín, Maria A. Blasco, Linda Partridge, Manuel Serrano, and Guido Kroemer (2013) The Hallmarks of Aging, *Cell*, 153(6):1194-1217; <https://doi.org/10.1016/j.cell.2013.05.039>

⁴⁶³ A high frequency of mutations within a cell’s genome.

⁴⁶⁴ The telomere ends of chromosomes get shorter as cells divide and eventually become too short for cells to divide further. Shortened telomeres are associated with aging cells that are senescent.

epigenetic alterations,⁴⁶⁵ loss of proteostasis,⁴⁶⁶ deregulated nutrient sensing,⁴⁶⁷ mitochondrial dysfunction,⁴⁶⁸ cellular senescence,⁴⁶⁹ stem cell exhaustion,⁴⁷⁰ and altered intercellular communication.⁴⁷¹

⁴⁶⁵ Epigenetics is the study of how your behaviours and environment can cause changes that affect the way your genes work. Unlike genetic changes, epigenetic changes are reversible and do not change your DNA sequence, but they can change how your body reads a DNA sequence;
<https://www.cdc.gov/genomics/disease/epigenetics.htm>

⁴⁶⁶ Proteostasis is a balanced state in which the body's production of proteins is stable and without defects. Proteins are molecules that do most of the work in cells and are needed for the structure, function, and regulation of the body's tissues and organs. They are composed of amino acids and are categorised according to their function: antibody, enzyme (carries out most of the chemical reactions that take place in cells), messenger (transmits signals to coordinate biological processes between different cells, tissues, and organs), structural component, and transport/storage. A loss of proteostasis is associated with the production of excess, insufficient or misshapen proteins that send incorrect signals. See: Steve Hill (2018) Hallmarks of Aging: Loss of Proteostasis, 23 May; <https://www.lifespan.io/news/hallmarks-of-aging-loss-of-proteostasis/>

⁴⁶⁷ Metabolism is the balance between anabolism (building up body tissues and energy stores) and catabolism (breaking down body tissues and energy stores to get fuel for body functions). The body has multiple nutrient sensing pathways to ensure that it takes in the right amount of nutrition – not too much, not too little. Excess metabolic activity, e.g., anabolic signalling, together with changes in nutrient availability and composition, damage cells and cause them to age faster. These damaging events also deregulate the nutrient-sensing molecules and downstream pathways, for example, signalling greater food intake when the body does not need it. Age-related obesity, diabetes and other metabolic syndromes result. Decreased nutrient signalling, achieved with caloric restricted diets or by stimulation of proteins called sirtuins, promotes healthspan and longevity. See: Deregulated Nutrient Sensing; <https://www.merckmillipore.com/GB/en/life-science-research/genomic-analysis/Epigenetics-and-Nuclear-Function/Deregulated-Nutrient-Sensing/FsCb.qB.u04AAAFQ6t52i0ib,nav>

⁴⁶⁸ Mitochondria are organelles – specialized subunits within cells with a specific function – found in most cells, in which the biochemical processes of respiration and energy production occur. Mitochondrial dysfunction occurs when the mitochondria do not work as they should due to damage, mutation or conditions such as progressive inefficiency of electron transport chain complexes resulting from destabilization or oxidative stress owing to excessive production of reactive oxygen species (ROS). This can affect other diseases, such as Alzheimer's, diabetes and cancer. See: Joshua N. Farr and Maria Almeida (2018) The Spectrum of Fundamental Basic Science Discoveries Contributing to Organismal Aging, *J Bone Miner Res*, 33(9): 1568–1584; doi: 10.1002/jbmr.3564

⁴⁶⁹ Irreversible cell cycle arrest driven by a variety of mechanisms, including telomere shortening, other forms of genotoxic stress, or mitogens or inflammatory cytokine. Senescent cells have stopped dividing and hence renewing themselves and so have lost their purpose, but can nevertheless destabilize neighbouring cells and promote inflammation. See: Edward J. Masoro and Steven N. Austad (eds) *Handbook of the Biology of Aging* (seventh edition, 2011); <https://www.sciencedirect.com/book/9780123786388/handbook-of-the-biology-of-aging>

⁴⁷⁰ A reduction in stem cell activity which can lead to diseases and other issues, such as immunosuppression through reduced production of bacteria-killing and virus-killing white blood cells, muscle loss, frailty, and the weakening of bones. See: Patrick Deane (2018) Hallmarks of Aging: Stem Cell Exhaustion, 18 September; <https://www.lifespan.io/news/hallmarks-of-aging-stem-cell-exhaustion/>

⁴⁷¹ Cells, as they age, show an increase in self-preserving signals that result in damage elsewhere. Altered intercellular communication with aging contributes to a decline in tissue health. In particular, senescent cells trigger chronic inflammation that can further damage aging tissues. See: Altered Intercellular Communication; <https://www.merckmillipore.com/GB/en/life-science-research/antibodies-assays/antibodies-overview/Research-Areas/cell-signaling/Altered-Intercellular-Communication/C.qb.qB.O48AAAFQe592i0hr,nav>

López-Otín et al. (op cit) continue: ‘Aging research has experienced an unprecedented advance over recent years, particularly with the discovery that the rate of aging is controlled, at least to some extent, by genetic pathways and biochemical processes conserved in evolution. ... A major challenge is to dissect the interconnectedness between the candidate hallmarks and their relative contributions to aging, with the final goal of identifying pharmaceutical targets to improve human health during aging, with minimal side effects’.

Dr Eric Verdin, president and CEO of the Buck Institute for Research on Aging⁴⁷² explains the origins of aging research: ‘The initial discoveries by several groups between 1985 and 1995 suggested that there are genes that can mitigate the aging process. If these genes are mutated to either gain or lose function, one can dramatically impact healthspan and lifespan. ... We’ve learned a number of key lessons. Firstly, we’ve learned that there are genetic pathways that interact together and appear to control aging. Secondly, these pathways seem to be conserved across different species. So, we find the same pathways in yeast, in worms and in humans. Thirdly, we can speak to these pathways via small molecule drugs to have the same effect as mutating the gene, and subsequently impacting the aging process. Finally, these genes that control aging don’t just control lifespan, they also control healthspan’.⁴⁷³

There have been a number of significant positive innovations that help to identify and treat noncommunicable diseases associated with aging, such as dementia and cancer. Examples include:

- Professor Steve Horvath (UCLA) and Ken Raj (Public Health England) have demonstrated that rapamycin⁴⁷⁴ retards the epigenetic aging of human cells – using an epigenetic clock (called the Skin and Blood Clock) which is an accurate biomarker for aging that relies on the mathematical precision of the relationship between chemical modifications on DNA called methylation and changes in age⁴⁷⁵
- The finding that rapamycin, administered to middle aged mice, increased survival significantly in both male and female mice.⁴⁷⁶
- Potential reversal of aging using a younger person’s blood, following successful experiments with mice.⁴⁷⁷
- Professor Tony Wyss-Coray (Stanford) has identified circulating factors in plasma that can rejuvenate or restore function in the aging brain, leading to the

⁴⁷² <https://www.buckinstitute.org/>

⁴⁷³ Interview in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁷⁴ A bacterial antifungal compound discovered in the soil of Easter Island in the 1970s. It is also an immunosuppressant used in organ transplants.

⁴⁷⁵ <http://mypharmacynews.com/health-problems/rapamycin-retards-epigenetic-ageing-of-keratinocytes/>

⁴⁷⁶ Randy Strong, Richard A. Miller, Molly Bogue, Elizabeth Fernandez, Martin A. Javors, Sergiy Libert, Paul Anthony Martinez, Michael P. Murphy, Nicolas Musi, James F. Nelson, Michael Petrascheck, Peter Reifsnyder, Arlan Richardson, Adam B. Salmon, Francesca Macchiarini, and David E. Harrison (2020) Rapamycin-mediated mouse lifespan extension: Late-life dosage regimes with sex-specific effects, *Aging Cell*. 2020;00:e13269. <https://doi.org/10.1111/ace1.13269>

⁴⁷⁷ Undulating changes in human plasma proteome profiles across the lifespan, *Nature Medicine*, 5 December 2019.

- development of anti-aging therapies based on the plasma proteome, suitable for treating age-related macular degeneration and neurodegenerative disorders.⁴⁷⁸
- Development of inhibitors for the protein⁴⁷⁹ complex TORC1 which extend lifespan and healthspan by, for example, reducing the incidence of respiratory tract infections or treating neurodegenerative diseases by inducing autophagy, a process which by which cells clear out toxic protein aggregates.⁴⁸⁰
 - Scientists have converted the cells of a deceased 114-year-old into young pluripotent stem cells, thereby reversing the telomere aging clock in a supercentenarian's cells and providing support for the hypothesis of no upper age limit for reprogramming cellular aging.⁴⁸¹
 - Identification of an inflammatory marker called sCD14 which is linked to cognitive decline and dementia, allowing early intervention.⁴⁸²
 - Randall J. Bateman (Washington University School of Medicine in St. Louis) has developed a simple blood test that can detect Alzheimer's disease in its earliest stages by measuring levels of the protein amyloid beta which begin to collect in the brain 15 to 20 years before symptoms arise and play a key role in the development of Alzheimer's.⁴⁸³ Researchers from the University of Gothenburg have developed a cheap test that measures the level of the p-tau217 protein in the blood.⁴⁸⁴
 - The development of protein-destroying drugs, capable of degrading the MYC cancer-fuelling protein or the tau protein responsible for Alzheimer's.⁴⁸⁵
 - The identification of two natural compounds – CMS121 and J147 – that can reverse age-related cognitive impairment and potentially treat Alzheimer's by restoring mitochondrial function, such as cell respiration and energy production, in the aging brain.⁴⁸⁶

⁴⁷⁸ Steven Braithwaite, Chief Scientific Officer, Alkahest, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁷⁹ Proteins are the foundation of life.

⁴⁸⁰ Joan Mannick, Chief Medical Officer, resTORbio, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁸¹ Phil Newman (2020) 114 year-old cells converted to pluripotent stem cells, *Longevity Technology*, 28 February; <https://www.longevity.technology/114-year-old-cells-converted-to-pluripotent-stem-cells>. See also: Old human cells rejuvenated with stem cell technology, *Science News*, 24 March 2020.

⁴⁸² Inflammatory marker linked to dementia, *EurakAlert! Science News*, 9 December 2019.

⁴⁸³ <https://medicine.wustl.edu/news/bateman-receives-potamkin-award-for-alzheimers-research/>; <https://www.labmedica.com/clinical-chem/articles/294789678/blood-based-biomarker-predicts-onset-of-symptomatic-alzheimers-disease.html>; <https://www.labmedica.com/hematology/articles/294792023/unique-diagnostic-test-based-on-mass-spectrometry-technique-accurately-identifies-early-stage-alzheimers-disease.html>; <https://www.labmedica.com/molecular-diagnostics/articles/294793970/blood-test-could-detect-alzheimers-up-to-17-years-in-advance.html>

⁴⁸⁴ <https://www.telegraph.co.uk/news/2024/01/22/alzheimers-blood-test-revolution-for-over-50s-dementia>

⁴⁸⁵ Protein-slaying drugs could be the next blockbuster therapies, *Nature Feature*, 20 March 2019.

⁴⁸⁶ Carla Heyworth (2020) Targeting mitochondria to fight aging, *Longevity Technology*, 22 January; <https://www.longevity.technology/targeting-mitochondria-to-fight-aging/>

- The discovery that higher levels of humanin, a peptide⁴⁸⁷ encoded in the small genome of mitochondria, are associated with longer lifespans, better health, and a lower risk for diseases such as Alzheimer's.⁴⁸⁸
- The development of an antibody that stimulates microglia, the brain's immune cells, in such a way that they live longer, divide more quickly and detect aberrant substances more easily, thus helping to prevent the progression of Alzheimer's.⁴⁸⁹
- The discovery that Alzheimer's establishes itself independently at various points in the brain from an early stage and it is the rate at which these clusters grow that determines the speed of a patient's deterioration, not the speed at which they spread. Previously, it was believed that it started at one specific point in the brain and then spread to other parts in a chain reaction.⁴⁹⁰
- The success of the drug donanemab in slowing down the progression of Alzheimer's by more than 20%, with greater impact in people at an earlier stage of the syndrome.⁴⁹¹
- The discovery that brain cells in Alzheimer's patients survived when they were able to block the protein MEG3 that was triggering cell suicide and necroptosis, the removal by the body of dead cells. Alzheimer's patients build-up two toxic proteins, tau and amyloid beta. Amyloid is believed to accumulate in spaces between neurons in brain cells, leading to brain inflammation. Tau tangles then begin to appear and the brain cells gradually start to die. Scientists believe that drugs that mimicked the blockage of MEG3 could prevent necroptosis.⁴⁹²
- The invention of a blood test for identifying Parkinson's disease ten years before symptoms emerge, allowing the early application of precision therapies. It is the second most prevalent neurodegenerative disorder globally and is caused by the brain cells' inability to process a protein called alpha-synuclein. As a result, abnormal clusters of the protein form and damage nerve cells, resulting in movement disorder.⁴⁹³
- The Institute of Ageing at Newcastle University and the Mayo Clinic in the US have demonstrated that senescent cells can be selectively killed (using a process known as senolytics) and this helps to postpone multiple age-related disabilities and disease.⁴⁹⁴

⁴⁸⁷ A peptide is a 'short chain of amino acids. The amino acids in a peptide are connected to one another in a sequence by bonds called peptide bonds. Typically, peptides are distinguished from proteins by their shorter length, although the cut-off number of amino acids for defining a peptide and protein can be arbitrary'; <https://www.nature.com/scitable/definition/peptide-317/>

⁴⁸⁸ Protein in mitochondria appears to regulate health and longevity, *Science Daily*, 24 June 2020; <https://www.sciencedaily.com/releases/2020/06/200624151613.htm>

⁴⁸⁹ Stimulating immune cells to protect against Alzheimer's, *Neuroscience News*, 10 March 2020.

⁴⁹⁰ <https://www.telegraph.co.uk/news/2021/10/29/scientists-pinpoint-exactly-alzheimers-grows-brain-breakthrough>

⁴⁹¹ <https://www.alzheimers.org.uk/news/2023-07-17/new-drug-donanemab-turning-point-alzheimers>

⁴⁹² Sarah Knapton (2023) Alzheimer's could cause brain cells to kill themselves, *Daily Telegraph*, 15 September; <https://www.telegraph.co.uk/news/2023/09/15/dementia-researchers-uncover-why-brain-cells-die/>.

⁴⁹³ <https://www.labmedica.com/molecular-diagnostics/articles/294799502/index.php>

⁴⁹⁴ Danny Buckland (2019) We're living much longer, but are we healthier?, *Raconteur.net*, 23 May. Ellie Dolgin (2020) Send in the senolytics, *Nature Biotechnology*, 12 November,

- The introduction of rejuvenation medicine that turns back biological age,⁴⁹⁵ rather than just slowing it down, by the restoration of the molecular and cellular structure and composition of tissues and organs. One example is the removal of ‘zombie’ cells, senescent cells that no longer divide, but remain alive, creating difficulties for their environment.⁴⁹⁶ Another example is organ regeneration using lymph nodes to regrow functioning organs within a patient’s own body, eradicating the problem of organ rejection in transplant patients and solving the problem of organ supply scarcity.^{497, 498}
- The use of hyperbaric oxygen therapy to reverse two key indicators of biological aging: telomere length and senescent cells accumulation. In a clinical study, 35 adults over 64 years were placed in a pressurized chamber and given pure oxygen for 90 minutes a day, five days a week for three months. At the end of the trial, the participants’ telomeres had increased in length by an average of 20%, while their senescent cells had been reduced by up to 37%.⁴⁹⁹
- Demonstration in an animal model that age-related frailty and immune decline can be halted and even partially reversed using a novel cell-based therapeutic approach. It is known that visceral adipose tissue or belly fat contributes to the development of chronic low-grade inflammation. Researchers at the University of Bern report that certain immune cells in the belly fat play an essential role in regulating chronic low-grade inflammation and downstream aging processes. They show that these immune cells may be used to reverse such processes.⁵⁰⁰
- The identification of 10 genomic loci which influence three key phenotypes⁵⁰¹ (years lived in good health (healthspan), total years lived (lifespan), and survival

⁴⁹⁵ Some scientists argue that biological age is a more useful indicator than chronological age. For example, Prof Jamie Timmons of King's College London argues that ‘There's a healthy ageing signature [in your body's cells], and it appears to be prognostic for a number of things including longevity and cognitive decline. It looks like from the age of 40 onwards you can use this to give guidance on how well an individual is ageing’; <https://www.bbc.co.uk/news/health-34153135>

⁴⁹⁶ Aubrey de Grey, co-founder and chief scientific officer, SENS Research Foundation, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁹⁷ *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁹⁸ Some scientists question whether it is currently possible to measure biological age accurately. One example is Jay Olshansky, chief scientific officer, Lapetus Solutions. Nevertheless, he has developed a metric based on face age ‘which illustrates the documented relationship between how young or old you look relative to your chronological age. It’s not a statement that you’re this many years younger or older, but it seems to be a reasonable biomarker giving you a clue that you might be aging more slowly or more rapidly’. Interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁴⁹⁹ Anthony Cuthbertson (2020) Human aging reversed in ‘Holy Grail’ study, *Independent*, 30 November; <https://www.independent.co.uk/life-style/gadgets-and-tech/anti-ageing-reverse-treatment-telomeres-b1748067.html>

⁵⁰⁰ Daniel Brigger, Carsten Riether, Robin van Brummelen, Kira I. Mosher, Alicia Shiu, Zhaoqing Ding, Noemi Zbären, Pascal Gasser, Pascal Guntern, Hanadie Yousef, Joseph M. Castellano, Federico Storni, Neill Graff-Radford, Markus Britschgi, Denis Grandgirard, Magdalena Hinterbrandner, Mark Siegrist, Norman Moullan, Willy Hofstetter, Stephen L. Leib, Peter M. Villiger, Johan Auwerx, Saul A. Villeda, Tony Wyss-Coray, Mario Noti, Alexander Eggel (2020) Eosinophils regulate adipose tissue inflammation and sustain physical and immunological fitness in old age, *Nature Metabolism*; DOI: 10.1038/s42255-020-0228-3

⁵⁰¹ Phenotypes are the observable characteristics of an organism that result from the interaction of its genotype (total genetic inheritance) with the environment. For individuals, this includes characteristics such

until an exceptional old age (longevity)). Of these five (FOXO3, SLC4A7, LINC02513, ZW10, and FGD6) have not been reported previously as of genome-wide significance. The majority of these 10 loci are associated with cardiovascular disease and some affect the expression of genes known to change their activity with age. The study also showed the importance of gene sets linked to how the body metabolizes iron, with too much iron in the blood appearing to increase risk of dying earlier. Professor Paul Timmers, one of the authors of the study, said: ‘We speculate that our findings on iron metabolism might also start to explain why very high levels of iron-rich red meat in the diet has been linked to age-related conditions such as heart disease’.⁵⁰²

- The identification of proteins associated with aging and increased frailty.⁵⁰³ A study of 4265 proteins measured in plasma found that 55 were positively associated with frailty, in particular, fatty acid-binding protein FABP and ANTR2.⁵⁰⁴
- The development by biotech company Elevian of drugs based on GDF11 (growth differentiation factor 11), a Harvard University-discovered protein linked to age-related diseases. The work on GDF11 – which involved a technique called parabiosis in which the circulatory systems of young and old mice were combined to allow blood to flow between the animals – suggested that injecting the protein into old mice regenerated cardiac, brain and muscle tissue.⁵⁰⁵
- By increasing the amount of the protein sestrin in fruit flies, researchers have been able to extend their lifespan and at the same time these flies were protected against the lifespan-shortening effects of a protein-rich diet. The researchers could further show that sestrin plays a key role in stem cells in the fly gut thereby improving the health of the fly.⁵⁰⁶
- The detection of cell senescence using fluorescence imaging and flow cytometry analysis.⁵⁰⁷
- The discovery that pro-inflammatory cytokines⁵⁰⁸ induce cellular senescence and hence aging by activating EGFR (Epidermal Growth Factor Receptor) signaling.

as height, eye colour and blood type (<https://www.britannica.com/science/phenotype>;
<https://www.genome.gov/genetics-glossary/Phenotype>).

⁵⁰² Paul R. H. J. Timmers, James F. Wilson, Peter K. Joshi, and Joris Deelen (2020) Multivariate genomic scan implicates novel loci and haem metabolism in human aging, *Nature Communications* volume 11, Article number: 3570 (2020); <https://doi.org/10.1038/s41467-020-17312-3>. David Nield (2020) Study of Over 1 Million People Finds Intriguing Link Between Iron Levels And Lifespan, *Science Alert*, 17 July; <https://www.sciencealert.com/a-study-of-1m-people-finds-a-strange-link-between-iron-levels-and-long-life>

⁵⁰³ Frailty is a state of decreased physiological reserve and increased vulnerability to adverse outcomes in aging, and is characterized by dysregulation across various biological pathways.

⁵⁰⁴ Sanish Sathyan, Tina Gao, Sofiya Milman, Nir Barzilai, Joe Verghese, Sanish Sathyan and Emmeline Ayers (2020) Plasma proteomic profile of frailty, *Aging Cell*, <https://doi.org/10.1111/ace.13193>

⁵⁰⁵ Ben Adams (2020) Anti-aging biotech Elevian raises \$15M as it looks to the clinic, *Fierce biotech*, 24 November; <https://www.fiercebiotech.com/biotech/anti-ageing-biotech-elevian-raises-15m-as-it-looks-to-clinic>

⁵⁰⁶ Jiongming Lu, Ulrike Temp, Andrea Müller-Hartmann, Jacqueline Esser, Sebastian Grönke, Linda Partridge. Sestrin is a key regulator of stem cell function and lifespan in response to dietary amino acids, *Nature Aging*, 2020; doi: 10.1038/s43587-020-00001-7

⁵⁰⁷ For example, by using Cell Meter™ Cellular Senescence Activity Assay Kits.

⁵⁰⁸ Cytokines are a broad category of small proteins or peptides – such as chemokines, interferons, interleukins, lymphokines, and growth factors – which are secreted by certain cells of the immune system and have an effect on – by sending signals to – other cells; <https://en.wikipedia.org/wiki/Cytokine>

The activity of five senescence-inducing cytokines (IL-1 β , IL-13, MCP-2, MIP-3 α , and SDF-1 α) could be significantly inhibited by treatment with cetuximab (an antibody targeting EGFR), gefitinib (a small molecule inhibitor of EGFR), and EGFR knockdown (the targeted reduction rather than inhibition of the EGFR peptide).⁵⁰⁹

- The discovery that lysine glycation in collagen appears to contribute to tendon stiffening with age and in diabetes.⁵¹⁰
- A study led by University College London suggests that weight management could play a significant role in reducing the risk of developing dementia, after finding that obesity increases the risk of dementia up to 15 years later. The study showed that people who are obese in late adulthood face a 31% increased risk of dementia compared with those whose body mass index is normal. The risk is particularly high for women.⁵¹¹
- Researchers at the University of Bonn have discovered a receptor in mice that regulates both increasing abdominal girth and shrinking muscles, two common side effects of aging. Experiments with human cell cultures suggest that the corresponding signaling pathways might also exist in humans.⁵¹²
- Adoptive cell therapies (ACTs) which involve the use of immune cells as anti-cancer agents and hold promise for the treatment of adult and paediatric cancer, ranging from liquid to solid tumors. One type of ACT involves chimeric antigen receptor (CAR)-engineered immune cells, with two CAR T-cell-based therapies recently approved by the US Food and Drug Administration, paving the way for the development of additional ACT therapies.⁵¹³
- Identification of a biomarker for tumour initiating (or cancer stem) cells.⁵¹⁴
- Early diagnosis of certain cancers (e.g., ovarian and brain) by identifying genetic errors in DNA.⁵¹⁵
- A new DNA test evaluates biomarkers in 517 cancer-relevant genes across 30 types of solid tumours.⁵¹⁶

⁵⁰⁹ Dongsheng Shang, Danlin Sun, Chunyan Shi, Jun Xu, Mingxiang Shen, Xing Hu and Hanqing Liu (2020) Activation of epidermal growth factor receptor signaling mediates cellular senescence induced by certain pro-inflammatory cytokines, *Aging Cell*, 22 April; <https://doi.org/10.1111/ace.13145>

⁵¹⁰ Melanie Stammers, Irina M. Ivanova, Izabella S. Niewczas, Anne Segonds-Pichon, Matthew Streeter, David A. Spiegel, and Jonathan Clark (2020) Age-related changes in the physical properties, cross-linking, and glycation of collagen from mouse tail tendon, *J Biol Chem*; doi: 10.1074/jbc.RA119.011031

⁵¹¹ Obesity linked to higher risk of dementia, *Pharma Times*, 29 June 2020; http://www.pharmatimes.com/news/obesity_linked_to_higher_risk_of_dementia_1343249

⁵¹² University of Bonn. Receptor makes mice strong and slim: Molecule that regulates two side effects of aging identified, *ScienceDaily*, 25 June 2020; www.sciencedaily.com/releases/2020/06/200625115916.htm

⁵¹³ Katy Rezvani, Marco Ruella, and Robbie Majzner (2020) Advances in Adoptive Cell Therapies, Cell Press webinar, 16 July.

⁵¹⁴ Labmedica.com, 28 November 2019.

⁵¹⁵ Rhys Blakely (2020) Cancer code offers hope of treatment decades early, *The Times*, 6 February.

⁵¹⁶ <https://www.labmedica.com/molecular-diagnostics/articles/294792025/groundbreaking-dna-test-evaluates-biomarkers-in-517-cancer-relevant-genes-across-30-types-of-solid-tumors.html>

- The development of a DNA biosensor to enable early diagnosis of cervical cancer.⁵¹⁷
- A new metabolism-based blood test detects multiple cancer types prior to symptoms.⁵¹⁸
- The development of a sterilizable nanowire-based device that can extract urinary microRNAs and use it as a liquid biopsy to detect cancers of the central nervous system.⁵¹⁹
- Researchers at the Georgia Institute of Technology in the US have invented a microfluidic chip called the Cluster-Well which can precisely locate each cell in a blood sample and determine if it is cancerous. This could lead to earlier and more targeted treatment.⁵²⁰
- A new liquid biopsy blood test can detect brain tumours where a conventional biopsy is not possible.⁵²¹
- Immunotherapy – the re-education of an individual’s own immune cells to fight diseases such as cancer.⁵²² An immunotherapy drug, AFM24, has been shown to work in patients with advanced cancers that had stopped responding to treatment, including bowel, lung and pancreatic cancers.⁵²³
- The development of tests that can transform cancer treatments. For example, a blood test developed by the Vancouver Prostate Centre and BC Cancer (British Columbia, Canada) analyzes the DNA that metastatic cancers shed into the bloodstream, known as circulating tumor DNA. By sequencing the entire genome of this ctDNA, the test reveals characteristics that are unique to each patient’s cancer, giving doctors new tools to develop more personalized treatment plans.⁵²⁴
- The development by Moderna and Merck of a personalized cancer vaccine, based on immunotherapy and designed to prime the immune system so the body can generate a response based on a person's specific type of cancer tumour, using the

⁵¹⁷ <https://www.labmedica.com/technology/articles/294799669/dna-biosensor-enables-early-diagnosis-of-cervical-cancer.html>

⁵¹⁸ <https://www.labmedica.com/molecular-diagnostics/articles/294793553/index.php>;
<https://www.labmedica.com/molecular-diagnostics/articles/294788864/blood-based-liquid-biopsy-test-accurately-detects-more-than-fifty-types-of-cancer.html>;

⁵¹⁹ <https://www.labmedica.com/molecular-diagnostics/articles/294788818/a-nanowire-based-liquid-biopsy-method-for-detection-of-tumors-of-the-central-nervous-system.html>

⁵²⁰ <https://www.labmedica.com/molecular-diagnostics/articles/294794252/index.php>: ‘Cancer spreads via circulating tumor cells (CTCs) that travel through the blood to other organs, and they are nearly impossible to track. When a tumor starts metastasizing, it sheds its cell into the blood. An individual cell often doesn’t survive the bloodstream on its own, but clusters of cells are much more robust and can travel to other organs, effectively pushing the cancer to a metastatic state [i.e., stage 4]. CTCs have proven difficult to study, let alone treat. Blood contains billions of cells per milliliter, and only a handful of those cells would be CTCs in a patient with metastatic cancer’.

⁵²¹ <https://www.labmedica.com/molecular-diagnostics/articles/294795854/blood-test-helps-diagnose-inaccessible-brain-tumors.html>

⁵²² Siddhartha Mukherjee (2022) *The Song of the Cell: An Exploration of Medicine and the New Human*, Simon & Schuster; <https://www.simonandschuster.com/books/The-Song-of-the-Cell/Siddhartha-Mukherjee/9781982117351>

⁵²³ <https://www.telegraph.co.uk/news/2022/04/08/new-killer-cancer-treatment-stops-one-three-tumours-growing>

⁵²⁴ <https://www.labmedica.com/molecular-diagnostics/articles/294793945/first-of-its-kind-blood-test-could-transform-cancer-treatment.html>

- same mRNA technology as in Covid-19 vaccines.⁵²⁵ When used in combination with Keytruda, it has reduced the risk of death or relapse in patients with the most deadly form of skin cancer by half after three years.⁵²⁶
- Scientists at the US cancer research hospital City of Hope⁵²⁷ have made a breakthrough against the proliferating cell nuclear antigen (PCNA) protein which in a mutated form helps to replicate expanding cancer tumours. They have developed a molecule, named AOH1996, which targets and kills the mutated PCNA. If clinical trials are successful, AOH1996 could be incorporated in a cancer-stopping pill which would provide protection against breast, prostate, brain, ovarian, cervical, skin and lung cancers.⁵²⁸
 - The development of an in vitro diagnostic test to detect hundreds of genetic variants that could indicate a higher likelihood of developing specific kinds of cancer.⁵²⁹
 - The development of an implantable ultrasound device that can open the blood-brain barrier and hence offers the possibility of more effective treatment for the range of neurocognitive diseases (including brain cancer) that previously had limited treatment options due to the blood brain barrier.⁵³⁰
 - The introduction of a new assay to detect and treat acute myeloid leukemia.⁵³¹
 - Anastrozole, taken daily, halves the risk of breast cancer (at a cost of £0.04 per day).⁵³²
 - The levels of antibodies against ALDOA and FH provide novel predictors of ischemic stroke, including transient ischemic attack (TIA) and cerebral infarction (CI), which are induced by atherosclerosis.⁵³³
 - A new blood-based cardiovascular risk test for more accurate risk prediction (of heart disease and sudden cardiac arrest) and patient management.⁵³⁴

⁵²⁵ <https://www.telegraph.co.uk/news/2022/12/13/skin-cancer-vaccine-based-covid-jab-technology-hailed-game-changer/>; <https://www.cancerresearch.org/treatment-types/cancer-vaccines/>;
<https://www.cancer.net/navigating-cancer-care/how-cancer-treated/immunotherapy-and-vaccines/what-are-cancer-vaccines>

⁵²⁶ <https://www.cnn.com/2023/12/14/moderna-merck-cancer-vaccine-reduces-risk-of-skin-cancer-return.html>

⁵²⁷ <https://www.cityofhope.org/>

⁵²⁸ The molecule is named after Anna Olivia Healey who was born in 1996 but who sadly did not survive cancer; <https://metro.co.uk/2023/08/01/cancer-cure-pill-treatment-scientists-19228101/>

⁵²⁹ <https://www.labmedica.com/molecular-diagnostics/articles/294798809/first-of-its-kind-dna-test-can-assess-predisposition-for-dozens-of-cancer-types.html>

⁵³⁰ Dr Adam Worthalter, neurosurgeon at Northwestern Memorial Hospital, speaking at the Fasano Longevity Conference, Washington DC, 6 November 2023.

⁵³¹ <https://www.labmedica.com/molecular-diagnostics/articles/294799362/new-assay-to-revolutionize-detection-and-treatment-of-acute-myeloid-leukemia.html>

⁵³² <https://www.telegraph.co.uk/news/2023/11/07/breast-cancer-risk-halved-daily-pill-anastrozole-nhs>

⁵³³ Hardening of the arteries caused by a buildup of plaque in the inner lining of an artery;
<https://www.labmedica.com/clinical-chem/articles/294789093/aldoa-and-fh4-antibodies-associated-with-cerebrovascular-disease.html>

⁵³⁴ <https://www.labmedica.com/hematology/articles/294792002/elisa-blood-test-uses-innovative-biomarker-to-detect-heart-disease-and-sudden-cardiac-arrest.html>;
<https://www.labmedica.com/hematology/articles/294789202/novel-ai-driven-cardiac-blood-test-provides-highly-accurate-prediction-of-one-year-risk-for-heart-attack-stroke-or-cardiac-death.html>

- The importance of selenium in antioxidant mixtures designed to reduce all-cause mortality, in particular, from cardiovascular disease and cancer.⁵³⁵
- The development of technology by Bit.Bio to reprogram stem cells to make any human cell desired.⁵³⁶ In June 2023, scientists at the University of Cambridge and the California Institute of Technology revealed that they have used stem cells to create synthetic human embryos, avoiding the need for eggs or sperm. The embryos resemble those in the earliest stages of human development and could be used to gain a better understanding of genetic disorders.⁵³⁷

Huge advances are expected to follow the final decoding of the entire human genome in March 2022.⁵³⁸ Cost and speed have fallen dramatically. A whole genome cost \$100m in 2001, but in 2022 it was \$400 and is anticipated to be just \$100 by 2024. The development of CRISPR technology for editing genomes allows scientists to change DNA sequences and modify gene function, so that, for example, genetic defects can be corrected and the spread of diseases can be prevented.⁵³⁹ Scientists claim that this will open the way to precision medicine for everybody. Professor Sir Mark Caulfield, former chief scientist at Genomics England, said: ‘We have got a fabulous future. We have only scratched the surface of what the whole genome can offer’. The first benefit will be the early diagnosis of illness and personalized medicine. This will be followed by the correction of faulty genes via gene therapy. As an early example of gene therapy, scientists, using a technique called optogenetics, have added light-sensitive proteins to a man’s retina, partially restoring his sight.⁵⁴⁰ All this will help to reduce working age sickness and extend the working life, with knock-on benefits for the sustainability of the pension system.⁵⁴¹

⁵³⁵ David J A Jenkins, David Kitts, Edward L Giovannucci, Sandhya Sahye-Pudaruth, Melanie Paquette, Sonia Blanco Mejia, Darshna Patel, Meaghan Kavanagh, Tom Tsirakis, Cyril W C Kendall, Sathish C Pichika, John L Sievenpiper, Selenium, antioxidants, cardiovascular disease, and all-cause mortality: a systematic review and meta-analysis of randomized controlled trials, *The American Journal of Clinical Nutrition*, nqaa245, <https://doi.org/10.1093/ajcn/nqaa245>

⁵³⁶ Tom Whipple (2020) Bit.Bio: British firm cracks code for stem cells, *The Times*, 27 October.

⁵³⁷ <https://www.theguardian.com/science/2023/jun/14/synthetic-human-embryos-created-in-groundbreaking-advance>

⁵³⁸ Timeline - Genetic breakthroughs:

- December 1999 - First human chromosome is sequenced
- April 2003 - Heads of government of Britain, the US, Japan, France, Germany, and China announce the successful sequencing of the entire human genome
- September 2005 - The chimpanzee genome is sequenced
- December 2009 - The first comprehensive analysis of cancer genomes is published, including lung cancer and malignant melanoma
- May 2010 - The Neanderthal genome is sequenced
- December 2018 - The 100,000 genomes project is completed, sequencing 100,000 genomes from patients affected by a rare disease or cancer
- March 2022 - Scientists finally decode the entire human genome

Source: <https://www.telegraph.co.uk/business/2022/08/19/britains-path-economic-national-renewal-genome-revolution>

⁵³⁹ Su Bin Moon, Do Yon Kim, Jeong-Heon Ko and Yong-Sam Kim (2019) Recent Advances in the CRISPR Genome Editing Tool Set, *Experimental & Molecular Medicine*, 51: 1–11.

⁵⁴⁰ <https://www.nytimes.com/2021/05/24/science/blindness-therapy-optogenetics.html>

⁵⁴¹ <https://www.telegraph.co.uk/business/2022/08/19/britains-path-economic-national-renewal-genome-revolution>

Dr Verdin expects the first anti-aging drugs to become available on the market in the next 5-10 years, following the completion of successful clinical trials. He also believes the new drugs will revolutionize the whole process of medical intervention which have traditionally focused on treating a specific disease, like heart or lung disease: ‘Aging biology presents a different way of organizing medicine and of treating disease. Aging affects every single organ, so if your intervention targets an aging pathway, you will affect the development of diseases in different organs. That doesn’t fit in the traditional field of medicine. So, one of the biggest challenges we face... is convincing people that we should be studying disease in the context of pathways that are universal across different organs. We need to change the way that we practice medicine to aim for a preventative approach’.⁵⁴² This point is reinforced by Steven Braithwaite, chief scientific officer of Alkahest: ‘Our long-term goal is that we will develop therapeutics that modulate the biology of aging and will have impact across multiple disorders’.⁵⁴³ Joan Mannick, chief medical officer of resTORbio, goes further: ‘In the future we may be able to personalize aging-related therapeutics. For instance, it would be useful to develop biomarkers of aging-related biochemical pathways and then use therapeutics targeting specific biochemical pathways in ...specific patients’, similar to how cholesterol became a biomarker for the use of statins.⁵⁴⁴ A huge investment is being made in healthcare innovation to slow the aging process by organizations like the Deep Knowledge Group.⁵⁴⁵

Governments are also setting up life science strategies. For example, the UK government introduced one in 2017 and updated it in 2021, building on the knowledge gained from the Covid-19 pandemic to tackle future disease missions, such as dementia research, the early-stage diagnosis and treatment of diseases such as cancer, and prevention of cardiovascular diseases. There will be greater use of genomics and health data to provide much deeper, real world evidence about the safety of new medicines and health technologies.⁵⁴⁶ There will also be greater use of oncology medicines, such as AstraZenica’s Enhertu (for treating breast cancer), Tagrisso (lung cancer) and Lynparza (ovarian cancer). Dave Frederickson, head of oncology at AZ, believes it will soon be possible ‘to eliminate cancer as a cause of death’.⁵⁴⁷

In April 2022, leading life sciences companies and Innovate UK called for the development of a national vision on cell and gene therapies (CGTs) in the UK.⁵⁴⁸ CGTs are treatments based on human cells or genes and a form of advanced therapy medicinal product

⁵⁴² Interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁵⁴³ Steven Braithwaite, chief scientific officer, Alkahest, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁵⁴⁴ Joan Mannick, chief medical officer, resTORbio, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁵⁴⁵ ⁵⁴⁵ <https://www.dkv.global/>

⁵⁴⁶ <https://www.pinsentmasons.com/out-law/news/genomics-and-health-data-central-to-uk-life-sciences-vision>

⁵⁴⁷ <https://www.telegraph.co.uk/business/2023/01/27/meet-scientist-working-eliminate-terminal-cancer/>

⁵⁴⁸

<https://ct.catapult.org.uk/sites/default/files/publication/National%20Cell%20and%20Gene%20Therapy%20Vision%20for%20the%20UK.pdf>

(ATMPs). Compared to small molecules and protein-based treatments, such as monoclonal antibodies, which require repeated administration to treat the underlying conditions, CGT treatments offer a solution in which a single dose can provide a durable therapeutic effect. Nearly 300 new CGTs were currently in development, but the UK needs to scale-up its manufacturing capacity to meet demand for CGTs in future. There was also a compliance challenge, since CGTs often have a very short shelf life.

Amongst these positive developments, there have been some negative ones. A key example in 2022 was the exposure by the journal *Science* in July that the study by Lesné et al (2006) published in the journal *Nature* on the causes of Alzheimer's disease may have been based on evidence tampering using 'manipulated' data.⁵⁴⁹ The 2006 study concluded that Alzheimer's is triggered by a build-up of amyloid beta plaques in the brain following experiments in which amyloid beta injected into young mice brought on dementia. However, the *Science* investigation claims to have found evidence that the images of amyloid beta in mice had been doctored by combining photos from different experiments. German psychiatrist Alois Alzheimer first identified plaques in the brains of dementia patients in 1906 and in 1984 amyloid beta was found to be their main component. Hundreds of different therapies targeting amyloid in the brain were trialled, but since they all failed, further experimentation was abandoned until the 2006 paper. Since then billions of dollars have been spent trialling new therapies to remove amyloid from the brain – again without success. Yet in June 2022, the US Food and Drug Administration approved the drug aducanumab (marketed as Aduhelm) to slow cognitive decline in people with mild memory and thinking problems. It was the first approved treatment to attack the disease process of Alzheimer's instead of just addressing dementia symptoms. This was despite the fact that the FDA's own independent advisory committee argued that there was insufficient evidence that the drug – which costs \$56,000 a year – can help patients.⁵⁵⁰ The authors of the 2006 paper responded by saying they 'still have faith' that amyloid is a cause of Alzheimer's. Alzheimer's Research UK said: 'the research that has been called into question is focused on a very specific type of amyloid, and these allegations do not compromise the vast majority of knowledge built up during decades of research into the role of this protein in the disease'.⁵⁵¹

Another negative development is the finding by Binghamton University in the US that early retirement can accelerate cognitive decline at older ages. The finding was based on an examination of China's New Rural Pension Scheme (NRPS) and the Chinese Health and Retirement Longitudinal Survey (CHARLS). The most significant indicator of cognitive decline was delayed recall which is an important predictor of dementia and was

⁵⁴⁹ <https://www.science.org/content/article/potential-fabrication-research-images-threatens-key-theory-alzheimers-disease>

⁵⁵⁰ <https://www.nytimes.com/2021/06/07/health/aduhelm-fda-alzheimers-drug.html>

⁵⁵¹ <https://www.telegraph.co.uk/news/2022/07/21/manipulated-alzheimers-data-may-have-misled-research-16-years/>

associated with increased social isolation. The findings were similar to those in higher income countries, such as the US, UK, and EU.⁵⁵²

As a final example, Gilmer et al. (2023) point out that female-specific aging trajectories are understudied. While the use of model organisms, such as worms, fruit flies, and mice, has helped researchers understand many aging processes, most do not match human sex specificity. As a result, there is a lack of data on how pregnancy, breastfeeding, and menopause impact aging-related diseases. Animal research is based on the assumption that the model organisms and humans have similar physiological characteristics, but there are significant differences between the physiology of these organisms and female reproductive biology. One example is bone mass: the bone mass of female rodents does not decline more than that of male rodents, but human females experience osteoporosis four times more often than human males. Similarly, with Alzheimer's disease and other types of dementia: these are more common in human females than age-matched human males, but female rodents have better retained memory-related functions over time than age-matched male rodents. The consequence is worse health outcomes with higher morbidity in the female population than age-matched human males. The authors recommend funding for more research on the impact of menopause, pregnancy, and breastfeeding on aging and disease progression and the use proper animal models and experimental setups, thus improving how their studies handle the particular ways in which females age.⁵⁵³

Preventative health care and later life wellness

The previous subsection highlights the importance of preventative health care – given how expensive it is to treat noncommunicable diseases, such as heart disease, cancer, diabetes, and dementia, which account for around 70% of deaths globally.

The OECD estimates that around 40% of cancer cases are preventable and mortality can be reduced through earlier diagnosis and the provision of more timely and effective treatments. Confirmation of this comes from the UK. Lung cancer is the most lethal form and in the UK it causes an average of 35,000 deaths per year, where the average stage of diagnosis is Stage 3. There was no nationwide screening program, but in 2019, the NHS introduced a lung cancer screening pilot scheme using low dose CT scanning for current and ex-smokers aged between 55 and 75, with 77% of patients being diagnosed with lung cancer at Stages 1 or 2 (compared with 33% previously). In October 2022, the NHS began to roll out of the program nationally.⁵⁵⁴

Around a million people in the UK have dementia, mostly Alzheimer's. About a third of people born in the UK are likely to experience dementia in their lifetime, according to recent estimates. It is the main cause of death, but current drugs (which cost £34.7bn

⁵⁵² <https://www.pensionpolicyinternational.com/early-retirement-can-accelerate-cognitive-decline-among-the-elderly-research-shows/>

⁵⁵³ Gabrielle Gilmer, Zachary R. Hettinger, Yetsa Tuakli-Wosornu, Elizabeth Skidmore, Julie K. Silver, Rebecca C. Thurston, Dawn A. Lowe and Fabrisia Ambrosio (2023) Female aging: when translational models don't translate, *Nature Aging*, 3: 1500–1508.

⁵⁵⁴ Murray et al. (2022).

annually) only help symptoms and do not stop progression.⁵⁵⁵ A 2019 analysis based on the Global Burden of Disease database predicted that the number of people with dementia would increase from 57.4m cases globally in 2019 to 152.8m cases in 2050. However, although dementia has been increasing globally, there is evidence that, when controlling for population aging, the prevalence has actually fallen in recent years. A 2020 study – led by Francine Grodstein, professor of internal medicine at the Rush Alzheimer’s Disease Center in the US – that followed the health of around 50,000 over-65s found the incidence rate of new cases of dementia in Europe and North America had dropped 13% per decade over the past 25 years.

The reasons are not currently well understood, but some scientists have put it down to improved cardiovascular health (how effectively the body’s arteries and veins carry blood to and from the heart) and especially the vascular health of the brain.⁵⁵⁶ Professor Albert Hofman, chair of the department of epidemiology at the Harvard TH Chan School of Public Health, says that: ‘In North America and in Western Europe, there has been for 50 years now an enormous emphasis on preventing cardiovascular diseases . . . that led to heart attacks and strokes’, adding that a third of the population over 50 now takes pills to control high blood pressure and the use of statins to reduce cholesterol has soared. Carol Brayne, professor of public health medicine at the University of Cambridge and the lead investigator of the Cognitive Function and Ageing Studies, argues that reducing the incidence of dementia requires ‘optimizing neurological function’ throughout the course of a person’s life by improving brain and physical health. A 13% decline would mean 15m fewer dementia cases by 2040 in high-income countries. Another important factor is ‘cognitive reserve’: people with more active brains are better able to delay the effects of dementia. Brayne found, using brain samples, that ‘the higher the level of education, in terms of years of exposure, the less likely you were to express dementia during your lifetime’. Brayne also discovered that the fall in dementia cases was lower in deprived areas, suggesting that there was a social link between dementia and the quality of nutrition and housing. Responding to this finding, Dr Susan Mitchell, head of policy at Alzheimer’s Research UK, said: ‘with [the] increased prevalence of diabetes [and] obesity [which are] risk factors for dementia, we may see the incidence rates start to increase in the future’. As supporting evidence for this, a 2023 study published by *The Lancet Public Health*, indicated that dementia incidence decreased in England and Wales by 28.8% between 2002 and 2008, but increased again by 25.2% between 2008 and 2016.

⁵⁵⁵ Sarah Knapton (2023) Alzheimer’s could cause brain cells to kill themselves, *Daily Telegraph*, 15 September; <https://www.telegraph.co.uk/news/2023/09/15/dementia-researchers-uncover-why-brain-cells-die/>

⁵⁵⁶ The US Centers for Disease Control and Prevention defines brain health as an ability to perform all the mental processes of cognition, including the ability to learn and judge, use language, and remember (What is a Healthy Brain? New Research Explores Perceptions of Cognitive Health Among Diverse Older Adults. Centers for Disease Control and Prevention: Healthy Aging; https://www.cdc.gov/aging/pdf/perceptions_of_cog_hlth_factsheet.pdf) and has established the Healthy Brain Initiative Road Map (Road Map for State and Local Public Health: Healthy Brain Initiative. Centers for Disease Control and Prevention: Alzheimer’s Disease and Healthy Aging program; <https://www.cdc.gov/aging/healthybrain/roadmap.htm>).

A 2020 *Lancet* study found that about 40% of dementia was preventable if people improved their mid-life health. Jonathan Schott, professor of neurology at the Dementia Research Centre at UCL, argues that ‘it may well be that the lowest hanging fruit in terms of preventing dementia, in the western world at least, has already been [reaped]. But considerable scope remains to improve things in more disadvantaged communities and in poorer countries. So there’s still a huge amount to be done in the developing world where those vascular risk factors perhaps aren’t being looked after as well’. Scientists now believe that preventive measures combined with new drugs is the best way of dealing with dementia.⁵⁵⁷

Professor Andrew Scott points out: ‘The dominant cause of many noncommunicable diseases is age itself. This suggests that efforts to slow the aging process should play a more prominent role in treatments rather than targeting particular diseases, such as cancer. A growing research program is focusing on understanding why we age and developing treatments that, if successful, could lead to dramatic changes in the malleability of age’⁵⁵⁸

Examples of these developments include:

- Periodic fasting or caloric restriction has been shown to be one of the most effective ways of preventing age-related disorders and promoting life expectancy and health span. The first study to examine caloric restriction in humans was the Comprehensive Assessment of Long-Term Effects of Reducing Intake of Energy (CALERIE) at Duke University.⁵⁵⁹ It showed that two years of caloric restriction could slow biological aging and reduce age-related markers, such as oxidative stress.⁵⁶⁰
- Diets and food supplements designed to treat age-related disorders. The Buck Institute’s Dr Eric Verdin reports the development of fasting-mimicking diets. There are also caloric restriction mimetics, supplements that offer the health-promoting effects of fasting, without the need for fasting. Metformin (previously used in the treatment of type-2 diabetes) is being examined as a drug for increasing healthspan by Dr Nir Barzilai, Professor of Medicine and Genetics and Director of the Institute for Aging Research at the Albert Einstein College of Medicine in New York, in his TAME (Targeting Aging with Metformin) trial.⁵⁶¹ Similarly, methionine, an amino acid that plays an important role in the metabolism, is being considered for the treatment of age-related disorders. Singapore-based Senescence Life Sciences aims to use nutraceuticals – ingredients and raw materials for dietary supplements – to combat natural brain aging by targeting an enzymatic process that has been shown to restore classical neuronal indicators of age – including learning,

⁵⁵⁷ Sarah Neville (2023) What is behind the unexpected decline in dementia?, *Financial Times*, 30 October; <https://www.ft.com/content/184f6e81-d9ce-4a14-84f0-5190ea36e798>.

⁵⁵⁸ Andrew Scott (2020) The Long, Good Life: Longer, more productive lives will mean big changes to the old rules of aging, *Finance and Development*, March.

⁵⁵⁹ <https://calerie.duke.edu/>

⁵⁶⁰ Carla Heyworth (2020) Metabolic aging, fasting and metformin, *Longevity Technology*, 10 March; <https://www.longevity.technology/metabolic-aging-fasting-and-metformin/>

⁵⁶¹ Carla Heyworth (2020) Metabolic aging, fasting and metformin, *Longevity Technology*, 10 March; <https://www.longevity.technology/metabolic-aging-fasting-and-metformin/>

memory and decision-making performance.⁵⁶² Food companies are promoting ‘future food’ which combines healthier eating and leveraging agricultural gene editing.⁵⁶³

- Recognition that low concentrations of circulating 25-hydroxyvitamin D (25[OH]D), a metabolite used as a clinical indicator of vitamin D status, are associated with an increased risk of cardiovascular disease and all-cause mortality, as well as other chronic diseases.⁵⁶⁴
- Developing a wearable device to detect early signs of Alzheimer's disease as part of the Early Detection of Neurodegenerative diseases (EDON) project run by Alzheimer's Research UK. EDON will analyse data from existing studies using artificial intelligence and use the results to design a prototype device within three years. The wearable will then collect data on gait, heart rate and sleep patterns etc which can be used to identify signs of the disease years before symptoms develop.⁵⁶⁵
- Neural engineering to deal with destructive addictions, such as alcohol and drug dependency. Addictions and also Parkinson's disease are linked to dopamine, the so-called pleasure chemical. Parkinson's gradually kills off dopamine-producing cells in the brain, but new therapeutic approaches involve replacing the lost dopamine. One example involves delivering the gene for the protein glial-derived neurotrophic factor (GDNF) into the brain, which then encourages dopamine production. Professor Krystof Bankiewicz from Ohio State University has published a study in *Nature Medicine* which assesses whether delivering GDNF to brain areas associated with addiction and reward through gene therapy could help reconfigure the dysfunctional brain pathways of alcoholics. The study involved macaque monkeys which, like humans, enjoy alcohol, but lost interest when given GDNF therapy. Bankiewicz said ‘we have to view all brain disorders, such as addictions, through the lens of different wiring. The brain is incredible at organizing connections, but certain individuals are more predisposed to being wired in certain ways’. Re-engineering the brain to alter human behaviour is a new field in medicine and is a response to the ineffectiveness of traditional psychotherapies, such as cognitive behavioural therapy where 60% of patients with alcohol dependency relapse within a year. Research is now showing that addictions also have a genetic origin. Certain genes (and their mutations) in the brain, linked to impulsivity, can create innate urges when exposed to addictive substances. For example, the melanocortin 4 receptor (MC4R) gene senses fatness and a mutation causes some people's brain to believe they are less fat than they are, leading to overeating. Semaglutide-based obesity drugs, such as Ozempic and Wegovy, deliver a synthetic version of the hormone GLP-1 (Glucagon-Like Peptide-1) which acts on the brain to create a sense of fullness. There are also examples of non-invasive brain stimulation which avoid the potential side effects associated with pharmacological

⁵⁶² Danny Sullivan (2020) Nutraceuticals to beat cognitive decline before it starts, *Longevity Technology*, 16 March; <https://www.longevity.technology/nutraceuticals-to-beat-cognitive-decline-before-it-starts>

⁵⁶³ Aging Analytics Agency, *Advancing Financial Industry: Longevity/AgeTech /WealthTech*

⁵⁶⁴ <https://www.labmedica.com/clinical-chem./articles/294790627/vitamin-d-deficiency-has-greater-risk-for-all-cause-mortality.html>

⁵⁶⁵ Jane Wakefield (2020) Wearable to spot Alzheimer's being developed, *BBC News*, 13 February.

drugs. One is transcranial magnetic stimulation (TMS) which can help people stop smoking, according to a study published in *Nature Communications* and led by Professor Barbara Sahakian from the University of Cambridge. She said: ‘In smoking, this area of the brain [the left ventromedial prefrontal cortex which is involved in willpower and feelings of pleasure] gets reduced, so then behaviour becomes disinhibited and that may be why smoking cigarettes can often lead on to marijuana and alcohol use. The hope might be that this reduction can be mitigated by transcranial stimulation, and thereby you could re-establish inhibitory control’. The aim of TMS is to adjust the brain’s reward, motivation and decision-making circuits in a way which reduces the cravings. In a similar vein, a study published in *Current Psychology* by scientists at the University of Messina in Italy found that applying low-level electrical activity to areas of the prefrontal cortex, which influences social skills, could help limit aggression, impulsivity and promote empathy – and hence help to reintegrate those with antisocial personality disorders, such as criminals, back into society. These are all different approaches for adjusting the chemicals, hormones and networks in the brain to alter damaging behaviour. However, this raises ethical issues, as Professor Bankiewicz points out: ‘I believe that these therapies will drive a permanent change in those who have incurable addictions. But would that predispose them to be more reckless, knowing that there is something available? It’s a good question, and I don’t know the answer. Perhaps in some people, maybe not in others’. There are also safety concerns when it comes to gene therapy, such as the possibility that it could lead to cancer, as well as the ethical issues associated with changing an individual’s behaviour and personality, possibly permanently. Bankiewicz argues that such therapies require weighing up the risks and benefits, and they should only be considered for those with very severe addictions and where all other approaches have failed.⁵⁶⁶

Equally important are measures that contribute to later life wellness, which, in turn, are likely to increase both lifespan and healthspan. Examples include:

- Exercise together with sleep and stress management (in addition to nutrition). But much more work needs to be done to understand the link to life expectancy, as Dr Verdin points out: ‘How exactly does exercise impact longevity? We know it does, but we don’t know what forms of exercise are effective – endurance vs high intensity interval training? 10,000 steps vs 4,000 steps? We need molecular-level data to increase our knowledge’.⁵⁶⁷
- Reducing non-adherence to medication. The World Health Organization has estimated that adherence to medication for chronic conditions is as low as 50% in developed countries and even lower in developing countries. The annual costs of medication non-adherence range from \$100bn to \$290bn in the USA, €125bn in Europe and AU\$7bn in Australia. Around 10% of hospitalizations in older people

⁵⁶⁶ David Cox (2023) New research suggests neural engineering could spell the end of humanity's destructive addictions – but at what cost?, *Daily Telegraph*, 2 September; <https://www.telegraph.co.uk/health-fitness/mind/brain-tweaking-addiction-transcranial-magnetic-stimulation/>

⁵⁶⁷ Interview in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

are attributed to non-adherence. The typical non-adherent patient requires three extra medical visits per year, leading to increased treatment costs of \$2,000 per annum. The International Longevity Centre (UK) said: ‘We could see a considerable improvement in health outcomes (and consequently longevity), not only by developing new drugs, but by helping people adhere to existing treatment regimens that have already been researched, tested and prescribed for them’.⁵⁶⁸

- The living environment. Where you live can have a significant impact on the likelihood that you will reach centenarian age, according a study from Washington State University’s Elson S. Floyd College of Medicine. Washingtonians who live in highly walkable, mixed-age communities may be more likely to live to their 100th birthday. The study also found socioeconomic status to be correlated, and an additional analysis showed that geographic clusters where the probability of reaching centenarian age is high are located in urban areas and smaller towns with higher socioeconomic status. Existing research estimates that heritable factors such as genes only explain about 20% to 35% of an individual’s chances of reaching centenarian age.⁵⁶⁹
- Targeting products and services at older people with the intention of improving their well-being and indirectly their life and healthspans. Companies doing this are not being altruistic. Rather they recognize the financial resources available to this demographic in developed countries. In the US, for example, people over 50 control 75% of net wealth and 50% of disposable income and will spend around \$4trn over the next twenty years. Tech companies like Amazon, Apple and Google are looking at designing new products and services for this group. Agetech⁵⁷⁰ in the form of digital health platforms and telemedicine is providing access to cost-effective healthcare, in combination with medical software and apps.⁵⁷¹ Agetech also targets other aspects of well-being, such as education and financial wellness.⁵⁷²
- The promotion of a ‘positive outlook’ to reduce memory decline. A study finds that people who feel enthusiastic and cheerful – what psychologists call ‘positive affect’ – are less likely to experience memory decline as they age, controlling for age,

⁵⁶⁸ <https://ilcuk.org.uk/doctors-orders/>

⁵⁶⁹ Centenarian study suggests living environment may be key to longevity, Washington State University, 17 June 2020; <https://news.wsu.edu/2020/06/17/centenarian-study-suggests-living-environment-may-key-longevity/>

⁵⁷⁰ Defined as the digital-enabled market of consumers over 50. It relies on this age group being willing and able to access the market digitally.

⁵⁷¹ Angela Tyrrell (2020) Eight sectors to be disrupted by longevity, *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁵⁷² Angela Tyrrell, SVP, Longevity Leaders, identifies ten consumer trends driving the preventative wellness market: 1) digital tracking tools (e.g., for counting steps, logging calories, tracking ovulation or recording sleep patterns), 2) consumer biological testing (e.g., personalized DNA testing to improve lifetime health management), 3) personalization (of, e.g., nutrition and skincare), 4) responding to climate change (e.g., by driving less and walking or cycling more), 5) meat alternatives, 6) alcohol alternatives, 7) natural products (without preservatives, sugar and salt), 8) mental health awareness (leading to diagnoses and treatments that reduce cognitive decline in later life), 9) meditation and mindfulness programs (to reduce stress, improve sleep quality or breathing, or accompany a physical activity such as yoga), and 10) Ethical leadership (e.g., via a corporate and social responsibility policy that enhances a company’s reputation with its customers and, as a consequence, has long-term benefits for the health of its employees). See *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

gender, education, depression, negative affect, and extraversion. This result adds to a growing body of research on positive affect's role in healthy aging.⁵⁷³

These developments led Bank of America to conclude that the human lifespan could soon pass 100 years for significantly more people than historically,^{574,575} with one of the biggest investment opportunities over the next decade being in companies working to delay human death, a market expected to be worth at least \$600bn by 2025.⁵⁷⁶ To illustrate, in June 2021, M&G Investments launched the Better Health Solutions fund which will invest in companies whose products or services are designed to promote better health and wellbeing.⁵⁷⁷ Investment in the biotech sector reached \$5.2bn globally according to analysts at Longevity.Technology, with 130 deals in 2022.⁵⁷⁸ This compares with \$6.2bn (190 deals) in 2021 and \$3.0bn (148 deals) in 2020. The largest investment in 2022 was Jeff Bezos's \$3bn financing for Altos Labs which focuses on cellular reprogramming. The Hevolution Foundation was also established. This is a Saudi-backed non-profit organization with an annual budget of up to \$1bn to spend on 'independent research and entrepreneurship in the emerging field of healthspan science'.⁵⁷⁹ The leading longevity domains are 'Longevity discovery platforms', 'Longevity drugs', renewal therapies ('Regeneration', 'Rejuvenation', 'Cellular reprogramming') and 'Gene therapies'.⁵⁸⁰

In order to take advantage of this increase in human lifespan, companies should exploit the longevity dividend, i.e., recognize the value of their older workforce and do not force them into retirement before they are ready to leave. Forced early retirement can have the effect

⁵⁷³ Emily F. Hittner, Jacquelyn E. Stephens, Nicholas A. Turiano, Denis Gerstorf, Margie E. Lachman, Claudia M. Haase (2020). Positive Affect Is Associated With Less Memory Decline: Evidence From a 9-Year Longitudinal Study, *Psychological Science*, 31(11), 1386-1395.

⁵⁷⁴ Centenarians make up around 0.03% of the population in both the UK and US, but as the *Economist* conjectures: 'Living to 100 today is not unheard of, but is still rare. ...Should the latest efforts to prolong life reach their potential, living to see your 100th birthday could become the norm; making it to 120 could become a perfectly reasonable aspiration'; <https://www.economist.com/leaders/2023/09/28/living-to-120-is-becoming-an-imaginable-prospect>

⁵⁷⁵ Lynda Gratton and Andrew J. Scott's book *The 100-Year Life* provides a 'raft of solutions, showing how to rethink your finances, your education, your career and your relationships and create a fulfilling 100-year life', including:

- How can you fashion a career and life path that defines you and your values and creates a shifting balance between work and leisure?
- What are the most effective ways of boosting your physical and mental health over a longer and more dynamic lifespan?
- How can you make the most of your intangible assets – such as family and friends – as you build a productive, longer life?
- In a multiple-stage life how can you learn to make the transitions that will be so crucial and experiment with new ways of living, working and learning?

The book is 'also fundamentally a call to action for individuals, politicians, firms and governments and offers the clearest demonstration that a 100-year life can be a wonderful and inspiring one' (Gratton and Scott (2016)).

⁵⁷⁶ <https://www.cnn.com/2019/05/08/techs-next-big-disruption-could-be-delaying-death.html>

⁵⁷⁷ <https://www.professionaladviser.com/news/4033150/unveils-impact-fund-focusing-health-wellbeing>

⁵⁷⁸ <https://longevity.technology/news/global-longevity-investment-hit-5-2-billion-in-2022/>

⁵⁷⁹ <https://longevity.technology/news/hevolution-ceo-on-how-to-spend-1-billion-a-year-on-longevity/>

⁵⁸⁰ <https://longevity.technology/investment/report/annual-longevity-investment-report/>

of harming health and reducing life expectancy because of depression and loss of self-worth which can, in turn, lead to alcoholism, excessive drug use and suicide.⁵⁸¹ Mercer's Next Stage research program, for example, showed that age and experience enhance business performance. Companies that use data analytics and business impact modelling to examine their own organizational demographic data have discovered some key drivers of business performance. To illustrate:

- Experienced workers lower costs because they – and the people they supervise – are less likely to leave. A 5% reduction in turnover saved one of Mercer's clients \$66m in cost per unit.
- Experienced workers increase productivity. Branch revenue at one US bank increased by \$40m per year for each year of extra service/age of its sales team.

An important aspect of this is life-long learning in order to increase later-life productivity. This is being promoted, for example, as part of a project called 'Living, Learning and Earning Longer'⁵⁸² by the OECD, the World Economic Forum, and the American Association of Retired Persons (AARP). Another aspect of the longevity dividend to companies from their employees working longer is potentially lower pension liabilities since additional pensions contributions are made and the pension, when it is paid, is drawn for a shorter period on average.⁵⁸³ Society also benefits from the increase in healthspan associated with the longevity dividend as a result of lower later-life healthcare costs.⁵⁸⁴

Another important aspect is financial wellbeing. The US Consumer Financial Protection Bureau argues that: 'A person's financial wellbeing comes from their sense of financial security and freedom of choice – both in the present and when considering the future. ...[A]dults' financial well-being [is influenced by]: income and employment; savings and safety nets; past financial experiences; and financial behaviours, skills, and attitudes'.⁵⁸⁵ A survey by WTW found that following the pandemic, employers in the UK had become more concerned about the financial wellbeing of their employees, with 80% saying that they were planning to introduce a financial wellbeing strategy. In addition to retirement savings, this could cover debt solutions, emergency savings and saving for housing. The main reasons given were that it supported broader welfare initiatives (including employee health), it enhanced employee benefits at a time of acute labour shortages, and it recognized

⁵⁸¹ There is some evidence for this in the US. See, for example, Kate W. Strully (2009) Job Loss and Health in the U.S. Labor Market, *Demography*, 46(2): 221–246; Clemens Noelke and Jason Beckfield (2014) Recessions, Job Loss, and Mortality Among Older US Adults, *Am J Public Health*, 104(11): e126–e134; and Anne Case and Angus Deaton (2015) Rising Morbidity and Mortality in Midlife Among White Non-Hispanic Americans in the 21st Century, *Proceedings of the National Academy of Sciences of the United States of America*, December 8, 2015 112 (49) 15078-15083.

⁵⁸² <https://www.aarpinternational.org/initiatives/future-of-work/living-learning-and-earning-longer>

⁵⁸³ Yvonne Sonsino, Global Co-Leader of Next Stage, Mercer, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

⁵⁸⁴ For a typical individual, around 70% lifetime healthcare costs occur in the last 3 years of their life. This is the sum of 47.1% for long-term care costs (average across 5 countries: Denmark, Germany, Netherlands, Taiwan and US) and 22.9% for hospital costs (average across 9 countries: Denmark, Germany, Netherlands, Taiwan, US, England, France, Japan and Quebec). See: Eric B. French et al. (2017) End-of-Life Medical Spending in Last Twelve Months of Life is Lower than Previously Reported, *Health Affairs*, 36(7): *Advanced Illness & End-Of-Life Care*; <https://doi.org/10.1377/hlthaff.2017.0174>

⁵⁸⁵ <https://www.consumerfinance.gov/data-research/financial-well-being-survey-data/>

employer duty of care.⁵⁸⁶ Pension schemes have also begun to offer financial wellness services to their members. One example in the UK is the Royal Mail Defined Contribution Pension Scheme which has chosen Destination Retirement from HUB Financial Solutions as a service to support scheme members making key financial choices in the run-up to retirement and beyond.⁵⁸⁷

A 2022 report⁵⁸⁸ from the Geneva Association and the Global Aging Institute, while accepting that ensuring financial wellbeing was the core purpose of life insurance, argued that ‘traditional business models have come under stress as socio-economic, demographic, health and technological developments, [and] combined with a protracted period of low interest rates, have dented the appeal of savings-oriented life insurance globally’. To counteract this, the report made four recommendations for insurers:

- *Step up efforts to directly affect the determinants of savings and risk protection.* Inherent in the concept of financial wellbeing is an ecosystem of consumer needs that transcends the traditional products offered by life insurers. If life insurers wish to position themselves more strategically, they will have to redefine their role to include directly affecting the determinants of retirement savings and risk protection through pathways such as education, advisory services, mentoring and financial incentives in partnership with government, financial advisers and wealth and asset managers. Doing so will require insurers to either create or buy new capabilities, or else partner to bring them in.
- *Promote financial literacy in young age.* The lack of attention to financial education leaves the young ill-prepared to navigate the insecurities of the current labour market and successfully prepare for their eventual retirement. It also overlooks the opportunity to cement the role of life insurance at an early age. With a relatively modest investment, insurers can partner with national educational agencies, schools, communities and digital platforms to develop innovative ways of propagating financial knowledge, including by gamifying it, using social media and leveraging word of mouth and ‘influencers’.
- *Improve risk exposure through preventive measures.* Very few life insurers cited limiting risk exposure as a primary motivation for developing new financial wellbeing products. Yet there are strong connections between financial wellbeing, general wellbeing and risky behaviours. Altering these behaviours will require insurers to embed data science at the heart of their products and indeed to see it as a key to understanding needs, shifting the paradigm from repair/replace to predict/prevent. Similarly, using data science to better integrate health and wellness products could have significant benefits.
- *Tap into the longevity economy.* Life insurers’ efforts to tap into the burgeoning longevity sector are currently modest. There is also little to suggest that their products address changing retirement patterns, such as unretirement, phased retirement and new careers post-retirement, or changing family structures,

⁵⁸⁶ <https://www.wtco.com/en-GB/Insights/2021/05/future-of-financial-wellbeing-survey-2021>

⁵⁸⁷ <https://www.ipe.com/news/uk-roundup-house-of-fraser-plan-strikes-600m-buyout/10060379.article>

⁵⁸⁸ Financial Wellbeing: Is it the key to reinventing life insurance?, May 2022;
<https://www.genevaassociation.org/financial-wellbeing-report>

including shifts in multigenerational living arrangements. New solutions such as silver sabbaticals to enable middle-aged adults to re-skill and to encourage longer working lives as well as supplementary health and care benefits that take over where government leaves off could help insurers unlock the potential of the silver economy and increase their relevance to aging societies.

There have also been significant negative developments. Examples include:

- An increase in deaths from heart and circulatory diseases in the UK for the first time in 50 years – as a result of an increase in obesity and type-2 diabetes.⁵⁸⁹
- Deaths of despair. The ‘longevity economy’ has not benefited older workers in jobs with low, unstable incomes without employee benefits. Such workers typically accumulate little wealth and savings over their working lives and face a retirement of poverty.⁵⁹⁰
- Increasing antibiotic resistance. The World Health Organization points out that a growing number of infections – such as pneumonia, tuberculosis, gonorrhoea, and salmonellosis – are becoming harder to treat as the antibiotics used to treat them become less effective. Antibiotic resistance occurs naturally, but misuse of antibiotics in humans and animals is accelerating the process. It is one of the biggest threats to global health, food security, and development. It leads to longer hospital stays, higher medical costs and increased mortality.⁵⁹¹ To illustrate, resistance rates to macrolide, an antibiotic used to treat pneumonia, is as high as 90% in parts of Asia; and this has been associated with an increase in child pneumonia cases in China which has spread to Europe.⁵⁹²
- The return of illnesses that had been eradicated. For example, the UK has been polio-free since 2003, with the last wild case detected in 1984. However, a polio virus mutation was detected in sewage system in London in early 2022, with tests indicating that it had been imported from a country where polio was still present.⁵⁹³ In July 2022, a case of polio was reported in New York state, the first in the US since 1993; again, it is believed that the person caught it from someone outside of the US.
- The development and spread of new viruses. For example, the Ebola virus was first discovered in 1976. There was a major outbreak in West Africa in 2014–2016 and in Uganda in 2022.⁵⁹⁴

⁵⁸⁹ Haroon Siddique (2019) UK heart disease fatalities rise for first time in 50 years, *Guardian*, 13 May.

⁵⁹⁰ U.S. Deaths of despair - Not everyone benefits from the ‘longevity economy’, *Pension Policy International*, 14 October 2020; <https://pensionpolicyinternational.com/us-deaths-of-despair-not-everyone-benefits-from-the-longevity-economy/>

⁵⁹¹ Antibiotic resistance, World Health Organization, 5 February 2018; <https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance>

⁵⁹² <https://www.telegraph.co.uk/global-health/science-and-disease/child-pneumonia-europe-france-ireland-denmark-netherlands>

⁵⁹³ <https://www.telegraph.co.uk/news/2022/06/22/polio-back-national-incident-declared-uk-disease-spreads-first>

⁵⁹⁴ https://www.who.int/health-topics/ebola#tab=tab_1

- Long Covid. Michael Fasano (2023)⁵⁹⁵ points out that ‘Most patients totally recover from acute Covid within 3 to 4 weeks after onset of infection. Long Covid has been reported in 10% to 30% of those with Covid-19,⁵⁹⁶ and in some studies, even more. It is more common in women, non-whites, hospitalized patients and those with a chronic obstructive pulmonary disease and/or smoking history. The World Health Organization characterizes Long Covid, or Post Covid-19 Syndrome, as being associated with:
 - Individuals with a history of probable or confirmed SARS-CoV-2 infection (the virus that causes Covid-19) who experience symptoms impacting everyday life, such as fatigue, shortness of breath and cognitive dysfunction; and
 - Symptoms that usually are present 3 months from the onset of acute Covid-19, that last for at least 2 months and can’t be explained by an alternative diagnosis. ... Approximately 25% of Americans with long Covid report significant activity limitations’.⁵⁹⁷
- Covid reinfection risk. There is currently conflicting evidence. On the one hand, Michael Fasano (2023)⁵⁹⁸ considers a number of studies which show that ‘those infected more than once with SARS-CoV-2 have a higher risk of experiencing diseases associated with Long Covid. ... However, the severity of the reinfection related impairments is less than that associated with primary infection’. On the other hand, a study published in *Nature Medicine* by Washington University researchers found that people who caught Covid more than once were twice as likely to die and three times more likely to be hospitalized than people only infected once. They were also likely to experience more damage to their lungs, heart, brain, blood, muscles and digestive system. The study was based on data from 500,000 US veterans.⁵⁹⁹

Yet even here, there have been some potentially positive developments. For example, scientists at the University of Exeter have developed a technique which can be used to assess whether a bacterium is likely to respond to antibiotics. It works by examining whether the fluorescent qualities of the antibiotics are taken up by bacteria. If so, the bacteria glow brighter under the microscope, revealing that the antibiotic has infiltrated the membrane and could be effective. The research could contribute to efforts to reduce prescribing, and also enable the development of more effective antibiotics, to help fight the global threat of antibiotic resistance.⁶⁰⁰

⁵⁹⁵ Michael Fasano (2023) Long COVID and Reinfection Risk, *Fasano eNewsletter*, February.

⁵⁹⁶ Nashville Chest, October 16-19, 2022.

⁵⁹⁷ CDC Survey, September 14-26, 2022.

⁵⁹⁸ Michael Fasano (2023) Long COVID and Reinfection Risk, *Fasano eNewsletter*, February.

⁵⁹⁹ <https://www.telegraph.co.uk/news/2022/11/10/catching-covid-doubles-risk-death>

⁶⁰⁰ Glowing bacteria to help tackle antibiotic resistance, Open Access Government, 3 July 2020; <https://www.openaccessgovernment.org/glowing-bacteria/89771/>

Dr Nir Barzilai argues that ‘Death is inevitable but aging is not’.⁶⁰¹ This is a key message that needs to be taken into account when quantifying longevity risk and projecting healthy life expectancy going forward. There are also clear implications for the PRT market. For example, Club Vita’s Erik Pickett conjectures that ‘If we assume that [GLP-1] treatments could help around a third of the population manage their weight from obesity into the healthy range, life expectancy could increase by around 1-2 years for 50-59 year-olds and 0.33-1.33 years for 60-69 year-olds. This could equate to an increase in liabilities for a pension plan or pension risk transfer portfolio of around 4%. To put this into perspective, in the UK, statins (one of the major success stories in public health over the last 30 years) have been estimated to have increased national life expectancy at age 70 by 2-3 years between 1987 and 2010’.⁶⁰²

Artificial intelligence, machine learning, robotics and quantum computing

There have been a number of significant developments:

- Combining natural-language processing (NLP) and other artificial intelligence (AI) could reveal clinical insights buried in existing medical records and scans.⁶⁰³
- Using AI for many health-related purposes, such as the early detection of heart disease and breast and prostate cancer,⁶⁰⁴ diagnosis of leukemia, reading retinal scans with as much accuracy as experienced junior doctors (using Google’s DeepMind), the use of minimally invasive procedures in hospitals to improve the quality of patient care, correcting faults in the human nervous system (e.g., robotic arms controlled by brain signals replacing lost human arms) and reducing false results in Covid-19 lateral flow tests.⁶⁰⁵
- The development of an AI tool called AlphaFold (by DeepMind) which has predicted the structure of almost (98.5% of) the entire human proteome (the full complement of proteins expressed by an organism).⁶⁰⁶

⁶⁰¹ Amelia Hill (2019) Scientists harness AI to reverse aging in billion-dollar industry, *Guardian*, 21 December; <https://www.theguardian.com/science/2019/dec/21/scientists-harness-ai-to-reverse-ageing-in-billion-dollar-industry>

⁶⁰² <https://www.clubvita.net/us/news-and-insights/vitamins-health-glp-1-obesity-medications-will-they-be-as-big-as-statins-for-life-expectancy>

⁶⁰³ Investment Week (2022) Healthcare is on the cusp of a digital revolution, 30 November.

⁶⁰⁴ <https://www.labmedica.com/molecular-diagnostics/articles/294797129/new-diagnostic-approach-combines-dna-testing-with-ai-analysis-for-coronary-heart-disease-risk-assessment.html>; <https://www.nytimes.com/2023/03/05/technology/artificial-intelligence-breast-cancer-detection.html>; <https://www.labmedica.com/pathology/articles/294796508/ai-powered-prostate-cancer-diagnosis-tool-accurately-identifies-and-classifies-tumors.html>

⁶⁰⁵ Christine Chow (2020) Artificial intelligence in healthcare, Investment Week, 4 December; <https://www.investmentweek.co.uk/feature/4023966/artificial-intelligence-in-healthcare-the-do-no-harm-ethos-must-be-extended-to-its-application-in-the-sector/>. Startups.co.uk Newsletter, 30 June 2019; <https://www.labmedica.com/industry/articles/294787904/artificial-intelligence-ai-in-medical-diagnostics-market-to-reach-usd-386-billion-by-2025.html>; <https://www.labmedica.com/hematology/articles/294789897/artificial-intelligence-helps-diagnose-leukemia.html>; <https://www.labmedica.com/covid-19/articles/294795002/ai-takes-guesswork-out-of-lateral-flow-testing.html>

⁶⁰⁶ <https://www.nature.com/articles/d41586-021-02025-4>

- AI has designed proteins with anti-microbial properties which could be incorporated into new medicines.⁶⁰⁷
- Researchers at Leipzig University are using AI to analyze the genetic structures of pathogens from 10 high-risk viral families that have the potential to mutate and trigger a pandemic. It will then help to develop a new generation of vaccines capable of protecting against the outbreak of a novel pathogen – known as ‘Disease X’.⁶⁰⁸
- Using microchips to repair motor function in human organs. Elon Musk set up Neuralink in 2016 to explore how to connect the human brain to a computer using the N1 microchip. Musk claims the N1 microchip can repair motor function in the paralysed, restore eyesight and hearing and help those suffering from memory loss through dementia and Alzheimer’s. The technology could also allow humans to compete with AI by controlling machines with the power of thought. The N1 microchip is a 4mm square. Each person could have up to 4 implanted in the skull. Attached to the chip are superfine wires. They are placed close to important parts of the brain, recording neuron impulses. The chips connect wirelessly to a device behind the ear containing a Bluetooth radio. This sends signals to control a smartphone or computer.⁶⁰⁹
- The development of a non-invasive blood test to assess the likelihood of someone developing Alzheimer’s up to two decades before any symptoms appear. The test is the result of combining nanotechnology and AI to analyze proteins in the blood for early indicators (biomarkers) of neurodegeneration. Previously, identifying proteins with early neurodegeneration markers was like looking for a needle in a haystack. But the new test involves an ultra-thin silicon chip embedded with nanopores (tiny nanometer-sized holes). A blood sample is placed on the silicon chip that is then inserted into a handheld device which employs an AI algorithm to search through the blood sample for protein markers indicative of early-stage Alzheimer’s.⁶¹⁰
- The launch of the miLab AI-based electro-dynamic blood and cancer diagnostic platform. It performs diagnostic processes, such as staining, digital imaging, and AI analysis, e.g., on cervical cells, thereby contributing to the early diagnosis of cervical cancer, the fourth largest cancer type for women.⁶¹¹
- Gestalt Diagnostics has released the Mitotic Counting AI algorithm which can help to identify the eight types of cancer – cutaneous mast cell tumors, breast cancer, lymphoma, lung cancer, melanoma, neuroendocrine, colon cancer, and bladder carcinoma – across seven scanner models – including Hamamatsu, Leica, 3D Histech and Aperio. Key to the broad applicability of deep learning algorithms

⁶⁰⁷⁶⁰⁷ <https://www.newscientist.com/article/2356597-ai-has-designed-bacteria-killing-proteins-from-scratch-and-they-work/>

⁶⁰⁸ <https://www.telegraph.co.uk/global-health/science-and-disease/scientists-ai-artificial-intelligence-vaccine-disease-x>

⁶⁰⁹ Emin Shinmaz (2020) Could Musk 's microchip really boost brainpower, *Daily Mail*, 29 August.

⁶¹⁰ <https://www.labmedica.com/molecular-diagnostics/articles/294798677/cheap-non-invasive-blood-test-predicts-alzheimers-risk-20-years-ahead-of-symptoms.html>

⁶¹¹ <https://www.labmedica.com/medica-2023/articles/294799318/noul-showcases-ai-driven-blood-and-cancer-diagnostic-platform.html>

is their ability to adapt to new scanners and different types of tissue – a very broad dataset is needed to do this.⁶¹²

- Paige and Microsoft are collaborating to revolutionize cancer diagnosis and treatment by creating the world's largest image-based AI models in the fields of digital pathology and oncology. Building on Paige's Large Foundation Model, which contains around a billion images from half a million pathology slides covering various types of cancer, the new AI model will have billions of parameters and leverage Microsoft's advanced supercomputing capabilities. It aims to capture the full complexities of cancer and is intended to be the cornerstone for future clinical tools and computational biomarkers in oncology and pathology. The model will be accessible to hospitals and labs worldwide via Microsoft's Azure platform. Desney Tan, vice president and managing director of Microsoft Health Futures, said 'Unleashing the power of [generative] AI⁶¹³ is a game changer in advancing healthcare to improve lives'.⁶¹⁴
- PFA, Denmark's largest pension fund, is using an AI model, developed by experts including quantum physicists and data scientists and using only standard data provided by members and 29 data points, to identify scheme members at risk of long-term illness and the measures it has taken – calling in members, discussing their chronic conditions and advising on early and proactive action – has led to a 70% lowering of that risk.⁶¹⁵
- Machine learning (ML) can radically reduce the workload of cell counting for disease diagnosis. Researchers at Benihang University (Beijing, China) have developed the new scheme for training a convolutional neural network (CNN) – a type of ML that mirrors the connection structure of the human visual cortex. The number and type of cells in the blood often play a crucial role in disease diagnosis, but the cell analysis techniques currently used to perform such counting of blood cells – involving the detection and measurement of physical and chemical characteristics of cells suspended in fluid – are expensive and require complex preparations. Worse still, the accuracy of cell analyzer machines is only about 90%.⁶¹⁶
- The use of ML to grow artificial organs, especially to tackle blindness. Researchers from the Moscow Institute of Physics and Technology, Ivannikov Institute for System Programming, and the Harvard Medical School-affiliated Schepens Eye Research Institute have developed a neural network capable of recognizing retinal tissues. Unlike humans, the algorithm achieves this without the need to modify cells, making the method suitable for growing retinal tissue for

⁶¹² <https://www.labmedica.com/pathology/articles/294798826/new-ai-algorithm-for-use-on-eight-types-of-cancer-trained-on-seven-scanner-models.html>

⁶¹³ Generative AI is capable of scanning test results, diagnosing illnesses, and suggesting treatments. It is also able to detect inefficiencies, advance drug discovery (including the generation new molecules), and improve clinical-trial planning and execution.

⁶¹⁴ <https://www.labmedica.com/pathology/articles/294798666/worlds-largest-image-based-ai-models-for-digital-pathology-and-oncology-to-fight-cancer.html>

⁶¹⁵ <https://www.ipe.com/news/pfa-says-ai-model-has-led-to-70-drop-in-long-term-illness-risk/10070534.article>

⁶¹⁶ <https://www.labmedica.com/hematology/articles/294793039/machine-learning-radically-reduces-workload-of-cell-counting-for-disease-diagnosis.html>

developing cell replacement therapies to treat blindness and conducting research into new drugs. The method could be adapted to create other human artificial organs.⁶¹⁷

- The use of ML, matrix factorization, deep learning, and topological data analysis, to improve understanding of the complex relationships between diseases or multimorbidities.⁶¹⁸
- Combining ML, epigenetics, and next-generation sequencing (NGS) in a blood test for multi-cancer early detection⁶¹⁹
- Combining AI and ML, e.g., in a blood test to identify cancer before it is visible or symptomatic.⁶²⁰
- The use of digital technologies, such as predictive analytics, by life companies for product innovation.⁶²¹ Predictive analytics makes use of data mining, predictive modelling and ML to analyze current and historical data in order to make predictions about the future. An example is a joint venture between Longevitytech.fund and Vesttoo to harness the power of AI and ML to forecast and price long-tail risks such as longevity, excess mortality, lapse, as well as Value-in-Force (VIF) monetization and excess mortality Industry Loss Warranties (ILW) and transfer them to the capital markets.⁶²²
- The development of a blood test, called ClarityDX Prostate, to improve the detection of prostate cancer – which affects one-in-six men – and reduces invasive biopsies. The test uses the ClarityDX ML algorithm which takes account of multiple factors, including PSA (prostate-specific antigen) levels to provide a more accurate risk score for aggressive prostate cancer. The test results can then be used to decide if a biopsy is needed.⁶²³
- Scientists at ETH Zurich and the University of Zurich have combined biomedical technology and mechanical engineering to create a robotic system to give more accurate cancer diagnoses by analysing tissue samples in their entirety, an improvement over the traditional approach of slicing tissue samples, examining them for abnormalities under a microscope, and then staining suspect cells. The new approach automates these processes and finally analyses the tissue using 3D imaging software and training algorithms.⁶²⁴
- Combining AI and robotics to improve healthcare for the elderly. For example, Taiwan has created an AI robot which can interact with and accompany elderly when they are outside the hospital. This robot analyses the elderly's medical

⁶¹⁷ Machine learning will help to grow artificial organs, Open Access Government, 7 July 2020; <https://www.openaccessgovernment.org/grow-artificial-organs/89945/>

⁶¹⁸ Abdelaali Hassaine, Gholamreza Salimi-Khorshidi, Dexter Canoy, and Kazem Rahimi (2020) Untangling the complexity of multimorbidity with machine learning, *Mechanisms of Ageing and Development*, Volume 190, September 2020, 111325; <https://doi.org/10.1016/j.mad.2020.111325>

⁶¹⁹ <https://www.labmedica.com/molecular-diagnostics/articles/294793279/index.php>

⁶²⁰ <https://www.labmedica.com/hematology/articles/294791085/blood-test-combines-ai-and-machine-learning-to-detect-cancer-before-it-becomes-visible-or-symptomatic.html>

⁶²¹ Demand for predictive analytics rises among life insurers, *The Actuary*, 26 November 2020.

⁶²² PRNewswire, 7 January 2021.

⁶²³ <https://www.labmedica.com/molecular-diagnostics/articles/294798810/innovative-blood-test-to-revolutionize-prostate-cancer-detection-and-reduce-invasive-biopsies.html>

⁶²⁴ <https://www.labmedica.com/pathology/articles/294799080/index.php>

records, reminds them to take their medication, and measures their blood sugar levels. The robot also helps doctors give more timely diagnosis and monitor patients. It is able to combine the physiological data of patients and upload it to the cloud, where doctors can view it remotely. This allows them to detect any abnormalities and immediately give a diagnosis. AI also helps doctors better communicate with their elderly patients. Most of the elderly in Taiwan speak only Hokkien. But an AI program has been developed that automatically translates Mandarin to Hokkien, and vice versa, to assist doctor-patient communication.⁶²⁵ China has developed similar robots to provide personalized support, companionship and ensure the safety of the elderly.⁶²⁶

- South Korea also has an aging problem, and, as a consequence of having the world's lowest birth rate at 0.7 children per woman, it will become a super-aging society – where more than 20% of the total population is above 65 and older – in 2025. In 2020, in response to the acute shortage of healthcare workers during the pandemic, the internet provider Naver Corporation created the CareCall system, an AI call robot designed to assist public health centres check and report Covid-19 symptoms. This has now developed into CareCall partnerships with local authorities, whereby the robot will call people weekly at the same time to help manage disease and medication, advise on diet and exercise, detect emotional problems, and help prevent lonely deaths. The calls are personalised, last only a few minutes, and the robot is trained to sound as natural as possible and recall details from previous discussions to increase the level of emotional care. At the end of the call, a report is sent to the local authority, with any points of concern followed up by human healthcare professionals. Users report an overall 90% satisfaction rate: some feel comforted by the calls, while others have made lifestyle changes following discussions about eating and exercising. The national government is planning to use AI to monitor high-risk groups by analysing power and water usage patterns to identify any signs of unusual behaviour.⁶²⁷
- Quantum computing is still in the early stage of development, but is likely to revolutionize a number of industries. Whereas classical computers use binary bits of 0s and 1s stored on silicon chips, quantum computers use quantum bits or qubits and subatomic particles like electrons and photons. A qubit can represent 0, 1, or a superposition state of both 0 and 1 simultaneously, where the probability of observing a 0 or 1 depends on the wave functions of the qubit. The advantage of qubits is vastly increased storage capacity compared with bits. To illustrate, 2-bits can store at any one time only one of 00, 01, 10 and 11, while 2-qubits can simultaneously store both 00, 01, 10 and 11 and 00, 01, 10 and 11. Similarly n-bits can only store one value at a time between 0 and 2^n total possible values, while n-qubits can simultaneously store any value at a time between 0 and 2^n total possible values and *every* value 0 and 2^n total possible values. IBM's quantum

⁶²⁵ <https://govinsider.asia/health/how-ai-and-robots-are-caring-for-the-elderly-in-taiwans-ageing-society-dr-jenny-su-ncku/>

⁶²⁶

<https://www.pensionpolicyinternational.com/robot-caregivers-chinas-solution-for-aging-population/>

⁶²⁷ <https://www.telegraph.co.uk/global-health/climate-and-people/south-korea-elderly-care-robots-artificial-intelligence>

computer, Eagle, has 127-qubits. To match the storage capacity of this computer, a classical computer would have to have more bits than there are atoms in the human race. IBM's Summit, the world's fastest supercomputer, is around 158 million times slower than Google's quantum computer. Quantum computers also use the entanglement property whereby two subatomic particles interact so the state of one impacts the state of the other. This is needed to overcome the 'Schrödinger Cat' paradox of quantum superposition whereby a cat in a sealed box is simultaneously alive and dead until the box is opened and the true state of the cat is observed. By analogy, once an attempt is made to read a qubit, the superposition of multiple states collapses and its computing power is lost. Quantum entanglement is used to observe the qubit indirectly by reading its entangled partner and inferring the state of the original qubit without it collapsing from superposition. Quantum computers are designed to process large complex data sets. They can be used in biochemistry to create models of proteins and in medicine to create new drugs without having to go through long trial periods.⁶²⁸

Clearly these developments are going to have a significant effect on diagnosing illnesses and improving health care and, in turn, on projections of future life expectancy.

Despite this, ethical concerns have been raised. For example, a study by Padhan et al. (2023) in the *Cureus Journal of Medical Science on AI and Robotics* recognised the potential benefits of AI algorithms in monitoring the health of the elderly, but argued that there should be robust security measures and clear consent procedures in place to address privacy concerns over the collection and use of personal health data: 'Cloud technologies that allow for real-time data analytics from numerous sources across integrated organizations and data sharing need to be carefully evaluated, information security needs to be maintained, and the threat of cyberattacks needs to be minimised. ...In addition, the issue of autonomy arises when older adults rely heavily on AI and robotic systems, raising questions about decision-making and the potential loss of human connection. ...The employment of robots by older persons may increase the danger of dishonesty, infantilization, and confusion among them as to why their human caretakers are using technology rather than face-to-face consultations'. The study called for guidelines and regulations to ensure responsible use of the technology.⁶²⁹

There have also been growing concerns by industry insiders about the risks of AI becoming smarter than humans. For example, Eliezer Yudkowsky, head of research at the Machine Intelligence Research Institute, gives this stark warning: 'Many researchers steeped in

⁶²⁸ Congressional Research Service (2023) *Quantum Computing*, Report R47685, 7 September, <https://crsreports.congress.gov/product/pdf/R/R47685>; Martin Giles (2019) Explainer: What is a quantum computer?, MIT Technology Review, 29 January, <https://www.technologyreview.com/2019/01/29/66141/what-is-quantum-computing>; Vidar (2021) Google's Quantum Computer Is About 158 Million Times Faster Than the World's Fastest Supercomputer, 28 February, <https://medium.com/predict/googles-quantum-computer-is-about-158-million-times-faster-than-the-world-s-fastest-supercomputer-36df56747f7f>

⁶²⁹ Srikanta Padhan, Avilash Mohapatra, Senthil Kumar Ramasamy, and Sanjana Agrawal (2023) Artificial Intelligence (AI) and Robotics in Elderly Healthcare: Enabling Independence and Quality of Life, *Cureus* 15(8): e42905; doi:10.7759/cureus.42905

these issues, including myself, expect that the most likely result of building a superhumanly smart AI, under anything remotely like the current circumstances, is that literally everyone on Earth will die. ... To visualize a hostile superhuman AI, don't imagine a lifeless book-smart thinker dwelling inside the internet and sending ill-intentioned emails. Visualize an entire alien civilization, thinking at millions of times human speeds, initially confined to computers – in a world of creatures that are, from its perspective, very stupid and very slow. A sufficiently intelligent AI won't stay confined to computers for long. In today's world you can email DNA strings to laboratories that will produce proteins on demand, allowing an AI initially confined to the internet to build artificial life forms or bootstrap straight to postbiological molecular manufacturing'. While some, including Elon Musk, have called for 'all AI labs to immediately pause for at least 6 months the training of AI systems more powerful than GPT-4' since AI presents 'profound risks to society and humanity',⁶³⁰ Yudkowsky argues that pausing is not enough and instead we must 'Shut it all down'.⁶³¹

Implications of global aging for financial markets and economic growth

Aging populations – as a consequence of both declining fertility and mortality – could have a big influence on the future returns and the volatility of returns on the assets in which pension funds and PRT providers invest, in addition to their impact on government spending on pensions and the sustainability of pension systems, as well as on the rate of economic growth.

Long-term real interest rates in developed countries have been falling since the mid-1980s. Before that they averaged around 3% back to the 1950s. They reached 0% in around 2012 and have fallen to as low as -2% in some European countries. The European Systemic Risk Board (2021) explains this new low interest rate environment (LIRE) in terms of:

- demographic developments including rising life expectancy and falling population growth rates (Acemoglu and Johnson (2007), Backus et al. (2014), Aksoy et al. (2019), Ferrero et al. (2019));
- falling (relative) price of investment goods and rising share of intangible investment (Karabarbounis and Neiman (2014), Thwaites (2015));
- slowing pace of technological innovation (Gordon (2016));
- falling marginal product of capital (related to demography and technical progress) (Cochrane (2021));
- rising wealth and income inequality (Summers (2014), Rachel and Summers (2019));
- rising savings rates in developing countries and the consequent increasing demand for assets issued by advanced economies (Bernanke (2005)); and
- declines in the consumption/wealth ratio which predict depressed real rates for an extended period of time (Gourinchas and Rey (2019)).

⁶³⁰ Billy Perrigo (2023) Elon Musk Signs Open Letter Urging AI Labs to Pump the Brakes, *Time*, 29 March; <https://time.com/6266679/musk-ai-open-letter/>

⁶³¹ Eliezer Yudkowsky (2023) Pausing AI Developments Isn't Enough. We Need to Shut it All Down, *Time*, 29 March; <https://time.com/6266923/ai-eliezer-yudkowsky-open-letter-not-enough/>

Summers (2013) describes the LIRE as ‘secular stagnation’ and some expect it to last for an extended period of time (e.g., Blanchard et al. (2014), Gourinchas and Rey (2019) and Kiley (2020)). The European Systemic Risk Board (2021) identifies four key areas of concern in the LIRE:

- the profitability and resilience of banks: as net interest margins have trended downwards, banks have responded by increasing interest-earning assets and shifting the composition of their assets towards riskier market segments – including towards commercial real estate, consumer lending and small and medium-sized enterprises (SMEs);
- the indebtedness and viability of borrowers, as the LIRE facilitates higher leverage and encourages search-for-yield behaviour;
- systemic liquidity risk, as the LIRE have made the financial system more sensitive to market shocks;
- the sustainability of the business models of insurers and pension funds offering longer-term return guarantees, as they experience increasing pressures in the LIRE.⁶³²

Focusing on the demographic developments, Jen (2007)⁶³³ argues that there are four important economic and financial implications:

- The level of real long-term interest rates will be affected by the changing fiscal outlook of countries. Potential economic growth rates vary with these demographic trends. Potential economic growth in countries with high dependency ratios will likely slow.⁶³⁴ Not only will the growth of labour supply slow, but justifications for capital accumulation will be less compelling in an aging country. Further, as the population of a country ages, *ceteris paribus*, the aggregate wage bill may shrink, reducing tax receipts. At the same time, medical expenditures and other healthcare-related spending may crowd out the education expenses needed to enhance the productivity of the shrinking work force.⁶³⁵ The end result is a shrinking tax base

⁶³² See also John Fell, Tuomas Peltonen and Richard Portes (2021) Lower for longer – macroprudential policy issues arising from the low interest rate environment, 2 June;

<https://voxeu.org/article/macprudential-policy-issues-arising-low-interest-rate-environment>

⁶³³ Drawn from Jen (2007) – with updated data. See also Bohl et al. (2016).

⁶³⁴ One study estimated that in Europe, a 1% increase in the old age dependency ratio (of those aged 65+ to those in work) decreased real per capita GDP by 0.4% (A ‘back of the envelope’ evidence on aging and growth in Europe, www.reforming.it, 30 March 2018). Key European countries are attracting headlines like this: ‘Aging Germany Is Running Out of Workers, Putting Europe’s Largest Economy at Risk’; <https://www.pensionpolicyinternational.com/aging-germany-is-running-out-of-workers-putting-europes-largest-economy-at-risk/>. In 2022, the German government announced that it wanted to attract 400,000 qualified workers from abroad each year to tackle both the demographic imbalance and labour shortages in key sectors that risk undermining the recovery from the coronavirus pandemic; <https://www.pensionpolicyinternational.com/germany-wants-to-attract-400000-skilled-workers-from-abroad-each-year/>

⁶³⁵ In theory, investment to enhance total factor productivity could keep output growth high, even with a shrinking population.

and rising budgetary demands. Without changes in the retirement age or female participation in the labour force, what this means is that the levels of real interest rates in countries with aging populations may rise above what could be justified by their potential growth rates, as public borrowing needs grow and the private sector starts to dis-save during retirement, both of which drive up interest rates.

Aksoy et al. (2019) provide empirical evidence from OECD countries which confirm that population aging leads to subdued output growth, higher net savings and lower interest rates. In particular, an increase in the share of the dependent population and a decline in the share of the working age population lead to a statistically significant decline in real interest rates. However, these rates would be even lower without the impact of increased public borrowing and retiree dissaving.

- Yield curves should flatten in countries with aging populations and steepen in countries with younger populations. The shapes of the yield curves may change as well. With the monetary policy of most central banks driven by formal or informal inflation targeting, demographic trends could distort the shapes of the yield curves.

In a country with an aging population (such as the US), in the short term, the Fed would need to have higher policy rates to stabilize inflation as potential growth decelerates. In other words, it should be more sensitive to lingering inflationary pressures at every given level of growth rate of aggregate demand. However, the long-term interest rate should be commensurate with the new, lower, potential growth rate and therefore should be lower, notwithstanding the possibility of a rise in the borrowing cost and retiree dissaving. This implies a flatter yield curve in the US and similar countries with aging populations.

Similar logic suggests that the accelerating potential growth rates in younger countries would tend to steepen their yield curves.

- Aging may affect the preferred structure of financial portfolios. Different generations have different risk preferences. There are two competing theories. On the one hand, it is thought that global aging may raise the equity premium, as aging households become less willing to warehouse risk. As a result, aging could benefit bond markets relative to equity markets. Most academics would agree with this.

However, recent experience in Japan suggests an interesting alternative hypothesis. A fixed retirement age, coupled with ever improving life expectancy, has created a 'longevity risk', whereby retirees can no longer be confident of their ability to defend their lifestyle if they end up living much longer than they expect at the time of their retirement. In the case of Japan, this has led to more risk-taking, not less, as retirees try to enhance their expected investment returns by diversifying away from assets with low credit risk. In contrast to the first hypothesis, this alternative hypothesis suggests that retirees should have a bigger appetite for equities.

- Asynchronous aging patterns in different parts of the world have implications for current account (C/A) imbalances. C/A imbalances are essentially savings-investment gaps.⁶³⁶ If demographic trends drive the savings patterns in countries, then C/A imbalances should also be affected. The permanent income (or life cycle) hypothesis suggests that very 'young' and very 'old' countries tend to dis-save, while those with low dependency ratios should be saving. However, the constellations of the C/A imbalances in the world are not consistent with this pattern.

Jen (2007) continues: 'What this may imply is that, as Japan ages, its savings rate should decline, as retirees start to draw down their savings. This may very well start to happen. With a high C/A surplus position [2.14% of GDP in 2022⁶³⁷], this prospective trend should not pose a problem for Japan. However, the same argument applies to the US, but with a high C/A deficit [3.8% of GDP in 2022⁶³⁸], the US does not seem to have a great deal of scope to dis-save further. [Two other countries with large C/A surpluses (Germany and China)] are themselves facing aging pressures, and therefore downward pressures on savings. The implications for the dollar will be a function of how fast the US savings rate changes relative to that of the rest of the world'.

More recently, Goodhart and Pradhan (2020) argue that 'the underlying forces of demography and globalization will shortly reverse three multi-decade global trends – it will raise inflation and interest rates. ...Deflationary headwinds over the last three decades have been primarily due to an enormous surge in the world's available labour supply, owing to very favourable demographic trends and the entry of China and Eastern Europe into the world's trading system. ...These demographic trends are on the point of reversing sharply, coinciding with a retreat from globalization. The result? Aging can be expected to raise inflation and interest rates, bringing a slew of problems for an over-indebted world economy, but is also anticipated to increase the share of labour [in national income], so that inequality falls'. However, while nominal interest rates might rise, this does not necessarily mean that real interest rates will rise.

There are differing views on whether population aging leads to price volatility in asset markets, which would be the case if, for example, a relatively large old generation attempted to sell its asset holding to a relatively smaller younger generation to finance its retirement. Mankiw and Weil (1989) argue that it does – at least in the housing market. However, Poterba (2001) could find no strong cohort effect. He estimated a flat financial asset profile in old age, indicating that there was little evidence of a mass disposal of assets in old age – at least in the US – and conjectured that this might be for precautionary or bequest motives. Similarly, Börsch-Supan (2006), using an open-economy model, predicts that capital outflows will restrict asset price reductions in the domestic economy, suggesting that open economies can avoid some of the demographic effects that depress

⁶³⁶ This follows from the national income accounting identity: savings – investment = exports – imports (if government expenditure = taxation). If savings are low relative to investment, this will be associated with a current account deficit.

⁶³⁷ <https://www.statista.com/statistics/1171474/japan-current-account-balance-as-share-of-gdp/>;
https://www.theglobaleconomy.com/Japan/current_account/

⁶³⁸ <https://data.worldbank.org/indicator/BN.CAB.XOKA.GD.ZS?locations=US>

saving rates and the rate of return on capital. On the other hand, it is possible that imperfections in international capital and traded goods markets could well contribute to international asset price volatility arising from differential aging across countries.⁶³⁹

The bottom line, according to Jen (2007) is that ‘demographic trends have important economic and financial implications’.

What pension funds need is, as Ferrero et al. (2019, p275) point out: ‘structural reforms and fiscal policies that encourage later retirement and promote innovation and investment in research and development. These policies would also reduce the negative impact of aging on potential output growth, although their effects would materialize only gradually. An acceleration in technological innovation (Brynjolfsson and McAfee, 2014), arising from the unfolding of the “the second machine age”⁶⁴⁰ could offset the impact of adverse demographic developments and raise potential output growth’.

Indeed, Acemoglu and Restrepo (2022) have found evidence that aging, because it creates a shortage of middle-aged workers specializing in manual production tasks, leads to greater industrial automation. Aging is associated with the greater adoption of robots and other automation technologies and that more automation innovation occurs in countries undergoing faster aging. Further, productivity improves relatively in industries that are more amenable to automation.

At the same time, a report by the American Association of Retired Persons found that the 50-year-plus population accounts for a large portion of global GDP and recommends that policies should be implemented that enable older citizens to be as productive as possible. This would require governments and companies to abandon ageist stereotypes and make the kind of investments that harness the opportunities unleashed by increased longevity, such as policies to promote lifetime training and initiatives to boost late-life entrepreneurship. The report looked at the 50-plus population across 79 countries between 2020 and 2050, and predicts that their contribution to global GDP could increase between

⁶³⁹ This is an implication of Borio and Disyatat’s (2015), Ford and Horioka’s (2016, 2017), and Horioka and Ford’s (2017) explanation of two of the so-called macroeconomic puzzles identified by Obstfeld and Rogoff (2000), in particular, the Feldstein-Horioka puzzle and the purchasing power and exchange rate disconnect puzzle. The former puzzle, identified by Feldstein and Horioka (1980), is the high correlation between domestic savings and investment rates when there should be no correlation if capital mobility is perfect. The second puzzle, identified by Meese and Rogoff (1983), is that real exchange rates can deviate from purchasing power parity exchange rates for considerable periods which should not be possible if there was a high degree of mobility in internationally traded goods. However, Borio and Disyatat (2015), Ford and Horioka (2016, 2017) and Horioka and Ford (2017) argue that these are not real puzzles at all. Borio and Disyatat (2015) argue that the puzzles are a consequence of the ‘failure to maintain a clear distinction between net resource flows [i.e., the gap between savings and investment] and financing flows’. Ford and Horioka (2016) make the same point in a different way: ‘financial markets alone cannot achieve net transfers of financial capital and cannot equalize real interest rates across countries – [and this] also helps explain why previous attempts to connect changes in the exchange rate to economic fundamentals have not been successful’. It is clear that, given the slow response of the global economic and financial system to savings, investment and trade imbalances, then differential population aging will add an additional source of asset price volatility.

⁶⁴⁰ ‘The automation of a lot of cognitive tasks that make humans and software-driven machines substitutes, rather than complements’.

2020 and 2050 from \$45 trillion to \$118 trillion. Much of that would be driven by people working longer and continuing to contribute in their 50s, their 60s, and even their 70s, depending on their health.⁶⁴¹

Workers are also taking a more flexible attitude to retirement in some countries. For example, a survey by abrdn for its *Class of 2022* study of 2,000 UK workers due to retire in 2022 found that 66% planned to remain employed in some form compared to 56% in 2021 and 34% in 2020. The survey found that 24% will go part-time with either the same job or a new one, 15% will continue to work for their own business, and 12% plan to become entrepreneurs and start their own business. The main reasons cited for 'flexi-retirement' include needing the income (31%) and wanting to keep busy (32%).⁶⁴²

Climate change and sustainable development

The problem: climate change

The issue of climate change is clearly linked to population size and some scientists have begun to ask whether there are global limits to human habitability. For example, Dr Steven Running, emeritus professor of ecology at the University of Montana and a member of the NASA Earth Observing System, argues that a population cannot grow indefinitely in a finite ecosystem, such as the Earth. He explains: 'Systems ecology theory predicts when resource limits are exceeded, a progressive system feedback of starvation, predation and disease limits uncontrolled population and consumption growth. The global human population has now nearly tripled since 1950, and economic activity increased tenfold, leading many to suggest that humanity is heading toward a population and consumption overshoot and correction this century. The global population, currently at [8]bn people, is projected to rise beyond 10bn by 2100. Future limits become an urgent policy issue when one considers the expansion in living standards aspired to by the underdeveloped world. Is humanity smart enough to anticipate global overshoot, and shift to sustainable policies before these morally unacceptable systems feedbacks take over?'

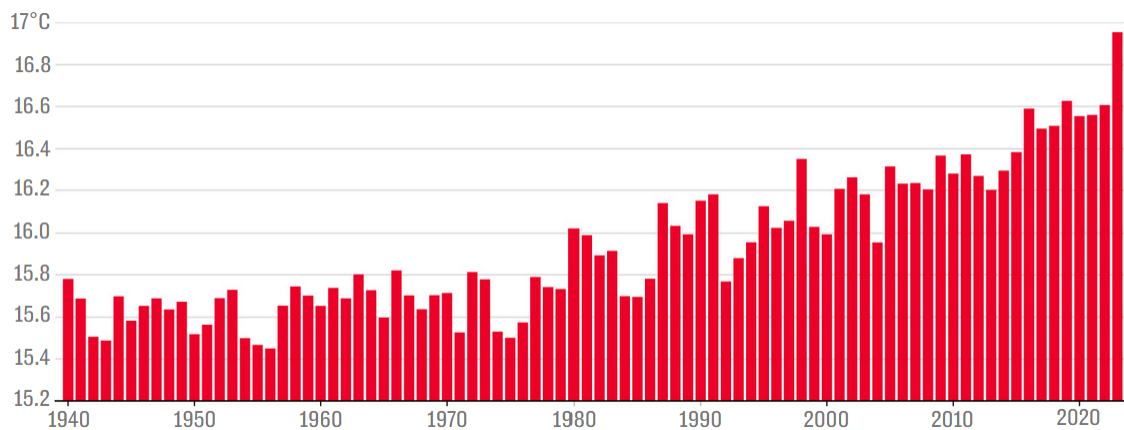
The core metric for quantifying total plant growth is net primary production (NPP), measured in kilograms per hectare of plant biomass. Land-based plants absorb around 30% of the carbon dioxide that human activity adds to the atmosphere. Increasing NPP slows down global warming. NASA has been monitoring global NPP for the last quarter century. Running points out that NPP depends on temperature and water availability: 'rising temperatures increase growing season length, but decrease water availability, and many of the NPP trends identified can be directly attributed to these effects. We showed how significant droughts between 2000 and 2009 caused the reduction in NPP in the Southern Hemisphere. Decreases in cloud cover increased sunlight over tropical areas causing the largest increases in NPP, particularly in the Amazon rainforest. It initially appeared that rising global temperatures were having a positive effect on the growth of plants, potentially increasing their ability to act as a sink for excess carbon dioxide produced by human

⁶⁴¹ <https://www.pensionpolicyinternational.com/why-an-aging-population-doesnt-spell-economic-doom/>

⁶⁴² <https://www.professionaladviser.com/news/4047456/flexi-retirement-trend-emerges-thirds-plan-research>

activity. However, the reduction in NPP from 2000 to 2009 from drought effects raises serious issues. If rising global temperatures reduce plant growth, the ability of vegetation to act as a carbon sink will be reduced, accelerating climate change'. He concludes: 'As the Earth's population continues to increase, and climate continues to change, consistent monitoring of NPP will become an even more essential tool for understanding and mitigating damage caused to the biosphere. It is essential for humanity to not reach catastrophic planetary limits risking collapse. There is no better and available global dataset than NPP, the foundation of food, fibre, biofuel and climate stabilization, for this essential monitor of global habitability'.⁶⁴³

Figure 9: Global surface air temperature, 1940-2023



Sources: C3S/ECMWF; Verity Bowman and Harriet Barber (2023) 'The world has experienced its hottest ever three-month period', *Daily Telegraph*, 13 September; <https://www.telegraph.co.uk/global-health/climate-and-people/climate-change-global-warming-wildfires-drought-floods/>

According to the World Meteorological Organization, hydrological cycles are 'spinning out of balance' and the world will experience an 'increasingly erratic' water cycle as climate change drives new patterns of both extreme flooding and drought. Droughts, extreme rainfall and melting snow and glaciers are threatening long-term water security. Petteri Taalas, WMO secretary-general, said that the overwhelming majority of disasters are water related: 'A warmer atmosphere holds more moisture. We are seeing much heavier precipitation episodes and flooding. And at the opposite extreme, more evaporation, dry soils and more intense droughts'.⁶⁴⁴ Between June-August 2023, the Earth experienced the hottest three-month period on record with an average global temperature of 16.7°C – see Figure 9. In September 2023, António Guterres, secretary-general of the United Nations, said that 'Climate breakdown has begun'. The UN forecasts that by 2050, more than 75%

⁶⁴³ Steven Running (2019) The biosphere: Global limits of human habitability, 30 October; <https://www.openaccessgovernment.org/biosphere-human-habitability/75469/>

⁶⁴⁴ Quoted in Aime Williams (2023) Global water cycles are 'spinning out of balance', weather agency reports, *Financial Times*, 12 October; <https://www.ft.com/content/a8c1b4cb-e7ec-4dd7-9eac-8adc2d874a96>

of the global population could be affected by drought and lack access to water, up from 1.1bn currently.⁶⁴⁵

The World Economic Forum's *Global Risks Report 2019* warned of increasing naturally emerging infectious disease pandemics and risks posed by revolutionary new biotechnologies, claiming that these could be as big a threat as climate change.⁶⁴⁶ And within a year this came to pass.

A study by Carlson et al (2022) asserts that at least 10,000 virus species have the capacity to infect humans, but, at present, the vast majority are circulating silently in wild mammals. However, climate and land use change will produce novel opportunities for viral sharing among previously geographically-isolated species of wildlife. In some cases, this will facilitate zoonotic spillover between species – a mechanistic link between global environmental change and disease emergence. The study uses a phylogeographic model of the mammal-virus network to simulate potential hotspots of future viral sharing and to make projections of geographic range shifts for 3,139 mammal species under climate change and land use scenarios for the year 2070. The model predicts that species will aggregate in new combinations at high elevations, in biodiversity⁶⁴⁷ hotspots, and in areas of high human population density in Asia and Africa, driving the novel cross-species transmission of their viruses an estimated 4,000 times. Because of their unique dispersal capacity, bats account for the majority of novel viral sharing, and are likely to share viruses along evolutionary pathways that will facilitate future emergence in humans. The study also conjectures that this ecological transition may already be under way, and holding warming under 2°C within the century will not reduce future viral sharing. The authors conclude that 'Our findings highlight an urgent need to pair viral surveillance and discovery efforts with biodiversity surveys tracking species' range shifts, especially in tropical regions that harbor the most zoonoses and are experiencing rapid warming'. Vector-borne diseases (which are caused by the bite of infected insects, such as mosquitoes, ticks, and sandflies, which act as carriers or 'vectors') account for more than 17% of all infectious diseases, leading to more than 700,000 deaths annually.⁶⁴⁸

Some scientists predict a new 'pandemic age'. Professor Eddie Holmes, an evolutionary biologist and virologist at the University of Sydney, said: 'Climate change and pandemics go hand-in-hand....The more animals are forced to mix, the more viruses will jump species'.⁶⁴⁹ A current example is the spread of dengue – or 'breakbone fever' because of the intense joint and muscle pain it causes – by mosquitos. It affected nine countries in the

⁶⁴⁵ Quoted in Verity Bowman and Harriet Barber (2023) 'The world has experienced its hottest ever three-month period', *Daily Telegraph*, 13 September; <https://www.telegraph.co.uk/global-health/climate-and-people/climate-change-global-warming-wildfires-drought-floods/>

⁶⁴⁶ <https://cirmagazine.com/cir/epidemic-risks-pose-as-big-a-business-threat-as-climate-change.php>

⁶⁴⁷ Biodiversity refers to the 8.7m varieties of life forms on Earth, such as plants, bacteria, animals and humans; <https://education.nationalgeographic.org/resource/biodiversity/>

⁶⁴⁸ Nicola Oliver (2023) 'The Impacts of Climate Change on Mortality', *Life Risk News*, 8 March; <https://liferisk.news/the-impacts-of-climate-change-on-mortality/>

⁶⁴⁹ <https://www.telegraph.co.uk/global-health/science-and-disease/hotter-sicker-climate-crisis-will-trigger-surge-spillover-events>

1970s, but has spread to more than 100 and affects around 400 million people a year. The main causes are climate change and rapid urbanisation.⁶⁵⁰

Bowman and Barber (2023) point out that: ‘Many [existing] infectious diseases are climate sensitive and global warming is giving them the opportunity to expand their reach, threatening the lives of millions. With flooding, population displacement and overcrowding caused by storms and extreme flooding, waterborne infections – such as cholera, typhoid and hepatitis – are on the rise. Milder winters, warmer summers, and fewer days of frost are also making it easier for disease-carrying mosquitoes to roam beyond their habitats, bringing infections like malaria⁶⁵¹ [and] Zika ...fever closer to countries previously out of their reach’.

Similarly with fungi. The high body temperature of humans has traditionally protected them against fungi, but fungi are beginning to adapt to higher temperatures, making transmission easier. An example is *Candida auris*, a fungus that first appeared in humans in 2009.⁶⁵² A study by Denning (2024) found that four million people have been dying annually from fungal infections, including chronic pulmonary aspergillosis, pneumocystis pneumonia and cryptococcal meningitis. This is nearly double the previous global estimate and means that fungal infections are killing six times more people than malaria and nearly three times as many as tuberculosis.⁶⁵³

A report on climate change and health published in December 2020 by *The Lancet*⁶⁵⁴ estimates that global warming has already caused a 50% increase in heat-related deaths of people older than 65, especially in Japan, China, India and parts of Europe. The main reasons for this are heat stroke, kidney failure (caused by kidneys overworking due to dehydration), and heart failure (caused by an excessive heart rate as the heart pumps more blood to the skin, with a corresponding reduction of blood flow to the brain).⁶⁵⁵ In the US, the report argues that rising temperatures, combined with pollution and wildfires, are endangering the health of Americans, with fatal consequences for many older people. The solution, according to the reports’ authors is to aggressively curb planet-warming gases in the next five years: ‘Climate action is a prescription for health’.

⁶⁵⁰ <https://www.telegraph.co.uk/global-health/science-and-disease/why-singapore-alert-record-breaking-year-disease>

⁶⁵¹ The parasite that causes malaria has a complicated life cycle and is able to avoid detection by the immune system. However, two malaria vaccines for children – one developed by GSK and the other by Oxford University – have recently been approved by the World Health Organization; *Telegraph World*, 3 October 2023.

⁶⁵² Verity Bowman and Harriet Barber (2023) ‘The world has experienced its hottest ever three-month period’, *Daily Telegraph*, 13 September; <https://www.telegraph.co.uk/global-health/climate-and-people/climate-change-global-warming-wildfires-drought-floods/>

⁶⁵³ David W. Denning (2024) Global incidence and mortality of severe fungal disease, *The Lancet Infectious Diseases*; [https://www.thelancet.com/journals/laninf/article/PIIS1473-3099\(23\)00692-8/fulltext](https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(23)00692-8/fulltext)

⁶⁵⁴ Reported in the *New York Times*, 3 December 2020.

⁶⁵⁵ <https://www.telegraph.co.uk/global-health/climate-and-people/climate-change-global-warming-wildfires-drought-floods>

In 2022, the UK Longevity Science Panel published a report (*The Effects of Climate Change on Health in the UK*) assessing the impact of climate change on the UK's health.⁶⁵⁶ The report suggests that climate change will be experienced unevenly across different sections of the UK population, and may deepen health inequalities in physical and mental health in the UK. The most economically deprived and those who are already frail through age or having long-term health conditions will be the most vulnerable to high temperatures and shocks induced by adverse weather events. Compared with many other countries, the report found that the direct impacts of climate change such as heat waves, flooding and the increased spread of vector-borne diseases, are likely to be relatively modest. This is because of the UK's geographic location in the Northern hemisphere and its economic power to adapt houses, workplaces and infrastructure to reduce the negative impact of climate change.

However, the indirect impacts could worsen existing inequalities in health for the following reasons:

- Socio-economic. When economies are stressed the health of the most disadvantaged is disproportionately affected.
- Climate change-related disruptions to global food production and supply chains will reduce food security, particularly for low-income families. Lower socio-economic households are more likely to be exposed to the damage caused by extreme weather events as poverty tends to force people to live in higher risk areas, but they often lack the disposable income to adequately prepare for the hazards associated with climate change. The build quality of certain lower income and private rental homes can make them more vulnerable to severe damage during adverse weather events.
- Gender inequalities. Women are likely to be impacted more by climate effects than men. They are more often the primary caregivers, and these responsibilities can be considered an additional source of stress in times of adversity, particularly when infants and children in their care are threatened directly by displacement or food insecurity.
- Age inequalities. The young and the old are disproportionately affected by climate change compared to working age adults. This is due to differences in physiology, impacts on education, development, exposure, vulnerability to illness, lack of social support, declining health, and disruption to daily activities.
- Mental health. Climate change can negatively impact mental health in two main ways: by causing actual harm to people, family members, homes, livelihoods or culture, or by acting as a threat of harm and source of uncertainty.
- Disruptions to the UK economy, in part caused by climate-induced global economic stresses, are a key indirect pathway through which climate change may adversely impact on population health in the UK.

Climate change can also have a major economic impact on companies and financial markets in the form of supply chain disruptions, reduced worker productivity, damage to

⁶⁵⁶ <https://www.pensionpolicyinternational.com/climate-change-poses-a-threat-to-health-equality-in-the-uk-the-longevity-science-panel-report/>

corporate infrastructure and the communities in which businesses operate. In the US, weather-related disasters, such as wildfires, flooding and drought, cost \$150bn annually, and are happening with increasing frequency, from an annual average of three in the 1980s to 18 in the 2020s.⁶⁵⁷

The solution: sustainable development

In 2015, the United Nations adopted 17 global Sustainable Development Goals (SDGs), including ending poverty, fighting inequality and addressing climate change.⁶⁵⁸

According to Schroders' 2020 *Global Investment Survey*, 'increasingly clients are using the Sustainable Development Goals as a common language' and estimated global ESG (environmental, social, and corporate governance) assets under management in excess of \$1trn.⁶⁵⁹ Investment strategies consistent with SDG include: negative screening (excluding companies based on controversial business practices), socially responsible investing (SRI), thematic (pursuing specific sustainable themes based on a company's operations or sources of revenue) and impact investing (investing in a measurable sustainable outcome in addition to financial returns).⁶⁶⁰

The UK was the first major country to publish a Green Finance Strategy in 2019.⁶⁶¹ It agreed to fund a new Green Finance Institute⁶⁶² with the City of London 'to foster greater cooperation between the public and private sectors, create new opportunities for investors, and strengthen the UK's reputation as a global hub for green finance' and a new Centre for Greening Finance and Investment (CGFI) 'to advise lenders, investors and insurers [in order to] enable them to make environmentally sustainable decisions, and support a greener global economy'.⁶⁶³ In September 2021, the UK government issued its first 'green gilt' to investors in order to finance projects with clearly defined environmental benefits, thereby helping the UK achieve net-zero carbon emissions by 2050. The bond satisfies the International Capital Market Association (ICMA) Green Bond Principles,⁶⁶⁴ a voluntary

⁶⁵⁷ <https://www.pensionpolicyinternational.com/the-largest-u-s-pension-fund-just-rolled-out-a-climate-transition-plan-focused-on-risk-and-opportunity/>

⁶⁵⁸ The Global Goals for Sustainable Development: Goal 1: No Poverty; Goal 2: Zero Hunger; Goal 3: Good Health and Well-being; Goal 4: Quality Education; Goal 5: Gender Equality; Goal 6: Clean Water and Sanitation; Goal 7: Affordable and Clean Energy; Goal 8: Decent Work and Economic Growth; Goal 9: Industry, Innovation and Infrastructure; Goal 10: Reduced Inequality; Goal 11: Sustainable Cities and Communities; Goal 12: Responsible Consumption and Production; Goal 13: Climate Action; Goal 14: Life Below Water; Goal 15: Life on Land; Goal 16: Peace and Justice Strong Institutions; Goal 17: Partnerships to achieve the Goal; <https://www.globalgoals.org>.

⁶⁵⁹ The power of measurement: Schroders approach to sustainability, *funds-europe*, November 2020.

⁶⁶⁰ Five reasons to choose indexing for sustainable, *portfolio institutional*, November 2020.

⁶⁶¹ <https://assets.publishing.service.gov.uk/media/643583fb877741001368d815/mobilising-green-investment-2023-green-finance-strategy.pdf>

⁶⁶² <https://www.greenfinanceinstitute.com/>

⁶⁶³ <https://www.ukri.org/news/10m-research-centre-to-spur-a-greener-global-financial-system/>

⁶⁶⁴ <https://www.icmagroup.org/sustainable-finance/the-principles-guidelines-and-handbooks/green-bond-principles-gbp/>

framework for issuers to follow and which promotes transparency and disclosure to reduce the risk of greenwashing.

The UK government set out 6 categories of expenditure or investment that will be financed by these gilts. Each category is also mapped to appropriate UN Sustainable SDGs:

1. Clean transportation, e.g., zero-emission buses (consistent with the SDG: sustainable cities and communities)
2. Renewable energy, e.g., wind, solar and hydrogen (affordable and clean energy)
3. Energy efficiency, e.g., support schemes for energy efficiency programs for the public, commercial, industrial and residential sectors (including heating, retrofit and insulation) and research and development for new energy efficiency technologies (affordable and clean energy, industry, innovation and infrastructure)
4. Pollution prevention and control, e.g., reduction of air emissions and greenhouse gas control (responsible consumption and production)
5. Living and natural resources, e.g., protection and enhancement of terrestrial and marine biodiversity, ecosystems and natural capital;⁶⁶⁵ sustainable land use and protection, including environmentally sustainable agriculture; environmentally sustainable clean water, water storage and wastewater management initiatives (zero hunger, clean water and sanitation, life below water, and life on land)
6. Climate change adaptation, e.g., flood protection, resilience and other risk mitigation programs (climate action).

In March 2023, the UK government published its 2023 Green Finance Strategy, *Mobilising Green Investment*,⁶⁶⁶ aimed at strengthening the rapidly growing global green finance market, while driving private investment to deliver its energy security, net-zero and environmental objectives.⁶⁶⁷

In December 2019, the EU introduced the European Green Deal⁶⁶⁸ with the aim of greening both the real economy, especially in agriculture, industry and transport, and its financing through the use of sustainable finance. One of key features of the deal is the Sustainable Finance Disclosures Regulation (SFDR) which requires asset managers to publish disclosure statements about which of their products fall into three distinct categories:

- Article 9 funds: those funds that specifically have sustainable goals as their objective (e.g., investing in companies whose goal is to reduce carbon emissions).

⁶⁶⁵ Discussed in more detail below.

⁶⁶⁶ This is the first update since 2019; <https://www.gov.uk/government/publications/green-finance-strategy>

⁶⁶⁷ *XPS Investment Briefing*, September 2021. In September 2021, the European Commission introduced a 'gold standard' for EU 'green bonds' where the proceeds are spent on environmentally friendly activities. The standard came into force in December 2023. European green bonds are aligned with the 'European taxonomy' which specifies the types of green projects that can be funded, making it more difficult for companies to engage in greenwashing; <https://www.ipe.com/news/eu-green-bond-standard-rules-to-enter-into-force-after-council-ok/10069660.article>.

⁶⁶⁸ <https://www.consilium.europa.eu/en/policies/green-deal/>

- Article 8 funds: those funds that promote E or S characteristics, but do not have them as the overarching objective (known as light green funds).
- Article 6 funds: funds that are not promoted as having ESG factors or objectives.

A survey by Morningstar (*SFDR – The First 20 Days*) found that Article 8 and 9 funds accounted for around 21% of total European funds and 25% of total European fund assets.⁶⁶⁹

The main ESG asset classes – which according to S&P Global account for 5% of the total global market – are sustainable investment funds (\$500bn) and ‘green’⁶⁷⁰ or ‘social’⁶⁷¹ bonds (\$500bn). Many of these bonds are issued by inter-governmental organizations (e.g., the EU’s SURE⁶⁷² bonds) or local authorities with high credit ratings and they offer higher yields than conventional sovereign bonds. The bonds are used for socio-economic enhancement (30%), housing (21%), education (20%), essential infrastructure (13%) and healthcare (11%).⁶⁷³

Another key feature is the EU’s Corporate Sustainability Reporting Directive (CSRD) which requires companies to include sustainability-related information in their annual reports that must meet European Sustainability Reporting Standards (ESRS). Investment funds are also required to make disclosures under SFDR which will allow investors to compare investment funds and their sustainability performance. An additional key feature is the European Taxonomy Regulation which requires companies to report on the percentage of their economic activities that are environmentally sustainable.⁶⁷⁴ On 31 July 2023, the European Commission released an initial batch of 12 European Sustainability Reporting Standards (ESRSs) developed by the European Financial Reporting Advisory Group (EFRAG). The EU has adopted a double ‘materiality approach’, implying

⁶⁶⁹ <https://esgclarity.com/sfdr-which-groups-have-the-most-article-8-9-funds/>

⁶⁷⁰ Green bonds (also known as climate bonds or sustainable bonds) are designated fixed-income bonds intended to encourage sustainability and to support climate-related or other types of special environmental projects. More specifically, they finance projects aimed at energy efficiency, pollution prevention, sustainable agriculture, fishery and forestry, the protection of aquatic and terrestrial ecosystems, clean transportation, clean water, and sustainable water management. They also finance the cultivation of environmentally friendly technologies and the mitigation of climate change; <https://www.investopedia.com/terms/g/green-bond.asp>

⁶⁷¹ Social bonds are used to fund projects with positive social outcomes, such as economic development by financing small businesses, affordable housing and transportation, promoting access to education and healthcare in low-income areas, and food supply protection. Traditionally, they have been issued by supnationals and governments. But corporate social bonds are also now being issued by companies wishing to demonstrate their corporate social responsibility to their employees, customers and local communities; <https://inews.co.uk/inews-lifestyle/money/ethical-money/social-bonds-what-how-work-available-who-invest-explained-1012606>

⁶⁷² Support to mitigate Unemployment Risks in an Emergency (SURE); https://commission.europa.eu/strategy-and-policy/eu-budget/eu-borrower-investor-relations/sure_en

⁶⁷³ ESG News, *portfolio institutional*, November 2020 (p26).

⁶⁷⁴ <https://www.sustainable-investment.com/opinion/4077463/european-green-deals-framework>

companies must consider both the impact of a sustainability topic, such as climate, on their activities and the impact of their activities on that topic.⁶⁷⁵

In December 2023, the European Securities and Markets Authority (ESMA), the EU financial regulator, issued guidelines for funds claiming to contribute to sustainability objectives, including the climate transition. Funds with ‘ESG’-related names should allocate at least 80% of their assets in line with their stated strategy, consistent with sustainable investments definitions in Article 2(17) SFDR, and reflecting the expectation investors may have based on the fund’s name. The funds must also abide by exclusions developed for Paris-aligned Benchmarks (PABs), screening out companies involved in controversial weapons and tobacco, as well as those deemed to have breached the UN Global Compact or the OECD Guidelines for Multinational Enterprises. In particular, PABs ban investments in companies that generate more than 1% of revenues from coal and lignite, 10% from oil, or 50% from gas, and in companies that generate more than 50% of their revenues from carbon-intensive electricity. At the same time, ESMA has made allowance for funds marketed as contributing to the climate transition, as well as those pursuing social or governance-related objectives. For funds with ‘transition’-related names, there is a new category with exclusions based on the EU’s Climate Transition Benchmarks, which are less strict than PABs, and allow investments in fossil fuels. ESMA requires such funds, as well as funds with ‘impact’-related names, to demonstrate that their investments ‘are made with the intention to generate positive, measurable social or environmental impact alongside a financial return or are on a clear and measurable path to social or environmental transition’.⁶⁷⁶

In November 2021, COP26, the 26th United Nations Climate Change Conference, took place in Glasgow, Scotland.⁶⁷⁷ The outcome was the Glasgow Climate Pact which:

- Reaffirmed the 2015 Paris Agreement to limit global warming to below 2°C, preferably to 1.5°C, compared with pre-industrial levels and to achieve a climate-neutral (‘net-zero’) world by 2050.⁶⁷⁸ However, it went further and expressed ‘alarm and utmost concern that human activities have caused around 1.1°C of warming to date, that impacts are already being felt in every region, and that carbon budgets consistent with achieving the Paris Agreement temperature goal are now small and being rapidly depleted’.
- Seeks accelerated action to reduce carbon dioxide emissions by 45% in the 2020s, with countries producing stronger national action plans by 2022.
- Agreed to a provision calling for a phase-down of coal power and a phase-out of fossil fuel subsidies.
- Reaffirmed the pledge by developed countries to deliver \$100bn a year for developing countries.

⁶⁷⁵ <https://www.ipe.com/news/eu-sustainability-board-under-pressure-to-finalise-materiality-guidance/10068505.article>

⁶⁷⁶ <https://www.ipe.com/news/eu-watchdog-spells-out-rules-for-transition-labelled-funds/10070714.article>

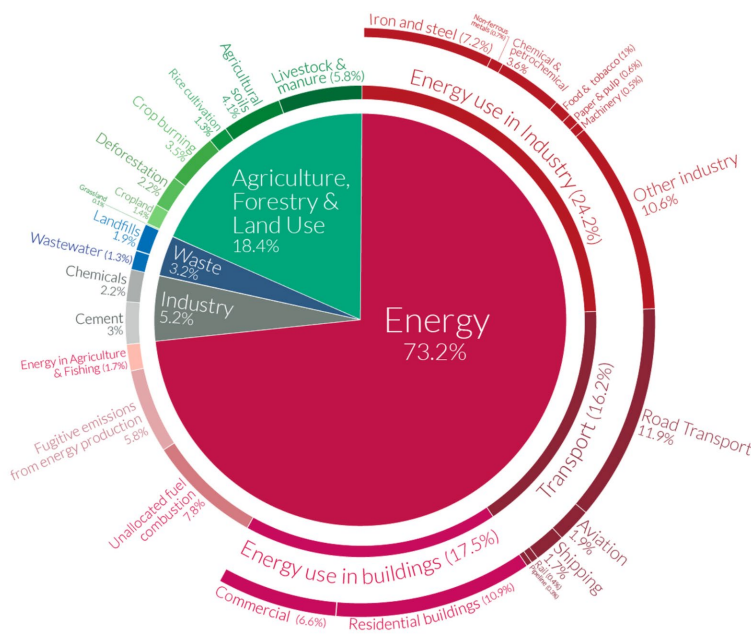
⁶⁷⁷ <https://www.un.org/en/climatechange/cop26>

⁶⁷⁸ <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>

- Called for a doubling of finance to support developing countries in adapting to the impacts of climate change and building resilience.
- Agreed to complete the Paris rulebook, the operational details for the practical implementation of the Paris Agreement. An example is the norms relating to carbon markets, which will allow countries struggling to meet their emissions targets to purchase emissions reductions from other nations that have already exceeded their targets.
- Agreed to strengthen the Santiago Network that connects vulnerable countries with providers of technical assistance, knowledge and resources to address climate risks.
- Agreed new deals on:
 - Halting and reversing forest loss and land degradation by 2030.
 - Limiting methane emissions – one of the most potent greenhouse gases and responsible for a third of current warming from human activities – by 30% by 2030, compared with 2020 levels.
 - Restricting all new car and van sales to be zero-emission vehicles by 2040 globally and 2035 in leading markets, thereby accelerating the decarbonization of road transport, which currently accounts for about 12% of global greenhouse gas emissions.
 - Private financial institutions and central banks realigning trillions of dollars towards achieving global net zero emissions.

Figure 10 shows the sectoral breakdown of global greenhouse gases in 2016.

Figure 10: Global greenhouse gas emissions by sector, 2016



Sources: OurWorldinData.org, Climate Watch, World Resources Institute (2020), <https://www.visualcapitalist.com/a-global-breakdown-of-greenhouse-gas-emissions-by-sector/>

While climate change has been in the news for around 30 years, only in the last few years has it begun to impact the pensions industry. For example, UK listed companies and asset managers, such as pension funds, were required to report on climate change risk by 2022, in line with recommendations made by the Financial Stability Board's Taskforce on Climate-related Financial Disclosures (TCFD).⁶⁷⁹ The UK Pensions Regulator and

⁶⁷⁹ The corporate disclosure recommendations are based on a framework of:

- Governance: the organization's governance around climate-related risks and opportunities.
- Strategy: the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy and financial planning.
- Risk management: the processes used by the organization to identify, assess and manage climate-related risks.
- Metrics and targets: which metrics and targets are used to assess and manage relevant climate-related risks and opportunities.

Pension scheme trustees face similar obligations:

- Governance
 - Trustees must establish and maintain oversight of the climate-related risks and opportunities relevant to the scheme.
 - Trustees must establish and maintain processes to satisfy themselves that any person responsible for the scheme's governance activities takes adequate steps to identify, assess and manage climate-related risks and opportunities.
- Strategy
 - Trustees must, on an ongoing basis, identify climate-related risks and opportunities which they consider will have an effect over the short-, medium- and long-term on the scheme's investment and funding strategy.
 - Assess the impact of the above risks and opportunities.
 - As far as they are able, trustees must undertake scenario analysis, considering the impact on assets and liabilities of two scenarios under which global temperatures rise.
 - One scenario to be consistent with 1.5-2 degrees warming.
 - Analysis is to be carried out in the first year in which the regulations apply, and then every three years thereafter.
- Risk management
 - Trustees must establish and maintain processes for the purpose of enabling them to identify, assess and effectively manage climate-related risks.
- Metrics and targets
 - Trustees must select a minimum of three metrics, two of which are prescribed; one giving total greenhouse gas emissions of the scheme's assets ('absolute emissions metric'), and one giving total carbon dioxide emissions per pound of assets invested ('emissions intensity metric').
 - As far as they are able, trustees must obtain scope 1, scope 2 and scope 3* greenhouse gas emissions data for the scheme's assets, to calculate their metrics and to identify and assess climate related risks and opportunities. (In the first scheme year in which the requirements apply, trustees are not required to collect and report on scope 3 emissions).
 - Trustees must set a target for at least one of the metrics, and subsequently measure performance relative to that target on an annual basis.

*Scope 1: all direct emissions from the activities of an organization or under its control (e.g., business operations).

Scope 2: indirect emissions created from the production of electricity/energy purchased and used by the organization.

Department for Work and Pensions have established the Pensions Climate Risk Industry Group (PCRIG) to produce guidance for pension schemes on ‘climate-related practices’, to ensure they are effectively governed in respect of the effects of climate change. Further, asset managers and other financial services firms are required to report publicly on how they manage climate risks.

Speaking at COP26, Thérèse Coffey, the UK secretary of state for work and pensions, said that ‘pensions can be a superpower that delivers prosperity for people and the planet in our race to net zero’. Her department launched a consultation on proposals to require occupational pension schemes that already fall within the scope of climate disclosure regulations to publish a ‘Paris alignment’ metric to show the extent to which their investment portfolio is aligned with the 1.5°C Paris Agreement. The UK government also published *Greening Finance: A Roadmap to Sustainable Investing* which includes a new economy-wide Sustainability Disclosure Requirement (SDR) which would apply to occupational schemes. This aims to tackle ‘greenwashing’ (where investors are misled about how sustainable an investment is) via the implementation of a Green Taxonomy, which will set out clear criteria for economic activities to meet in order to be considered sustainable. The Pension Schemes Act 2021 introduced new climate reporting obligations on UK schemes, together with annual implementation statements in respect of scheme assets.

The UK Pensions and Lifetime Savings Association (PLSA) which represents pension funds in the UK also supports the TCFD recommendations as well as measures to increase climate reporting and regulatory obligations throughout the investment chain, together with clarifying definitions of climate-aware investment. Related to this is ESG which are the three central factors in measuring the sustainability and societal impact of an investment in a company or business. In the UK, this is implemented via the Stewardship Code. The PLSA wants to work with the investment industry and regulators to develop principles for ESG asset management funds to adhere to on ESG generally, or specifically with regard to climate.⁶⁸⁰

In November 2021, the UK Pensions Regulator published a climate adaptation report into the climate risks most relevant to occupational pension schemes which found that too few

Scope 3: all other indirect emissions from activities of the organization (from sources the organization does not directly control, e.g., supply chain or customer emissions when using a company’s product).

Sources: <https://www.fsb-tcf.org/>; <https://www.willistowerswatson.com/en-GB/Insights/2021/09/reporting-pension-scheme-climate-risks-what-how-when>

The World Resources Institute has now introduced Scope 4 emissions to refer to the emission reductions that occur outside of a value chain or the life cycle of a product, sometimes called avoided emissions, e.g., the energy or emissions that have been saved as a result of the new climate or energy-saving technology associated with a product or service. Scope 4 emissions also include homeworking emissions, e.g., the emissions created to keep utilities on, laptops running, and to maintain central air conditioning or heating systems; <https://greenly.earth/en-gb/blog/company-guide/what-are-scope-4-emissions>.

⁶⁸⁰ Richard Butcher (2020) The PLSA is here to help overcome barriers as industry embraces climate-aware investment, *portfolio institutional*, November.

schemes were giving enough consideration to climate-related risks and opportunities. Only 43% of DC schemes surveyed took account of climate change when devising their investment strategy, while 51% of DB schemes had not spent any time or resources assessing financial risks and opportunities associated with climate change.⁶⁸¹

In 2022, a pension consultant offered this advice to trustees considering a net-zero target:⁶⁸²

- Define your beliefs and priorities
- Set your overall net-zero objective
- Review your current portfolio
- Engage with your investment managers and define a net-zero pathway
- Consider sustainable funds
- Establish ongoing engagement and monitoring.

Charles Counsell, TPR's chief executive, said: 'Climate change is a risk to long-term sustainability [that] pension trustees need to consider when setting and implementing investment strategy, while many schemes are also supported by employers whose financial positions and prospects for growth are dependent on current and future policies and developments in relation to climate change'.⁶⁸³

Ashley Hamilton Claxton, head of responsible investment at Royal London Asset Management, argues that 'ESG is here to stay. Covid-19 has accelerated the trend towards greater awareness of sustainability and the interconnectedness between our economy, environment and society'. However, standards differ in different parts of the world. In the EU, for example, ESG is part of the fiduciary duty of fund managers, whereas in the US, the fiduciary duty is purely a financial duty.⁶⁸⁴

In February 2022, the UK Employer Covenant Practitioners Association (ECPA) published a report which argued that climate change is 'progressively impacting' the covenant of a range of employers sponsoring DB defined benefit schemes, from affecting future cashflows to representing a 'fundamental risk' to scheme longevity. The report said that DB schemes should consider the impacts of climate change through sectoral analysis, including technological evolution, in order to identify 'red flags for their sponsor'. It added that covenant practitioners sit in the middle of the impact on the sponsor and the impact on

⁶⁸¹ Further climate change disclosures in the offing as world leaders meet at COP26, *XPS Insights*, November 2021.

⁶⁸² Carbon Reduction Pathways: How your pension scheme investments can become Net Zero aligned now, *XPS*, July 2022

⁶⁸³ Susanna Rust (2019) UK to explore mandatory climate reporting for pension funds, companies, *IPE*, 2 July; <https://www.ipe.com/uk-to-explore-mandatory-climate-reporting-for-pension-funds-companies/10032058.article>. Susanna Rust (2020) UK pension trustees presented with guide to climate-related risks, *IPE*, 12 March; <https://www.ipe.com/news/uk-pension-trustees-presented-with-guide-to-climate-related-risks/10044243.article>

⁶⁸⁴ Romil Patel (2020) Spinning on a sustainable axis, *funds-europe*, November 2020.

other aspects of the scheme such as funding and investment. They will need to work with an increasing number of stakeholders and face a ‘steep’ regulatory trajectory.⁶⁸⁵

In June 2022, the UK Department for Work and Pensions, in collaboration with the Behavioural Insights Team, Aviva, Smart Pension and Hargreaves Lansdown, launched a ‘green nudge’ trial, designed to encourage pension scheme members to learn more about making greener pension choices. The trial will test the impact of behavioural nudges and messages on increasing saver engagement with the sustainability of pension investments and how it could translate into greener pension decision-making. Around 160,000 pension scheme members will be involved. The DWP said: ‘Through the productive long term investment power of pensions, we can help the UK get to net zero and deliver both investment returns and a sustainable planet’.⁶⁸⁶

In May 2023, UK consultancy LCP introduced a new tool – LCP Beacon – to help pension scheme stakeholders improve their understanding and engagement with sponsor-related climate risks and opportunities to ensure DB pensions are protected. The tool enables trustees to analyse company business plans and forecasts, linking what was promised to a sponsor’s stakeholders around net zero and climate risk mitigation goals and the cost of implementation.⁶⁸⁷

In December 2023, UK consultancy XPS reported that UK pension schemes were still holding assets that were misaligned with the climate transition. It reviewed the Taskforce on Climate-related Financial Disclosures of 35 pension large schemes, with total assets of £344bn. It said that that progress has been made among schemes to manage climate risk, since most schemes had changed their investment mandates to include climate-aware objectives and to finance climate solutions more directly. However, it also said that there was ‘room for improvement’, since most schemes had focused specifically on carbon emissions reduction, leaving other aspects of climate transition underrepresented. XPS estimates that UK pension schemes’ asset holdings have a weighted average of reported Implied Temperature Rise of 2.8°C, whereas the Paris Agreement limits the temperature rise to 1.5°C, explaining XPS’s conclusion that UK pension schemes are currently misaligned with the climate transition. The TCFD also requires schemes to stress test the financial impacts of physical risks in a high global warming scenario every three years. The XPS analysis found that 56% of £5bn+ schemes did not conduct the test in 2023 and many that did said that they did not find meaningful conclusions. In the light of these findings, XPS recommends that: scheme trustees undertake ongoing training to understand the latest TCFD developments, speak to their pension consultants on enhancing their

⁶⁸⁵ <https://www.professionalpensions.com/news/4044614/climate-change-fundamental-risk-scheme-longevity>

⁶⁸⁶ <https://www.pensionpolicyinternational.com/new-uk-trial-seeks-to-nudge-people-into-making-greener-pension-choices/>

⁶⁸⁷ <https://www.ipe.com/news/lcp-sets-up-climate-risk-tool-for-pension-scheme-stakeholders/10066769.article?>

climate strategy, assess the transition alignments across their portfolios, and consider increasing range of funds with embedded climate objectives.⁶⁸⁸

In December 2020, the European Insurance and Occupational Pensions Authority (EIOPA) published a discussion paper on a methodology for including climate change in the Solvency II standard formula when calculating natural catastrophe underwriting risk.⁶⁸⁹ The frequency and severity of natural catastrophes and extreme weather, such as heat waves, heavy precipitation, droughts, top wind speeds and storm surges, is expected to increase due to climate change. EIOPA wants to ensure the financial resilience of (re)insurers covering natural catastrophes, implying that the solvency capital requirements for natural catastrophe underwriting risk need to be appropriate in light of climate change.

In April 2022, EIOPA launched its first stress test of the impact of climate change on European pension scheme investments. It would include not only an assessment of the effects of a rise in inflation, but also a climate risk stress which will test schemes' resilience against a climate change scenario developed with the European Systemic Risk Board and the European Central Bank. The scenario involves a disorderly transition to climate neutrality due to delayed policy action, specifically, that new climate policies are not introduced until 2030 and this leads to an abrupt carbon price increase which affects the entire economy. The stress test will focus on both the impact on pension fund investments and the financial situation of scheme sponsors.⁶⁹⁰

In December 2022, EIOPA reported the findings from this stress test. The test covered 187 pension funds from 18 EU member states with €2trn of assets (65% of total assets in defined benefit and defined contribution schemes). The funds were tested for resilience to a sharp rise in carbon prices caused by a sudden disorderly transition to carbon neutrality resulting from delayed policy actions. The funds held 6% of their share and 10% of their corporate bond investments in carbon intensive industries such as mining, electricity, gas and land transport. The stress test resulted in a fall in asset values of 12.9%. EIOPA concluded that the funds were 'materially exposed' to transition risks.⁶⁹¹

We consider examples of some large pension schemes' climate change considerations that have been publicly reported.

In March 2023, TPT Retirement Solutions, one of the UK's largest workplace pension plans, announced that it had introduced climate change considerations into its investment decisions. Cliff Speed, TPT's chief investment officer, said: 'Climate change has the potential to reduce the security of our members' retirement benefits and represents a

⁶⁸⁸ <https://www.ipe.com/news/uk-schemes-misaligned-with-climate-transition-says-xps-study/10070610.article>

⁶⁸⁹ EIOPA launches discussion paper on a methodology for integrating climate change in the standard formula, *Pensions Policy International*, 4 December 2020; <https://pensionpolicyinternational.com/eiopa-launches-discussion-paper-on-a-methodology-for-integrating-climate-change-in-the-standard-formula>

⁶⁹⁰ <https://www.ipe.com/news/eiopa-launches-climate-risk-focussed-2022-pension-fund-stress-test/10059031.article>

⁶⁹¹ <https://www.pensionpolicyinternational.com/climate-change-could-cost-pension-funds-billions-eu-watchdog-says/>

systemic risk to the long-term value of our investment portfolio. At the same time, the investment required to transition to a net-zero economy presents an opportunity to support the expansion of climate solutions. For us, this means taking an approach to managing our investment risks and opportunities on behalf of our members in line with our fiduciary duty'. In 2016, TPT made its first allocation to renewable energy generation and renewable supporting technologies. It also invested in two additional renewable energy strategies in 2021. It is on the global steering group of the Paris Aligned Investment Initiative, a global forum representing investors with \$34trn in assets aligning their portfolios and activities to the goals of the Paris Agreement.⁶⁹²

A 2024 survey of UK pension funds by AlphaReal, a real assets manager, found that a majority (90%) of pension funds planned to increase their allocation to renewable energy in the next year: 28% reported they would increase their allocations to 21% or more of the portfolios they manage, while 39% said they would increase their allocations to between 16% and 20%.⁶⁹³

In August 2023, a study by Columbia University, the World Bank and the Sustainable Finance Institute examined the portfolios of five of the world's largest pension funds: the Japan Government Pension Investment Fund (GPIF, assets of \$1.5trn), the Norway Government Pension Fund Global (GPFG, \$1.4trn), the Netherlands' Stichting Pensioenfondsen (ABP, \$465bn), the Canada Pension Plan Investment Board (CPPIB, \$420bn), and the New York State Common Retirement Fund (NYSCRF, \$242bn). All invest in renewable energy and all assess the environmental sensitivity of any new investments. GPIF, the world's largest public pension fund, is reducing its holdings of carbon-based companies, invests in two low-carbon-oriented stock indexes, and issues green bonds to raise capital to invest in renewable energy and low-carbon companies. GPFG's revenues come from North Sea oil and gas wells, but it has divested from companies that do not meet its climate or ethical standards. ABP is planning to reduce its portfolio's carbon footprint by 40% by 2025. CPPIB is heavily invested in real estate and infrastructure (which includes the ownership of 295 'green-certified' buildings in 25 countries) and has issued \$109bn in euro-denominated green bonds. NYSCRF has divested from investments in shale oil and gas and has pledged to have a net-zero portfolio by 2040 by investing in its own low-carbon index. With the exceptions of ABP and GPIF, the report noted that the other funds 'fail to define their objectives in numeric terms'.⁶⁹⁴

In December 2023, the California Public Employees' Retirement System (CalPERS), the largest US public pension fund, managing \$446bn, announced plans to invest \$100bn in climate solutions by 2030, as part of its strategy of cutting emissions from its portfolio investments to net zero by 2050, while securing long-term financial returns for its members. CalPERS said it wanted to address the major risks that financial markets and companies face as a result of the changing climate, such as business interruptions and

⁶⁹² <https://www.ipe.com/news/uk-workplace-pension-scheme-plans-investment-in-climate-solutions/10065832.article?>

⁶⁹³ <https://www.pensionpolicyinternational.com/uk-pension-funds-turn-to-renewable-energy-investment/>

⁶⁹⁴ <https://www.pensionpolicyinternational.com/how-5-of-the-worlds-largest-pensions-funds-invest-to-combat-climate-change/>

damage to assets as a result of hurricanes or flooding. It also wanted to participate in the ‘booming new clean economy, creating new markets, and investing in the next batch of winners as this shift continues to accelerate exponentially – and avoiding being left behind with dwindling markets, outmoded business models, and stranded assets’. According to the International Energy Agency, a record \$1.8trn was invested in clean energy in 2023, more than was invested in fossil fuel energy.⁶⁹⁵

However, a survey of 24 US public pension funds conducted for a report called *The Hidden Risk in State Pensions: Analyzing State Pensions’ Responses to the Climate Crisis in Proxy Voting* found that ‘too few state pensions are taking adequate steps to address climate-related financial risks and protect their members’ hard-earned savings, raising serious concerns about their execution of fiduciary duty’.⁶⁹⁶ On the other hand, a study by Kahn et al. (2024) found that ownership and active constructive engagement from US public pension funds were more effective than confrontational tactics, such as voting or shareholder proposals. In particular, they found that companies reduced their greenhouse gas emissions when stock ownership by ‘green’ funds (where the majority of trustees were Democrats or were located in states with a Democratic governor) increased, and did not alter their emissions when ownership by ‘non-green’ funds (e.g., those in Florida or Texas) changed. The authors concluded that widespread disinvestment from companies currently in the fossil fuel business could be misguided and lead to unintended consequences.⁶⁹⁷

In December 2023, the Dutch pension fund Pensioenfond Metaal & Techniek (PMT) announced it had divested from 40 oil and gas companies, but remained invested in nine European companies (Shell, Aker BP ASA, BP, Enbridge, Eni, Equinor, Galp Energia, Neste and OMV) with ‘sufficiently convincing plans’ for the energy transition and carbon reduction. The 40 companies sold did not have sufficiently ambitious and substantiated CO₂ reduction targets to commit to the Paris Agreement goals. Although the retained companies were not currently operating in line with the goals – which applies to the entire global economy – they made progress during the two-year engagement program with the fund and will be continuously monitored to confirm sufficient progress. PMT insists the companies must stop developing new oil fields by 2025, but can continue to develop new gas fields due to the global scarcity of natural gas. PMT’s strategy is to keep talking to polluters and ‘not simply exclude companies or a sector’. This contrast with two other large Dutch pension funds, ABP and PME, which have divested from the entire fossil sector.⁶⁹⁸

We now consider some UN-supported initiatives relating to asset owners, asset managers and insurers.

⁶⁹⁵ <https://www.pensionpolicyinternational.com/the-largest-u-s-pension-fund-just-rolled-out-a-climate-transition-plan-focused-on-risk-and-opportunity/>

⁶⁹⁶ <https://www.pensionpolicyinternational.com/us-too-few-public-pension-funds-address-climate-in-proxy-voting-report/>

⁶⁹⁷ Matthew E. Kahn, John G. Matsusaka and Chong Shu (2024) Measuring the unintended consequences of public pension fund disinvestment from fossil fuel companies, CEPR, 26 January; <https://cepr.org/voxeu/columns/measuring-unintended-consequences-public-pension-fund-disinvestment-fossil-fuel>

⁶⁹⁸ <https://www.pensionpolicyinternational.com/dutch-pension-fund-pmt-sells-most-fossil-fuel-holdings/>

The UN-convened Net-Zero Asset Owner Alliance (NZAOA)⁶⁹⁹ was established in 2019 by Allianz, Caisse des Dépôts, La Caisse de dépôt et placement du Québec (CDPQ), Folksam Group, PensionDanmark and Swiss Re – with Alecta, AMF, CalPERS, Nordea Life and Pension, Storebrand, and Zurich Insurance joining shortly after. Members commit to transitioning investment portfolios to net-zero greenhouse gas emissions by 2050. In May 2021, four UK pension asset owners joined the Alliance – Phoenix Group, L&G, Rothesay and Prudential (UK) – bringing the total membership to 42 and combined assets of \$6.6trn.⁷⁰⁰ By October 2023, assets had grown to \$9.5trn⁷⁰¹ and there were 86 members, of which around 60 were European pension funds and insurers, with new joiners such as Danica Pension, the BT Pension Scheme and AXA.

In November 2023, NZAOA published its engagement expectations for investment managers wanting to win and retain mandates from its members: ‘asset managers must adopt a consistent, transparent, and outcomes-oriented climate engagement strategy, which recognises that climate change poses systemic risks to asset owner portfolio returns. [Such an approach would be] critical for asset managers’ continued ability to win mandates of clients committed to net zero’. Managers were recommended to get climate engagement processes and standards verified or assured. In addition, asset managers would be expected to explain their approach, objectives and deadlines for securing real-world change for each engagement they undertake, as well as ‘transparently share their expectations of issuers and, importantly, their successes and learnings from engagement’.⁷⁰²

The Net Zero Asset Managers initiative (NZAM) was launched in December 2020 – as a formal partner of the UN’s Race to Zero Campaign⁷⁰³ – and aims to galvanize the asset management industry to commit to a goal of net zero emissions.⁷⁰⁴ At the time of COP26, NZAM announced that 35% of their assets under management were being managed in line with net-zero emission targets.⁷⁰⁵ Morningstar reported that in 2021 there were 860 mutual funds and exchange-traded funds (ETFs) with a climate-focused mandate with total assets of \$408bn, double the previous year.⁷⁰⁶ Climate Impact Consistent (CIC) Indices have been introduced for net-zero investors. They weight each company in proportion to its net-zero alignment, as measured through its carbon emissions intensity, its emissions disclosure/quality, its forward-looking emissions targets and their credibility, and its

⁶⁹⁹ <https://www.unepfi.org/net-zero-alliance/>

⁷⁰⁰ <https://www.pensionpolicyinternational.com/uk-pension-asset-owners-join-net-zero-asset-owner-alliance/>

⁷⁰¹ *Insurance Asset Management*, 19 October 2023.

⁷⁰²⁷⁰² <https://www.ipe.com/news/net-zero-engagement-asset-owners-publish-rules-for-managers/10070072.article>

⁷⁰³ <https://unfccc.int/climate-action/race-to-zero-campaign>

⁷⁰⁴ <https://www.netzeroassetmanagers.org/>

⁷⁰⁵ <https://www.ipe.com/news/average-35-of-assets-initially-in-scope-for-net-zero-manager-targets/10056078.article>

⁷⁰⁶ <https://www.investmentweek.co.uk/news/4048291/assets-climate-focused-funds-soar-usd408bn-2021>

revenues from climate solutions.⁷⁰⁷ At the end of 2023, NZAM had 315 members with \$57trn in assets under management.

At the COP26 meeting, BlackRock, a NZAM member, announced that it had raised \$673m in public and private sector money for a new infrastructure fund which would invest in climate-related projects in emerging markets.⁷⁰⁸ The International Energy Agency estimates that investment in energy transition in emerging markets needs to rise to \$1trn a year by 2030 if the world is to reach the net-zero target by 2050.⁷⁰⁹ In 2023, British International Investment (BII), the UK's development finance institution, signed an agreement with ILX, an Amsterdam-based manager of an emerging market private debt fund, to co-finance up to \$500m of debt to support long-term sustainable development in developing and low-income countries in Africa, Asia, and the Caribbean, through investing in sectors, such as renewable energy, infrastructure, financial services, manufacturing and agribusiness.⁷¹⁰ In 2023, there were around 400 private debt impact funds and more than two-thirds were lending to emerging markets. Although the total was only 3% of private credit globally, there was growing recognition of the potential for financial returns that create positive social and environmental outcomes, according to Vincent Lemaitre, head of ESG for private debt at Tikehau Capital.⁷¹¹

However, in December 2022, Vanguard, the world's second largest fund manager, announced: 'After a considerable period of review, we have decided to withdraw from NZAM so that we can provide the clarity our investors desire about the role of index funds and about how we think about material risks, including climate-related risks – and to make clear that Vanguard speaks independently on matters of importance to our investors. [The move] will not affect our commitment to helping our investors navigate the risks that climate change can pose to their long-term returns'.⁷¹² The move followed pressure from some investors and Republican politicians in the US to decrease reliance on ESG criteria when making investments, on the grounds that this negatively impacts the ability of companies such as Vanguard to maximise returns for shareholders, requires disinvestment from fossil fuel at a time when energy security is paramount, and violates anti-trust rules. Index funds face a particular issue since they, by definition, invest in all securities in proportion to their market value and do not discriminate on the basis of the economic activities of the companies issuing those securities. Further, there are no commonly agreed sustainable investment benchmark indices in which index funds could invest. As a result, Vanguard has committed less than 5% of its assets under management with net-zero goals.⁷¹³ Larry Fink, the CEO of BlackRock, the world's largest fund manager which remains a NZAM member, said he has stopped using the term ESG because it had become too politicized and 'entirely weaponised... by the far Left and by the far Right'. Former

⁷⁰⁷ *IPE*, 17 May 2021.

⁷⁰⁸ *Financial News*, 7 March 2022.

⁷⁰⁹ *Financial News*, 7 March 2022.

⁷¹⁰ Lauren Mills (2024) Bridging the SDG funding gap with private debt impact funds, *Impact Investor Guide 2024*.

⁷¹¹ <https://impact-investor.com/bridging-the-sdg-funding-gap-with-private-debt-impact-funds>

⁷¹² <https://www.investmentweek.co.uk/news/4061376/vanguard-quits-net-zero-asset-managers-initiative>

⁷¹³ <https://impact-investor.com/vanguard-exit-unlikely-to-trigger-mass-defections-from-net-zero-initiative/>

DWS executive Desiree Fixler has said: ‘Beyond politics, there are plenty of other factors fuelling the anti-ESG movement. Lacklustre fund performance, too much red tape and greenwashing have left a sour taste. There’s been pervasive greenwashing in the market, and people are fed up with having to pay more for green products which it turns out aren’t very green’.⁷¹⁴

The Net-Zero Insurance Alliance (NZIA), also convened by the UN Environment Programme (UNEP), was launched in 2021 and has developed the foundational concepts and frameworks to support its members as they work towards decarbonizing their insurance and reinsurance underwriting portfolios.⁷¹⁵ However, in 2023, a number of major insurers pulled out of NZIA, including Munich Re, Zurich Insurance, Hannover Re, Swiss Re, SCOR, Allianz and AXA. Political pressure from some US states and the threat of anti-trust claims have caused these companies to leave. John Neal, CEO of Lloyd’s of London, called on NZIA to make its membership rules less prescriptive or risk falling apart. AXA said it would focus on its own sustainability goals.⁷¹⁶

There are also some multi-national initiatives outside the UN’s remit.

One example is the Institutional Investors Group on Climate Change (IIGCC) was established in 2001 as a forum for collaboration between pension funds and asset managers on issues related to climate change.⁷¹⁷ In 2005, it and the Carbon Trust worked with Mercer to develop a guide for pension trustees to support them in understanding and addressing climate risk. In 2012, IIGCC established the Global Investor Coalition (GIC) to collaborate on joint international projects focused on climate policy, corporate engagement and investment practices. In November 2023, it published a ‘users guide’ to defining, measuring and investing in climate solutions, building on its net-zero framework, which requires investors to help decarbonise assets. It estimates that \$120trn of investment will be required by 2050 in order to keep the world below 1.5°C. Danielle Boyd, head of climate strategy implementation at IIGCC, said that: ‘Without a concerted effort to increase investment into climate solutions, the decarbonisation part of that approach is unlikely to happen. But there’s a big gap in what this actually means for investors, so this guidance tries to help investors understand how to identify climate solutions, how to measure their impacts, and how to engage with data providers and companies on these issues’. The guidance discusses climate solutions in public equities and corporate fixed income portfolios, and their role in corporate transition plans. IIGCC plans to provide guidance on other asset classes, such as private equity, real estate infrastructure and sovereign bonds.⁷¹⁸

Another example is a fund manager initiative to establish a standardized method for calculating avoided emissions in commercial environmental projects, such as electric car manufacturing. The initiative is led by Mirova and Robeco, and includes Edmond de

⁷¹⁴ <https://www.fn.london.com/articles/its-time-to-dismantle-this-circus-esg-has-served-its-purpose-say-blackrocks-tariq-fancy-and-dwss-desiree-fixler-20230821>

⁷¹⁵ <https://www.unepfi.org/net-zero-insurance/>

⁷¹⁶ <https://www.reinsurancene.ws/axa-and-allianz-have-announced-their-exit-from-the-nzia/>

⁷¹⁷ <https://www.iigcc.org/>

⁷¹⁸ <https://www.ipe.com/news/iigcc-publishes-investor-guidance-on-climate-solutions/10070079.article>

Rothschild, Natixis CIB, Lombard Odier, Comgest, Man Group, Sienna IM and Caisse des Dépôts. It aims to develop a standardized toolkit to calculate avoided emissions and then to encourage data providers to introduce avoided-emissions (i.e., low-carbon) solutions based on the metrics. The toolkit will also be used by fund managers with exposure to asset classes, such as infrastructure and project financing. Two consultancies, I Care by Bearing Point and Quantis, were appointed in January 2024 to build the database and toolkit. The database will initially at least 80 low-carbon solutions, such as biomass energy, recycled plastic and low-carbon concrete. As an example, the group said if it is relevant to take into account all the resources and the recyclability of components that come into play in the production of an electric vehicle, it is also relevant to understand and measure the carbon emissions that can be avoided by an electric vehicle in a transport sector still very dependent on thermal engines. Lucian Peppelenbos, climate and biodiversity strategist at Robeco, said: ‘Avoided emissions are the missing piece of the puzzle when it comes to facilitating transition finance. At a global level, much more capital needs to go into climate solutions. This metric can help to direct capital flows towards companies that provide the most effective climate solutions’. The toolkit will be ready by early 2025 and fees will be ‘reasonable’ to encourage widespread market use.⁷¹⁹

A further example is the International Organization of Securities Commissions (IOSCO) which cover 95% of the world’s securities markets. In December 2023, it announced that around 130,000 companies world-wide would adopt the sustainability-related financial disclosure standards, across both trading and capital raising, developed by the International Sustainability Standards Board (ISSB) and published in June.⁷²⁰ The ISSB was set up by the International Financial Reporting Standards (IFRS) Foundation during COP26 in 2021 to counter the problem that ESG disclosure was being hindered by differing sets of rules, leading to confusion amongst investors and companies, and hence inaction. Erkki Liikanen, chair of the IFRS trustee board, said: ‘By endorsing the ISSB standards, securities regulators around the world are working to achieve the consistency and comparability of information that capital markets demand’.⁷²¹ However, in contrast to the double materiality approach of the EU, the ISSB has adopted a single materiality approach, where companies report only on the impact of a sustainability topic on their business.

In December 2023, COP28, the 28th United Nations Climate Change Conference, took place in Dubai, United Arab Emirates. The outcome is the UAE Agreement or Consensus, a key component of which is the Global Stocktake, a progress report on climate change measures since the signing of the Paris Agreement in 2015 and what measures are needed to fill the gaps. The UAE Agreement has the following key components:⁷²²

⁷¹⁹ <https://www.funds-europe.com/news/fund-managers-select-consultants-to-create-missing-piece-of-climate-finance-puzzle>; <https://www.responsible-investor.com/investor-backed-avoided-emissions-data-project-kicks-off/>

⁷²⁰ The standards published by the ISSB currently only include climate and sustainability, but the board is considering expanding the disclosures to include human capital and rights.

⁷²¹ <https://www.fnlonon.com/articles/more-than-100000-firms-to-use-new-sustainability-disclosure-standards-says-global-securities-chair-issb-iosco-20230725>

⁷²² This section is drawn from: <https://www.investmentweek.co.uk/news-analysis/4156897/cop28-agreed-climate-summit-dubai>; <https://impact-investor.com/cop28-pledges-aplenty-now-for-the-action>

- The pathway to 1.5°C

The agreement recognizes that to avoid breaching 1.5°C by 2050 requires global greenhouse gas emissions to peak before 2025, followed by deep, rapid and sustained reductions in emissions of 43% (relative to 2019 levels) by the end of 2030, by 60% by 2035, before reaching net-zero carbon dioxide emissions by 2050. Developed nations are expected to take a lead in the ‘transition away’ from fossil fuels and provide technological and financial support to help developing nations follow them. All countries are expected to develop updated national climate plans (called Nationally Determined Contributions (NDCs)) by 2025, taking account of different national circumstances, pathways and approaches.

- The future of fossil fuels

For the first time in a UN climate declaration, the agreement specifically references the need to reduce global reliance on all fossil fuels – coal, gas, and oil – in order to combat climate change, and, in particular, accelerate moves to ‘phase-down unabated coal power’. This is in line with the ‘ratchet’ mechanism in the Paris Agreement which requires countries individually and collectively to continuously increase their efforts to transition away from fossil fuels in order to achieve the 2050 target. There are caveats, however. For example, the final text of the agreement ‘recognises that transitional fuels can play a role in facilitating the energy transition, while ensuring energy security’, which is seen as a concession to fossil fuel-dependent countries and new gas-fired power generation projects. There are also potential loopholes. For example, the call to transition away from fossil fuels exclusively refers to ‘energy systems’, thereby excluding any mention of non-energy uses of fossil fuels, such as plastics and transport.

- Fossil fuel subsidies

The agreement calls for the ‘phasing out inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible’. This follows on from COP26’s recognition of the urgent need to transition public funds away from supporting carbon-intensive industries and towards clean energy solutions. The challenge is significant, however, since global subsidies for fossil fuel consumption exceeded \$1trn in 2022, a record high according to the International Energy Agency. The term ‘inefficient’ has been criticised for being a potential loophole, given its ambiguity.

- Carbon capture, removal, and abatement

The agreement calls on countries to support global efforts to develop carbon capture and storage (CCS), carbon removals and abatement technologies ‘particularly in hard-to-abate sectors’ – although these are not defined.

- Renewables and clean technologies

The agreement calls for support for new targets to triple renewable energy capacity and double the annual rate of energy efficiency improvements by 2030. These are accepted as challenging targets, but are believed to be achievable if supported by strong policy, investment and planning reforms. It also calls for the accelerated use of ‘zero and low emission technologies, including inter alia, renewables, nuclear... and low carbon hydrogen production’ to help reduce greenhouse gas emissions, and for the accelerated reduction in road transport emissions ‘including through development of infrastructure and rapid deployment of zero and low emission vehicles’. There is also strong support for wind, solar, and energy storage systems that aid the transition away from fossil fuels, with the added bonus that their costs ‘have fallen continuously’.

- Methane and non-CO₂ emissions

Methane has a far greater impact on global warming than CO₂. The agreement calls on countries to support global efforts to accelerate and ‘substantially’ reduce non-CO₂ emissions ‘including in particular methane emissions’ by 2030. This implicitly targets oil and gas producing countries and companies whose pipeline leaks and flaring are a key source of global methane emissions. It also calls on agriculture, another major contributor, to reduce methane emissions. Major global dairy companies, such as Danone, Kraft Heinz and Nestle, have committed to reporting on their success in reducing their own methane emissions. The Global Cooling Pledge was agreed by 63 countries at the conference with the aim of reducing other key greenhouse gases, such as HFCs and F-gases which are used in air conditioning and refrigeration.

- Nature, agriculture, and food systems

The agreement also includes text explicitly linking climate and nature, and offered support for the international goals set out in the Global Biodiversity Framework⁷²³ adopted by 188 countries at the UN Biodiversity Conference COP15 in Montreal, Canada, in December 2022, which included protecting 30% of the land and oceans by 2030 and recover 30% of the planet’s degraded ecosystems.⁷²⁴ The text recognises the importance of ‘conserving, protecting and restoring nature and ecosystems towards achieving the Paris Agreement goal, including through enhanced efforts towards halting and reversing deforestation and forest degradation by 2030’. It also emphasises the importance of ‘ensuring social and environmental safeguards’ for nature-based climate solution projects, and invites countries to ‘preserve and restore oceans and coastal ecosystems’ as a key climate mitigation action. However, while recognizing the vulnerability of food production to the negative impacts of climate change and the need to protect, conserve and preserve water systems, there is little reference in the text about how to transform food systems to reduce emissions and end deforestation.

⁷²³ <https://www.cbd.int/gbf/>. Biodiversity is discussed in more detail below.

⁷²⁴ <https://www.cbd.int/conferences/2021-2022>

- International trade

The text says that ‘measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade’. The conference was concerned to avoid countries introducing protectionist measures in the name of climate change mitigation. One potential example of this is the 2022 US Inflation Reduction Act (IRA) which promises billions of dollars of subsidies for clean tech investments, but these could mainly benefit US businesses. Similarly, the EU’s introduction of a Carbon Border Adjustment Mechanism (CBAM) in 2026 is concerning developing economies because it could involve import levies on their goods and services if they fail to meet EU climate regulations and standards. While the agreement did not explicitly oppose CBAMs, it did call for greater ‘transboundary cooperation’ to meet the Paris goals and for a recognition that developing economies ‘have significant capacity constraints’ when trying to decarbonise.

- Circular economy and sustainable lifestyles

The text notes ‘the importance of transitioning to sustainable lifestyles and sustainable patterns of consumption and production in efforts to address climate change, including through circular economy⁷²⁵ approaches, and encourages efforts in this regard’.

- Carbon markets and offsetting

A carbon market trades carbon credits, in which the owners of projects delivering reductions in CO₂ from the atmosphere can sell credits for this which can then be purchased by CO₂ emitters and hence used to offset (i.e., compensate for) those emissions.⁷²⁶ Article 6 of the Paris Agreement covered carbon credit trading between nations and organizations, but the terms have not been formally agreed, and hence the market is still largely an informal one. Indeed, COP28 deferred discussions again until COP29 in Azerbaijan. The main concerns relate to verification and transparency, i.e., ensuring that projects are delivering the promised emission reductions and preventing the issuance of unjustified credits. An example of a current practice that needs to end is ‘double-counting’, where both the selling and purchasing country or organization claim emissions reductions from the same credits. The absence of formally regulated markets reduces to some extent the incentive to invest in carbon offset projects.

- Climate adaptation

The agreement established a new Global Goal on Adaptation, requiring countries to establish climate adaptation plans by 2025 and implement them by 2030, via their updated NDCs. The goals cover issues such as poverty eradication, gender equality, nature-based

⁷²⁵ The circular economy is discussed in more detail below.

⁷²⁶ One carbon credit constitutes the reduction, avoidance or removal of one tonne of carbon dioxide or its carbon dioxide-equivalent (CO₂e). The reduction, avoidance or removal must be permanent, additional to that which was going to happen in any case, and be verifiable. Carbon pricing mechanisms covered around 20% of global emissions in 2023 (*Financial News*, 27 November 2023, Issue 1359, p9).

solutions, climate resilient agriculture and food systems, water security, and reducing climate impacts on health, ecosystems, biodiversity, and human infrastructure. However, there was lack of detail on how this was going to be financed.

- Climate finance, and loss and damage

COP28 agreed to set up a global Loss and Damage Fund, through which vulnerable countries facing climate impact costs could apply for financial support. At the conference, richer countries committed \$792m to the fund. However, the annual cost of losses and damages from climate impacts for developing nations is estimated to be \$400bn.

The agreement also lacked a clear financial program to support countries engaged in energy transition and climate adaptation activities. Many developing countries, including the Alliance of Small Island States (AOSIS), were concerned about the limited progress on climate finance, adaptation, and loss and damage. However, the text of the agreement only requires developed countries to ‘provide such support voluntarily’, although they ‘should take the lead in mobilizing climate finance from a wide variety of sources’ and that this ‘should represent a progression beyond previous efforts’.

The COP27 global climate agreement signed in Egypt in November 2022⁷²⁷ had estimated that the global transition to a low-carbon economy would require annual investments of \$4-6trn, or approximately 4-6% of 2022 global GDP of \$95trn.⁷²⁸ Yet developed countries are still failing to reach an agreed goal to jointly raise \$100bn in climate finance annually.

Kieron Boyle, CEO of the Impact Investing Institute, who attended the summit said that key themes discussed by financial services industry leaders, regulators, and policymakers included the need for more effective capital, greater collaboration among financial market actors, governments and civil society, as well as improved risk-sharing mechanisms between the public and private sectors. Much of the heavy lifting in capital mobilization will need to be via mechanisms such as blended finance and catalytic capital. Funding and guarantees from developed world governments and multilateral development finance institutions to leverage much larger flows of private finance into climate change investments is seen as crucial, especially in low-income countries, where perceptions of high investment risk are blocking private capital flows.

On the opening day of COP28, the UAE announced that it would create a \$30bn climate-related investment fund called Alterra,⁷²⁹ with the aim of attracting \$250bn of investment in carbon emissions reductions and climate resilience projects by 2030. The fund is seeking to make profits from these climate projects, rather than being a development initiative. Launch partners include BlackRock, Brookfield and TPG. The UAE hoped its presence as an investor would be catalytic, giving others the confidence to invest too. A \$5bn component of the total will be used to provide risk mitigation capital to incentivize

⁷²⁷ <https://unfccc.int/cop27>

⁷²⁸ <https://www.statista.com/statistics/268173/countries-with-the-largest-gross-domestic-product-gdp/>

⁷²⁹ <https://www.alterra.ae/>

investment flows into developing countries. One of the first projects will be the development of 6 gigawatts of clean energy capacity in India.

Existing funds received additional funding commitments: the Green Climate Fund⁷³⁰ has pledges totalling \$12.8bn from 31 countries; the Least Developed Countries Fund⁷³¹ and Special Climate Change Fund⁷³² have combined pledges of \$174m; and the Adaptation Fund⁷³³ has pledges of \$188m.

We end this subsection by considering three sustainability issues attracting the attention of pension schemes: biodiversity, natural capital and the circular economy.

Mark Thompson (2023),⁷³⁴ a pension scheme trustee, argues that pension funds should consider biodiversity on their investment strategy:

Biodiversity is the variety of animals, plants, fungi and micro-organisms that make up the natural world. These species and organisms work together in ecosystems to maintain balance and support life. The planet's biodiversity is being seriously depleted, threatening the viability of human existence. Since 1970, the Earth's wildlife populations have fallen by almost 70% – a result of deforestation, excessive human consumption and industrial scale pollution.⁷³⁵ Mother Nature's cupboard cannot be raided forever without serious consequences. ...It is estimated that around half of the world's GDP is dependent on nature.

Against this background, there are four possible risks supporting why trustees should incorporate biodiversity considerations into their investment processes:

- *Companies that rely on threatened ecosystems will suffer from increased financial risk, with negative effects on their share prices and credit ratings.*
- *Like climate change, there is transition risk, as governments legislate to mitigate the systemic risk of biodiversity loss.*
- *Companies that exploit unpriced biodiversity externalities run the risk of reputational risk as media and public opinion turns against them with the resultant impacts on shareholder value.*
- *Finally, schemes are unlikely to reach their climate net-zero objective without significant improvements in biodiversity loss. This is because marine and terrestrial ecosystems are the sole sinks of anthropogenic carbon emissions.*

⁷³⁰ <https://www.greenclimate.fund/>

⁷³¹ <https://www.thegef.org/what-we-do/topics/least-developed-countries-fund-ldcf>

⁷³² <https://www.thegef.org/what-we-do/topics/special-climate-change-fund-sccf>

⁷³³ <https://www.adaptation-fund.org/>

⁷³⁴ Mark Thompson (2023) Biodiversity: What trustees need to know, *portfolio institutional*, 17 January; <https://www.portfolio-institutional.co.uk/opinion/biodiversity-what-trustees-need-to-know/>

⁷³⁵ If the global average temperature rises above 1.5°C, this could constitute a threat to 20-30% of all remaining species.

In December 2022, almost 200 countries signed up to the UN Biodiversity accord.⁷³⁶ The accord commits to halting and reversing biodiversity loss by 2030. Implementation will be key to the accord's success and that will need increased legislation around the globe.

However, in doing this, unlike climate change (which is essentially a case of controlling carbon emissions) biodiversity has many facets, and they are location-specific. This makes constructing a framework to manage biodiversity risks, and develop disclosure requirements, more complicated. This is the challenge the Taskforce on Nature-related Financial Disclosures (TNFD) has taken up. It is sensibly adopting the framework pioneered by the TCFD to build on.

Assets managed by funds focused on biodiversity increased from \$525m to \$1.3bn between 2020 and 2022. However, the Convention on Biological Diversity estimates that to reverse biodiversity losses would require global investment in conservation of \$536bn annually by 2050, while current expenditure is only \$133bn per year.⁷³⁷ In January 2024, 320 organizations across more than 46 countries and representing US\$14trn in assets under management committed to making nature-related disclosures based on TNFD recommendations. These included PwC, EY Global, Candriam, Cardano, Robeco, Van Lanschot Kempen, the UK Local Government Pension Scheme pools Brunel Pensions Partnership and London CIV, UK asset managers such as Fidelity International and Schroders, and the London Stock Exchange Group.⁷³⁸

Natural capital is a new asset class in which land is used to generate an investment return. There are three sub-categories: food production (the traditional use of land), afforestation (for carbon sequestration) and timber (as an alternative to steel and concrete in real estate construction). But with total productive land in scarce supply, there is an increasing competition over these uses.

The outcome in any particular country will depend on the price of carbon generated by the country's emission trading scheme. If demand from companies for carbon offsets increases the price of carbon credits, this makes carbon farming more attractive.

For example, in New Zealand, which is one of the world's highest per-capita carbon emitters (because of its red meat industry), carbon credits are above US\$50 per tonne. This has resulted in prime farmland being sold to forestry investors for NZ\$20,000 per hectare, up from NZ\$4,000 per hectare, reflecting the higher net present value of the cash flows that can now be generated from it. This, in turn, has led to criticism from the red meat industry (Beef + Lamb New Zealand) which is forecasting significant economic damage to the sector and its rural communities.

⁷³⁶ The Global Biodiversity Framework discussed above.

⁷³⁷ CAMRADATA (2023) Biodiversity; <https://s42854.pcdn.co/wp-content/uploads/2023/12/Biodiversity-whitepaper.pdf>

⁷³⁸ <https://www.pensionpolicyinternational.com/uk-pension-funds-to-begin-tnfd-reporting/>

The University of Melbourne's *Land Gap Report*, published in November 2022, has the following warning: 'Governments' over-reliance on carbon removal could push ecosystems, land rights and food security to the brink – with new land area equivalent to 50% of the world's croplands currently being required to meet [climate pledge] targets. Climate pledges should focus on protecting and restoring existing ecosystems with carbon benefits'.

Asset manager Gresham House has produced a Forest Charter, outlining six core pillars for investment managers, which include biodiversity and integration with the community.⁷³⁹ It argues that a long-term sustainable supply of timber is 'enabling the world to transition to a lower carbon, sustainable model, through the continued replacement of concrete and steel as building materials'.⁷⁴⁰

According to Florence Chong (2023): 'Global asset managers now see as a central tenet of their management practices an ability to deliver benefits to surrounding communities in the first instance, then to the wider community. An ongoing emphasis on sustainability, preservation, biodiversity and rehabilitation of degraded land is seen as paramount. They point out that, in the first instance, they are accountable to their investors as to how both carbon credits are generated and the timber products produced. Increasingly, too, they are under no illusion that land is finite, and that their ongoing viability as businesses depends on co-existing with other forms of land use, especially farmland'.⁷⁴¹ Further, investors in natural capital assets will have to take into account both climate mitigation and climate adaptation and understand the physical risks to their portfolios.

A key feature of a sustainable future is the Circular Economy. This has been defined, by Amundi Asset Management, as an economy which 'allows [the production of] sustainable consumer goods, while protecting nature – by giving it time to regenerate – and ensuring the well-being of individuals. There is an urgent need to promote a society in which natural resources are protected, in which nature has the time to regenerate, where consumption is reasoned, where the life of goods is extended to the maximum and where waste is treated to be recycled in new products... We therefore need to move from a linear economic model to a circular economic model that will limit the damage to the environment, giving it time to regenerate by promoting the extension of the life span of produced goods – notably through eco-design, reparability, durability, and the second-hand market. It must also include better treatment of waste allowing raw materials to be reused to create new goods... thus closing the loop'.⁷⁴²

SDG/ESG considerations have begun to impact the investments held by PRT providers in the UK. For example, they are investing in social housing. Not only does this meet one of the SDGs, it also provides a regular income stream to pay pension annuitants from an

⁷³⁹ <https://greshamhouse.com/forest-charter/>

⁷⁴⁰ <https://greshamhouse.com/news-media/global-timber-outlook/>

⁷⁴¹ Florence Chong (2023) Natural capital: food, timber or carbon?, *IPE Real Assets*, January/ February; <https://realassets.ipe.com/forestry-agri/natural-capital-food-timber-or-carbon/10064740.article>

⁷⁴² The wheels of a Circular Economy go round and round, Amundi Asset Management, 26 January 2022; <https://research-center.amundi.com/article/wheels-circular-economy-go-round-and-round>

investment that generates higher returns than UK government bonds. Similarly, in March 2022, the Aon MasterTrust and Aon's Group Personal Pension Plan seeded the UBS Global Equity Climate Transition Fund with £700m. The fund offers cost-efficient and broad-based exposure to global equity markets, providing investors with the ability to mitigate climate-related investment risks while aiming to have a positive effect on society.⁷⁴³ As another example, in July 2022, Railpen, the UK railways pension scheme, and the Alberta Investment Management Corporation (AIMCo) bought a grid-scale battery energy storage platform in the UK from investment firm Constantine for £400m. Railpen said: 'This acquisition marks Railpen's first direct investment into battery storage and reflects our ambition to drive positive change through our portfolio, working with management to develop the critical infrastructure needed to support the UK's transition to net zero'.⁷⁴⁴

The findings in this subsection have implications for life expectancy (including that of pension scheme members), the assets in which pension funds invest, and the risk and return on those assets (including the risk of investing in what become stranded assets). These factors affect both the asset and liability side of pension fund balance sheets and also of insurers buying out pension fund assets and liabilities. There are other global developments that could affect life expectancy – some positively, others negatively.

It is clear from this look into the future that longevity risk is likely to increase going forward – even the direction of the trend change in life expectancy will be more uncertain than it has been in recent decades. In addition, there is likely to be increasing uncertainty about the real level and volatility of the returns on the assets which pension funds and PRT providers need to hold to achieve their objectives. Technological developments and changing retirement patterns will also influence outcomes.

In addition, and despite all these initiatives, a report from the Oxford Sustainable Law Programme by Wetzer et al. (2024) argues that investors are 'flying blind' to the risk of 'increasingly impactful climate litigation and regulatory enforcement actions' that could hit companies with trillions of dollars in damages. The report counted 2,485 climate lawsuits filed globally against large corporate carbon emitters, with Chevron alone liable for up to \$8.5trn if the climate lawsuits it faces are successful. The report recommends five ways for investors and regulators to assess climate-related legal risks: market-impact analysis; analysis using the social cost of carbon; attribution of climate change damages; estimating costs of accelerated climate mitigation, and qualitative analysis of legal, financial and scientific variables to predict legal action and its financial impact.⁷⁴⁵ Further, according to Will Martindale, former head of policy and research at the UN Principles for Responsible Investment, asset owners, such as pension funds, do not have the budget to

⁷⁴³ <https://www.ipe.com/news/aon-mastertrust-pension-plan-seed-ubs-climate-fund/10058957.article>

⁷⁴⁴ <https://realassets.ipe.com/news/railpen-aimco-to-pump-400m-into-uk-battery-energy-storage-projects/10061353.article>

⁷⁴⁵ Thom Wetzer, Rupert Stuart-Smith, and Arjuna Dibley (2024) Climate risk assessments must engage with the law: Legal actions determine the allocation and magnitude of climate-related financial risk exposures, *Science*, 383(6679): 152-154; 10.1126/science.adj0598

meaningfully contribute to asset managers' stewardship efforts, such as policy engagement, in respect of sustainability challenges.⁷⁴⁶

Longevity 17: 2022

As with the previous conferences, *Longevity 17 (L17)* consisted of both academic papers and more practical and policy-oriented presentations. There were four plenary sessions and the following keynote speakers and panellists contributed to these sessions:

- Plenary Session 1: Climate change and longevity risk (video presentation)
 - Nick Spencer (Gordian Advice) presented on 'Expected physical impacts of climate change and impacts on the economy'. There would be physical impacts, e.g., health impacts from prolonged and extreme exposures; it would not just be hotter, there would be more floods, wildfires, hurricanes, cold/freezing weather and sea level rises/storm surges. He quoted Henri de Castries, CEO of AXA speaking in 2015 about the rise in global temperature: 'a 2°C world might be insurable, a 4°C world certainly would not be'. There would also be economic and social impacts: e.g., underperformance by 60% or more for some asset classes by 2060 (for global equities over 70%); a reduction in GDP and wealth will impact healthcare spending as well as healthcare R&D and financing physical adaptations; a significant impact on price and the variability of supply, leading to food nationalism and thus a significant geopolitical issue; and access to, and equality of, nutrition will be reduced.
 - Nicola Oliver (Medical Intelligence) gave a talk entitled 'Habitat destruction, loss of biodiversity and the emergence of zoonotic diseases'. She explained how an infectious disease which can be transmitted from an animal to a human: vector-borne (by living organism), direct contact with bodily fluids of infected animals, indirect contact with contaminated surfaces, food-borne and water-borne. She then discussed what can we do to minimize the risk of future outbreaks and increase the speed of detecting novel pathogens before they spread locally and globally: expand viral discovery and surveillance; monitor wildlife hunting and trade as well as large, high-density animal husbandry for viral infections; and prevent deforestation and other land-use changes associated with agricultural expansion.
 - Melissa Leitner (Swiss Re) asked 'Why do heat and air matter for longevity?'. She explained that increased heat has the following effects on the body: heart – blood pressure falls when blood moves from central organs to the periphery for cooling and the heart beats faster and this can cause fainting, even heart failure; brain – nerve cell malfunction, personality changes, clumsiness, may never fully recover in up to 20% of heatstroke cases; kidneys – control water and salt, lost through sweat, recurrent heat stress and dehydration causes chronic kidney

⁷⁴⁶ Will Martindale (2024) *Responsible Investment: An Insider's Account of What's Working, What's Not and Where Next*, London: Palgrave Macmillan.

disease; and gut – blood moves to the periphery, a lack of oxygen causes inflammation, nausea, vomiting, and flare-ups of inflammatory bowel disease. The most vulnerable are: the elderly, less abled and already infirm; infants, children and pregnant women; outdoor and manual workers; athletes; and the poor, displaced and homeless. She then discussed air quality and the effect of particulate matter (extremely small particles – less than 1/5 of width of a hair or PM10 – that enter via the lungs, are absorbed by blood, and spread within the body) that is released by burning fossil fuels and climate-related wildfires. There are 7m premature deaths p.a. due to air pollution compared with a total of around 60m, and 99% of the global population breathes air below WHO recommended limits. A study of 29 European countries showed that respiratory mortality increased by 0.58% for every 10 µg/m³ increase in PM10. Melissa concluded by asking how will human behaviour and choices change? She believed that there would be a new era of adaptation, with people staying longer indoors and limiting outdoor exercise. There would also be increased ventilation of indoor spaces and increased use of home air filtration systems.

- Plenary Session 2: Pension risk transfers plus new capital introduced from capital markets investors via sidecars ([video presentation](#))
 - Rohit Mathur (Prudential Financial) gave a presentation called '[Prime time for pension risk transfer: Funded status improvements, attractive pricing support a thriving global market place](#)'. He explained how pension de-risking can accelerate enterprise transformations by: decreasing or eliminating future contributions, redirecting cash flows to R&D or M&A, increase focus on restructuring initiatives, increase investor returns compared to pension-heavy peers, and secure the pensions and financial wellness of employees and retirees.
 - Kirsty Maclean (Willkie Farr & Gallagher) discussed the UK government's proposals for '[Solvency II reforms – and the impact on pension risk transfer market](#)'. She said the market was generally happy with the proposed reduction in the Risk Margin, but felt that the benefit could be offset by Matching Adjustment reforms which could increase best estimate liabilities. There would still be an increase in UK investment in more diverse investments which was welcomed, but the suggested 10-15% capital reduction was unlikely to be reached.
 - Amy Kessler (Prudential Financial) chaired a panel session entitled 'When three wheels are better than two: the reinsurance sidecar'. This discussed the growing use of third-party capital in the life and annuity sector. The panel comprised Alex Cochran from Debevoise and Plimpton, and Paul Puleo from Deutsche Bank.
- Plenary Session 3: Challenges and opportunities with longevity risk ([video presentation](#))

- David Lipovics (RGA) gave a presentation on ‘exporting longevity risk transfer (LRT): Challenges and opportunities in new markets’. He opened by describing the size of the global LRT market for defined benefit pension plans. The current active markets are: the UK (\$1.9trn), Netherlands (\$1.5trn), US (\$3.2trn), and Canada (\$1.5trn). But there were potential new markets: Switzerland (\$0.8trn), Germany (\$0.6trn), the Nordics (\$0.3trn) and Japan (\$0.4trn). He then discussed the preconditions for a successful transaction in a new market: catalyst for demand – moving from curiosity to need; data access – enabling necessary research and development; converging expectations especially on future mortality – price points within shooting distance; and the regulatory framework – both for pension risk transfer and associated reinsurance. The appropriate regulatory groundwork both at the consumer level and the insurance carrier level is essential in the emergence of today’s effectively functioning longevity risk transfer markets.
- Chris Pigott (Senior Longevity Actuary, Munich Re) and Jess Elkin (Commercial Longevity Actuary, Munich Re) talked about ‘The nature and development of international longevity swap markets’. They said that the UK market is the best developed for longevity swaps because: credible mortality experience data are widely available and there is an alignment of view between pension schemes and providers on base tables/improvements (e.g. SAPS,⁷⁴⁷ the CMI model) and there are multiple industry base tables. However, other markets with good PRT transactions might struggle to introduce longevity swaps: Netherlands – has limited potential for pension schemes to undertake a longevity swap in current regime, but regulatory change is coming, which could open up the buy-in market; US – pension schemes transact bulk annuities, but not longevity swaps as these are too onerous for the amount of risk hedged, and the regulatory regime means limited drivers to de-risk, but this may change; Canada – the market is developing and expectations are for (some) further growth, and there is a change in pension schemes’ approach/cultural view to analysing longevity risk and mortality improvements. Nevertheless, these markets are ready to de-risk at an acceptable price and there are adequate data available to produce a suitable pricing basis.

Other markets are less attractive: Germany (small market; lack of socioeconomic data; occupational schemes written onto company balance sheet and there is no minimum funding requirement, so no driver to de-risk), Ireland (small market, but recent improvement in pricing which has increased interest from pension schemes and sponsors; basis-setting may be considered easier from the UK as Ireland could be seen as having a similar population), Switzerland (evidence of improvements – but majority of scheme managers/trustees in Aon’s 2019 pension risk survey were comfortable with retaining longevity risk; small market, but one that may open up in the future), France (small market), Australia (lifetime annuities are not popular; often

⁷⁴⁷ <https://www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation/cmi-investigations/self-administered-pension-scheme-saps-mortality-investigation>

people buy term annuities (20 years) at retirement then rely on the state; superannuation is a mandatory DC system established in 1992; DC occupational pensions more common, so low pension risk borne by companies), Chile (small market; unreliable or lack of historic longevity data), and Japan (current pension system relatively new, with the Defined Benefit Occupational Pensions Act introducing DB and DC in 2001; significant longevity risk due to high and growing life expectancy; material DB assets of c\$3.5trn, with \$1trn reported to be represented by annuities in 2016 and Government Investment Pension Fund worth \$1.4trn; corporate pensions often paid as a lump sum at retirement, and increasingly DC-oriented or risk-sharing arrangements).

- Al Klein (Principal and Consulting Actuary, Milliman) gave a presentation on ‘Long Covid’. Long Covid is a wide range of new, returning or ongoing physical and mental health problems people can experience four or more weeks after first getting infected with SARS-CoV-2 (Centers for Disease Control definition). There is no laboratory test that can definitively distinguish Long Covid, most likely because Long Covid is more than one disease. Symptoms include fatigue, cognitive and mental health issues, such as brain fog, headaches, muscle pain, joint pain, cough, fever, breathing issues, gastro issues, and loss of taste or smell. Key factors associated with future Long Covid symptoms: level of coronavirus RNA in person’s blood; presence of certain autoantibodies, i.e., antibodies that attack the body; reactivation of Epstein-Barr virus; and having type 2 diabetes. Multiple early factors anticipate post-acute Covid-19 sequelae. Those most at risk: female, ethnic minority, socioeconomic deprivation, smoking, obesity, multiple comorbidities, treated with mechanical ventilation, and inflammation.

There is no standard treatment yet, and probably there will never be one treatment because of diversity of issues, e.g., some have blood clots and a suppressed immune system, while others have an out-of-control immune system. Some treatments have been tried: non-invasive brain stimulation (NIBS), alternating microcurrents to improve cognitive/visual deficits; rehabilitation to help the brain rewire itself by using errorless learning; anti-coagulants to help with the blood clots in children; breathing exercises, physical therapy, medications; and antihistamines and cytokine blockers to address inflammation, antacids, beta blockers, and anti-clotting agents. Prospective treatments in development include: a drug to reduce inflammation and restore mitochondria function; a drug for lung tissue damage; a combination of friendly bacteria to help ease gut symptoms and improve overall wellbeing; and the use of antivirals to try to remove the RNA virus that remains in the gut of those with Long Covid.

Al concluded by saying that while much is still unknown, much has been learned. Long Covid is complex and not one disease. Long Covid mostly affects ages 30-59, females, and those with multiple comorbidities. We need to look beyond outward symptoms to find underlying cause to be able to treat it.

Someone with Long Covid should have a doctor determine what is causing their symptoms, e.g., blood clots or an out-of-control immune system. These involve a completely different approach to treatment. Long Covid, like Covid itself, is both undercounted and overcounted.

- David Blake chaired a panel entitled ‘Large pension funds’ perspective on longevity risk and its management’ and interviewed Guy Coughlan (Universities Superannuation Scheme) and Holly Copley (British Airways Pension Fund).
- Plenary Session 4: The development of an exchange market for longevity risk – The time is now ([video presentation](#))
- Avery Michaelson (Longitude Exchange, LE) discussed ‘[The new longevity risk marketplace](#)’. He began by pointing out that there is an enormous amount of longevity-linked liabilities in public and private pension and annuity markets. The magnitude of the risk dwarfs the capacity of traditional providers (insurers and reinsurers) and capital markets investors must get involved. This will only happen if longevity transactions become index-based. Index transactions: streamline hedging and investing in longevity risk; lower barriers; bring in more participants and lead to better pricing.

There are pros and cons. The pros: no data requirements, so easy to price and calculate transaction cash-flows; more capital market participation improves pricing and capacity; standardization leads to liquidity and a secondary market; and customization of risk is possible by transacting the desired risk layer, possibly via a CDO/CLO-type approach. The cons: does not provide full indemnification, so there is basis risk, but it can be quantified and managed; there is no regulatory framework for basis risk so far and this would need to be placed in a capital (e.g., Solvency II-type) framework; not all markets have good indices, but the main markets do; and there is counterparty risk, but LE has set up a central counterparty with collateral.⁷⁴⁸ While index transactions are not the current standard, the market can evolve and reinsurers are seeking additional capacity.

Longevity risk hedging demand comes from:

- Pension funds: pension plans preparing to do a buy-out in the coming years can insulate against price increases due to longevity improvement; and while not all pension plans are suitable for a buy-out (e.g., public plans), longevity risk hedging still makes sense in a risk management framework.
- Buy-out insurers: want to diversify sources of longevity capacity, since many insurers have executed billions of dollars of hedges with the same few

⁷⁴⁸ See section ‘2022’ above.

reinsurers, presenting a concentrated credit risk exposure; and will get a lower overall cost of longevity protection by utilizing both index-based and indemnity protections than just executing longevity swaps.

- Life reinsurers: after a decade of writing longevity swaps, many reinsurers' life books are relatively balanced between longevity and mortality, so they currently lack any longevity offtake; and reinsurers are currently at the end of the value chain for longevity risk and seek a way to hedge to continue writing significant new business.

Sources of longevity risk taking capacity:

- Capital markets: longevity risk is uncorrelated from other capital markets investments and can increase the Sharpe ratio through uncorrelated, attractive risk-adjusted returns; index transactions have lower analytical requirements which can be reused on any trade referencing the same underlying data, allowing the deployment of significant capital, while limiting analytical resource needs.
- Life insurers: face negatively correlated exposure to mortality risk and most have more mortality risk than longevity risk, so adding additional longevity risk exposure can balance risks with limited capital requirements; index transactions do not require underwriting expertise by referencing public data sets, so insurers do not need to consider the idiosyncrasies of the underlying pensioner pool.
- Life reinsurers: life reinsurers already have expertise in longevity risk, so index-based transaction are an easy way to add exposure; reinsurers may offer indemnity swaps in only one country, while index trades can bring country diversification with less underwriting basis, so index transactions can diversify across countries

Longevity risk is the largest asset class that does not exist. To date, the hedging market is dominated by a few large reinsurers whose capacity is insufficient to meet the long-term demand, globally. There has been limited capital markets participation. Accessing this capacity is the only way to fulfil the longevity risk markets potential.

The current market has: insufficient long-term capacity, low capital markets participation, limited flexibility on structures, and high costs and timelines. An improved market would: provide an abundance of well-priced capacity, allow the broad involvement by investors, make hedge optimization possible, and be efficient and liquid. In short, the market lacks a marketplace.

- Douglas Anderson (Club Vita) gave a presentation on ‘Why capacity constraints in the insurance industry are leading to the introduction of an exchange market’.
- Steven Baxter (Club Vita) gave a presentation called ‘What does hedge effectiveness mean and the importance of scenario analysis for the development of the exchange market’.
- The session closed with a panel discussion with David Burton (EY), Daniel Ryan (COIOS Health) and Uzma Nazir (Pension Insurance Corporation) chaired by Douglas Anderson.

The academic papers that were selected by us as the editors of this Special Issue went through a refereeing process subject to the usual high standards of the Geneva Papers on Risk and Insurance. They cover the following themes: longevity-linked products, such variable lifetime retirement income solutions and equity release mortgages; health inequalities; socioeconomic mortality indices; reserving for longevity risk using frailty-based mortality models; mortality forecasting with machine learning and neural networks; and life expectancy, health and long-term care in Taiwan. We briefly discuss each of the 9 papers selected.

In ‘A Sustainable, Variable Lifetime Retirement Income Solution for the Chilean Pension System’, Olga M. Fuentes, Richard K. Fullmer, and Manuel García-Huitrón argue that defined contribution retirement pension systems need to improve the level and stability of payments as pensioners age. Longevity risk pooling is key, but so is flexibility to satisfy members' individual needs and preferences. The authors propose a tontine construct as a flexible and cost-effective investment option for the Chilean pension system. Payouts are for life, but variable since there are no explicit guarantees. The authors' proposal provides transparency, investment flexibility, and higher expected income streams than any of the existing options available to the country's pensioners. Importantly, it does not distort the existing investment and annuity markets; on the contrary, it complements them. Additionally, it provides a means to offer a form of longevity insurance even if insurers are unwilling to supply it. Furthermore, it is in line with the movement of many countries toward promoting longevity-risk sharing within their defined-contribution systems.

In ‘How Suitable are Equity Release Mortgages as Investments for Pension Funds?’, Dean Buckner, Kevin Dowd and Hardy Hulley examine the claim that equity release mortgages, the UK equivalent of reverse mortgages in the United States, are suitable investments for pension funds. They present valuation, stress test and scenario analysis results that suggest that equity release mortgages are unsuitable for pension funds because: (i) they bear returns that are typically below the risk-free rate; (ii) they are not hedges for annuity books, let alone good hedges; and (iii) they are heavily exposed to house price risk, which annuity books are not. Their results suggest that equity release mortgages meet none of these criteria to be suitable for pension funds and are almost entirely dominated by risk-free government bonds. They end by offering an explanation for why investors appear to be unaware of the low returns on equity release mortgages.

In ‘The Great Health Challenge – Levelling Up in the UK’, Les Mayhew, Mei Sum Chan, Andrew J.G. Cairns, argue that around the world there are persistent and growing health inequalities both between and within countries. The UK government's flagship policy for addressing inequalities is called ‘Levelling Up’. One of its missions is to narrow the gap in healthy life expectancy (HLE) between the healthiest and unhealthiest areas in England and to improve overall HLE by 5 years by 2035. The authors show that smoking is one of the major causes of health inequalities. They find a 17-year difference in HLE between local authorities, and that the number of years spent in ill-health tended to be greatest in areas with the highest mortality from smoking related disease. The aim of the paper is to see if the 5-year target could be achieved, assuming there were drastic controls on the sale and consumption of tobacco. The authors show that never-smokers enjoy 6 more years of good health at age 20 than current or ex-smokers. A complete ban on smoking would lead to a 2.5-year improvement in HLE, and also lengthen the working lives of both men and women. The authors conclude that while a complete tobacco ban is significant, other public health measures are needed for the full achievement of the target. The paper briefly considers wider issues and suggestions for further research and its international significance.

In ‘Bringing Parametric Mortality Indexes to Practice: A Generalized CBD Model with Stochastic Socioeconomic Differentials in Mortality Improvements’, Kenneth Q. Zhou, Johnny S.-H. Li and Pintao Lyu recall that the concept of CBD mortality indexes was proposed in 2014. Further, they note that, while it has been shown that the use of CBD mortality indexes can effectively reduce longevity risk exposures in idealized settings, the risk mitigation potential of such indexes in a more realistic environment, whereby, for example, population basis risk exists, is yet to be investigated. This research gap is addressed in this paper through the development of a generalized CBD model with stochastic socioeconomic differentials in mortality improvements. The proposed model incorporates possible co-integration effects between mortality dynamics of socioeconomic subgroups and the general population, and features a form of coherence that is less restrictive than the typically assumed full coherence. The paper then conducts various numerical experiments to demonstrate the possible bias in hedge effectiveness that may result if the key features of the proposed model are altered.

In ‘Frailty-Based Mortality Models for Reserving for Longevity Risk’, Maria Carannante, Valeria D’Amato, Massimiliano Menzietti, and Steven Haberman argue that, for the life insurance industry and for pension schemes, mortality projections represent a critical issue for accurately managing their exposure to longevity risk. Frailty shows a significant role in the future evolution of mortality, having been identified as the main latent factor explaining this component, mainly due to comorbidities determining deterioration in terms of the human body’s physiological capacity. In this paper, the authors analyse the gap between the actuarial evaluations on premiums and technical provisions calculated under the frailty-based mortality approach and traditional stochastic mortality models that depend on the size of the shock on mortality on some life insurance products. They observe that the former grasp higher riskiness due to the presence of comorbidities. Accordingly, they obtain some noteworthy policy-oriented recommendations: encompassing frailty in

mortality modelling allows to the profiling of mortality according to the portfolio in force for the insurer, by avoiding the problem of adverse selection.

In ‘Machine Learning in Long-term Mortality Forecasting’, Yang Qiao, Chou-Wen Wang and Zhu Wenjun propose a new machine learning-based framework for long-term mortality forecasting. Based on the ideas of neighbouring prediction, model ensembling, and tree boosting, the authors show that this framework can significantly improve the prediction accuracy of long-term mortality. In addition, the proposed framework addresses the challenge of a shrinking pattern in long-term forecasting with information from neighbouring ages and cohorts. An extensive empirical analysis is conducted using various countries and regions in the Human Mortality Database. Results show that this framework reduces the mean absolute percentage error (MAPE) of the 20-year forecasts by almost 50% compared to classic stochastic mortality models, and it also outperforms deep learning-based benchmarks. Moreover, including mortality data from multiple populations can further enhance the long-term prediction performance of this framework.

In ‘Mortality Improvement Neural Network Model with Autoregressive Effect’, Hung-Tsung Hsiao, Chou-Wen Wang, I-Chien Liu, and Ko-Lun Kung propose a neural network (NN) architecture for a mortality improvement model with a cohort effect. They then extend the mortality improvement NN model to consider the autoregressive effect which allows the mortality improvement to depend on the lagged mortality rates. The advantage of their NN model setup is that the parameters of the period and cohort effects are implicitly estimated by the NN models and hence the mortality projection can be obtained without taking the extra steps of selecting and estimating a suitable time-series model for the period and cohort effects. This empirical results suggests that, based on 48 populations in Human Mortality Database with complete set of observations from 1950 with the age span of 55 to 90, the NN models with cohort and autoregressive effects improve the forecast accuracy of mortality rate projections and provide better predictive performance.

In ‘A Spatial Analysis of Health and Longevity of Taiwan People’, Jack C Yue, Ming-Huei Tu, and Yin-Yee Leong point out that Taiwan’s National Health Insurance (NHI) program, introduced in 1995, now covers over 99.6% of its residents, ensuring widespread medical access. Despite this, regional disparities in medical resource allocation persist. This study investigates the potential urban-rural divide in life expectancy and healthcare utilization. Drawing data from the Ministry of the Interior (population registration records), NHI Research Database (medical utilization), and Ministry of Health and Welfare (leading causes of death), the authors employ spatial analysis, visualization tools, and the standardized mortality ratio for assessing regional disparities. Their findings reveal distinct regional mortality differences in Taiwan, with lower rates in northern counties and higher in mountainous regions. However, healthcare utilization shows no significant regional variations. Notably, patterns of overall mortality rates and primary death causes demonstrate spatial clustering.

Finally, in ‘Using the Taiwan National Health Insurance Database to Explore the Need for Long-term Care’, Jack C. Yue, Hsin-Chung Wang, and Yizhen Liou argue that several factors contribute to the lack of LTC insurance in Taiwan, and insufficient experience data

and absence of unified definitions of LTC are two of them. In this study, the authors use LTC-related catastrophic illness (CI) as the assessment criteria to investigate the demand of LTC insurance. They selected 13 categories of CI and explored the spatial-temporal properties of LTC incidence rates and mortality rates from the National Health Insurance Research Database. The study results show that the incidence rates did not change much, while mortality rates decreased significantly. Taiwan's LTC population, which was 0.29 million in 2013, is accordingly expected to triple before 2040 based on the proposed Cohort Change Ratio (CCR) approach. Currently, Taiwan's government has planned to fund LTC insurance via a pay-as-you-go system. Furthermore, the increasing LTC population indicates that commercial insurance can play a vital role as a supplement to social LTC insurance.

Longevity 18 took place on 7-8 September 2023 at Bayes Business School in London; the *European Actuarial Journal* will publish a special issue. *Longevity 19* will be in Amsterdam on 16-17 September 2024; *Insurance: Mathematics & Economics* will publish a special issue. *Longevity 20* and *Longevity 21* are planned for Singapore and Rome in 2025 and 2026, respectively.

References

- Acemoglu, D., and Johnson, S. (2007) 'Disease and Development: The Effect of Life Expectancy on Economic Growth', *Journal of Political Economy*, 115(6): 925-985.
- Acemoglu, D., and Restrepo, P. (2022) 'Demographics and Automation', *Review of Economic Studies*, 89(1): 1-44.
- Agarwal, A., Ewald, C. O., and Wang, Y. (2023) 'Hedging Longevity Risk in Defined Contribution Pension Schemes', *Computational Management Science*, 20(1): 1-34.
- Ai, J., Brockett, P.L., Golden, L.L, and Zhu, W. (2017) 'Health State Transitions and Longevity Effects on Retirees' Optimal Annuitization', *Journal of Risk and Insurance*, 84(S1): 319-343.
- Ai, J., Brockett, P. L., and Jacobson, A. F. (2015) 'A New Defined Benefit Pension Risk Measurement Methodology', *Insurance: Mathematics and Economics*, 63: 40-51.
- Aksoy, Y., Basso, H. S., Smith, R. P., and Grasl, T. (2019) 'Demographic Structure and Macroeconomic Trends', *American Economic Journal: Macroeconomics*, 11(1): 193-222.
- Alai, D. H., Arnold, S., Bajekal, M., and Villegas, A. M. (2018) 'Mind the Gap: A Study of Cause-Specific Mortality by Socioeconomic Circumstances', *North American Actuarial Journal*, 22(2): 161-181.
- Alai, D. H., Arnold, S., and Sherris, M. (2014a) 'Modelling Cause-of-Death Mortality and the Impact of Cause-Elimination', *Annals of Actuarial Science*, 9(01): 167-186.
- Alai, D. H., Chen, H., Cho, D., Hanewald, K., and Michael Sherris, M. (2014b) 'Developing Equity Release Markets: Risk Analysis for Reverse Mortgages and Home Reversions', *North American Actuarial Journal*, 18(1): 217-241.
- Alai, D. H., and Sherris, M. (2014) 'Rethinking Age-Period-Cohort Mortality Trend Models', *Scandinavian Actuarial Journal*, 2014(3): 208-227.
- Albrecher, H., Bladt, M., and Yslas, J. (2022) 'Mortality Modeling and Regression with Matrix Distributions', *Insurance: Mathematics and Economics*, 107(C): 68-87.

- Alho, J. M. (1990) ‘Stochastic Methods in Population Forecasting’, *International Journal of Forecasting*, 6(4): 521–530.
- Aleksic, M.-C., and M. Börger (2012) ‘Coherent Projections of Age, Period, and Cohort Dependent Mortality Improvements’, Discussion Paper, University of Ulm.
- Alonso-García, J. (2023) ‘Mortality: from Lee–Carter to AI’, *Annals of Actuarial Science*, 17(1): 212–214.
- Álvarez, J.-A., Kallestrup-Lamb, M., and Kjærgaard, S. (2021) ‘Linking Retirement Age to Life Expectancy Does Not Lessen the Demographic Implications of Unequal Lifespans’, *Insurance: Mathematics and Economics*, 99(C): 363–375.
- Antolin, P. and Blommestein, H. (2007) ‘Governments and the Market for Longevity-Indexed Bonds’, Organization for Economic Cooperation and Development Working Papers on Insurance and Private Pensions, No. 4, OECD Publishing, Paris.
- Antonio, K., Bardoutsos, A. And Ouburg, W. (2015) ‘A Bayesian Poisson Log-Bilinear Model for Mortality Projections with Multiple Populations’, *European Actuarial Journal*, 5(2): 245–281.
- Antonio, K., Devriendt, S., de Boer, W., de Vries, R., De Waegenare, A., Kan, H-K., Kromme, E., Ouburg, W., Schulteis, T., Slagter, E., van der Winden, M., van Iersel, C., and Vellekoop, M. (2017) ‘Producing the Dutch and Belgian Mortality Projections: A Stochastic Multi-Population Standard’, *European Actuarial Journal*, 7(2): 297–336.
- Apicella, G., Dacorogna, M., Di Lorenzo, E., and Sibillo, M. (2019) ‘Improving the Forecast of Longevity by Combining Models’, *North American Actuarial Journal*, 23(2): 298–319.
- Arik, A., Uğur, Ö., and Kleinow, T. (2023), ‘The Impact of Simultaneous Shocks to Financial Markets and Mortality on Pension Buy-Out Prices’, *ASTIN Bulletin*, 53(2): 392–417.
- Arnold, S., and Glushko, V. (2021) ‘Cause-Specific Mortality Rates: Common Trends and Differences’, *Insurance: Mathematics and Economics*, 99(C): 294–308.
- Arnold, S., and Sherris, M. (2013) ‘Forecasting Mortality Trends Allowing for Cause-of-Death Mortality Dependence’, *North American Actuarial Journal*, 17:273–82.
- Arnold, S., and Sherris, M. (2015) ‘Modelling Cause-of-Death Mortality: What do We Know on Their Dependence?’, *North American Actuarial Journal*, 19(2): 116–128.
- Arnold, S., and Sherris, M. (2016) ‘International Cause-Specific Mortality Rates: New Insights from a Cointegration Analysis’, *ASTIN Bulletin*, 46 (1): 9–38.
- Aro, H. (2014) ‘Systematic and Non-Systematic Mortality Risk in Pension Portfolios’, *North American Actuarial Journal*, 18(1): 59–67.
- Aro, H., and Pennanen, T. (2017) ‘Liability-Driven Investment in Longevity Risk Management. In *International Series in Operations Research and Management Science*, 245: 121–136, New York: Springer.
- Atance, D., Debón, A., Navarro, E. (2020) ‘A Comparison of Forecasting Mortality Models using Resampling Methods’, *Mathematics*, 8: 1550.
- Awad, Y., Shaul, Bar-Lev, S. K., and Makov, U. (2022) ‘A New Class of Counting Distributions Embedded in the Lee–Carter Model for Mortality Projections: A Bayesian Approach’, *Risks*, 10: 111.
- Ayuso, M., Bravo, J. M., Holzmann, R., and Palmer, E. (2021) ‘Automatic Indexation of the Pension Age to Life Expectancy: When Policy Design Matters’, *Risks*, 9(5), 96.

- Backus, D., Cooley, T., and Henriksen, E. (2014) ‘Demography and Low-frequency Capital Flows’, *Journal of International Economics*, 92(Supp. 1): 94-102.
- Bahl, R. K., and Sabanis, S. (2021) ‘Model-Independent Price Bounds for Catastrophic Mortality Bonds’, *Insurance: Mathematics and Economics*, 96(C), 276-291.
- Bakar, Ö., and Büyükyazıcı, M. (2022) ‘Stochastic Analysis of Longevity Risk in Dependent Multiple Life Annuities’, *Sigma J Eng Nat Sci*, 40(2), 235-242.
- Balasooriya, U., Li, J. S.-H., and Li, J. (2020) ‘The Impact of Model Uncertainty on Index-Based Longevity Hedging and Measurement of Longevity Basis Risk’, *Risks*, 8(3), 80.
- Balland, F., Boumezoued, A., Devineau, L., Habart, M., and Popa, T. (2020) ‘Mortality Data Reliability in an Internal Model’, *Annals of Actuarial Science*, 14(2): 420–444.
- Balter, A. G., Bjerre, D. S., and Kallestrup-Lamb, M. (2023) ‘The Effect of Marital Status on Life Expectancy: Is Cohabitation as Protective as Marriage?’, *Journal of Demographic Economics*, 89(3):373-394.
- Balter, A. G., Kallestrup-Lamb, M., and Rangvid, J. (2020) ‘Variability in Pension Products: A Comparison Study between the Netherlands and Denmark’, *Annals of Actuarial Science*, 14(2): 338–357.
- Balter, A. G., Kallestrup-Lamb, M., and Rangvid, J. (2021) ‘Macro Longevity Risk and the Choice between Annuity Products: Evidence from Denmark’, *Insurance: Mathematics and Economics*, 99(C): 355-362.
- Barbarin, J. (2008) ‘Heath–Jarrow–Morton Modelling of Longevity Bonds and the Risk Minimization of Life Insurance Portfolios’, *Insurance: Mathematics and Economics*, 43: 41-55.
- Barigou, K., Goffard, P.-O., Loisel, S., and Salhi, Y. (2023) ‘Bayesian Model Averaging for Mortality Forecasting using Leave-Future-Out Validation’, *International Journal of Forecasting*, 39(2): 674-690.
- Barigou, K., Loisel, S., and Salhi, Y. (2021) ‘Parsimonious Predictive Mortality Modeling by Regularization and Cross-Validation with and without Covid-Type Effect’, *Risks*, 9(1), 5.
- Barrieu, P., Bensusan, H., El Karoui, N., Hillairet, C., Loisel, S., Ravanelli, C., and Salhi, Y. (2012) ‘Understanding, Modeling and Managing Longevity Risk: Key Issues and Main Challenges’, *Scandinavian Actuarial Journal*, 3: 203–231.
- Barrieu, P. M., and A.M. Veraart, L. (2016) ‘Pricing q-Forward Contracts: An Evaluation of Estimation Window and Pricing Method under Different Mortality Models’, *Scandinavian Actuarial Journal*, 2016 (2): 146-166.
- Basellini, U., Camarda, C. G., and Booth, H. (2023) Thirty Years On: A Review of the Lee–Carter Method for Forecasting Mortality, *International Journal of Forecasting*, 39(3): 1033-1049.
- Basellini, U., Kjærgaard, S., and Camarda C. (2020) ‘An Age-at-Death Distribution Approach to Forecast Cohort Mortality’, *Insurance: Mathematics and Economics*, 91: 129-143
- Bauer, D. (2006) ‘An Arbitrage-Free Family of Longevity Bonds’, Discussion Paper, University of Ulm.
- Bauer, D., Benth, F. E., and Kiesel, R. (2010a) ‘Modeling the Forward Surface of Mortality’, Discussion Paper, University of Ulm.
- Bauer, D., Börger, M., and Russ, J. (2010b) ‘On the Pricing of Longevity-Linked Securities’, *Insurance: Mathematics and Economics*, 46: 139-149.

- Bauer, D., Börger, M., Russ J., and Zwiesler, H. J. (2008) ‘The Volatility of Mortality’, *Asia-Pacific Journal of Risk and Insurance*, 3: 172-199.
- Bauer, D., Fasano, M., Russ, J., and Zhu, N. (2018) ‘Evaluating Life Expectancy Evaluations’, *North American Actuarial Journal*, 22: 198-209.
- Bauer, D., and Kramer, F. (2007) ‘Risk and Valuation of Mortality Contingent Catastrophe Bonds’, Discussion Paper, University of Ulm
- Bauer, D., and Ruß, J. (2006) ‘Pricing Longevity Bonds using Implied Survival Probabilities’, Discussion Paper, University of Ulm.
- Bayraktar, E., Milevsky, M., Promislow, D., and Young, V. (2009) ‘Valuation of Mortality Risk via the Instantaneous Sharpe Ratio: Applications to Life Annuities’, *Journal of Economic Dynamics and Control*, 3: 676-691.
- Beard, R. E. (1971) ‘Some Aspects of Theories of Mortality, Cause of Death Analysis, Forecasting and Stochastic Processes’, *Biological Aspects of Demography*, 999:57–68.
- Bégin, J. F., Kapoor, N., and Sanders, B. (2023a) ‘A New Approximation of Annuity Prices for Age–Period–Cohort Models’, *European Actuarial Journal*; <https://doi.org/10.1007/s13385-023-00370-4>
- Bégin, J. F., Sanders, B., and Xu, X. (2023b) ‘Modeling and Forecasting Subnational Mortality in the Presence of Aggregated Data’, *North American Actuarial Journal*; 10.1080/10920277.2023.2231996
- Bernanke, B. S. (2005) ‘What Explains the Stock Market's Reaction to Federal Reserve Policy?’, *Journal of Finance*, 60(3): 1221-1257.
- Bernhardt, T., and Donnelly, C. (2019) ‘Modern Tontine with Bequest: Innovation in Pooled Annuity Products’, *Insurance: Mathematics and Economics*, 86(C): 168-188.
- Berstein, S., and Morales, M. (2021) ‘The Role of Longevity Insurance in Defined Contribution Pension Systems’, *Insurance: Mathematics and Economics*, 99(C): 233-240.
- Beutner, E., Reese, S., and Urbain, J. (2017) ‘Identifiability Issues of Age-Period and Age-Period-Cohort Models of the Lee–Carter Type’, *Insurance: Mathematics and Economics*, 75: 117-125.
- Beyaztas, U., and Shang, H. L. (2022) ‘Machine-Learning-Based Functional Time Series Forecasting: Application to Age-Specific Mortality Rates’, *Forecasting*, 4, 394–408.
- Biffis, E. (2005) ‘Affine Processes for Dynamic Mortality and Actuarial Valuations’, *Insurance: Mathematics and Economics*, 37: 443-468.
- Biffis, E., and Blake, D. (2010) ‘Securitizing and Tranching Longevity Exposures’, *Insurance: Mathematics and Economics*, 46: 186-197
- Biffis, E., and Blake, D. (2013) ‘Informed Intermediation of Longevity Exposures’, *Journal of Risk and Insurance*, 80: 559-584.
- Biffis, E., and Blake, D. (2014) ‘Keeping Some Skin in the Game: How to Start a Capital Market in Longevity Risk Transfers’, *North American Actuarial Journal*, 18(1): 14-21.
- Biffis, E., Denuit, M., and Devolder, P. (2010) ‘Stochastic Mortality under Measure Changes’, *Scandinavian Actuarial Journal*, 2010: 284-311.
- Biffis, E., Lin, Y., and Milidonis, A. (2017) ‘The Cross-Section of Asia-Pacific Mortality Dynamics: Implications for Longevity Risk Sharing’, *Journal of Risk and Insurance*, 84(S1): 515-532.

- Bisetti, E., and Favero, C. A. (2014) 'Measuring the Impact of Longevity Risk on Pension Systems: The Case of Italy', *North American Actuarial Journal*, 18(1): 87-104.
- Bjerre, D. S. (2022) 'Tree-Based Machine Learning Methods for Modeling and Forecasting Mortality', *ASTIN Bulletin*, 52(3): 765-787.
- Black, F. (1976) 'The Pricing of Commodity Contracts', *Journal of Financial Economics*, 3: 167-179.
- Blackburn, C., Hanewald, K., Olivieri, and Sherris, M. (2017) 'Longevity Risk Management and Shareholder Value for a Life Annuity Business', *ASTIN Bulletin*, 47(1): 43-77.
- Blackburn, C., and Sherris, M. (2013) 'Consistent Dynamic Affine Mortality Models for Longevity Risk Applications', *Insurance: Mathematics and Economics*, 53: 64-73.
- Blake, D. (2018) 'Longevity: A New Asset Class', *Journal of Asset Management*, 19: 278-300.
- Blake, D., Boardman, T., and Cairns, A. (2014) 'Sharing Longevity Risk: Why Governments Should Issue Longevity Bonds', *North American Actuarial Journal*, 18(1): 258-277.
- Blake, D., and Burrows, W. (2001) 'Survivor Bonds: Helping to Hedge Mortality Risk', *Journal of Risk and Insurance*, 68(2): 339-48.
- Blake, D., Cairns, A.J.G., Coughlan, G. D., Dowd, K. and MacMinn, R. (2013) 'The New Life Market', *Journal of Risk and Insurance*, 80: 501-558.
- Blake, D., Cairns, A., and Dowd, K. (2006a) 'Living with Mortality: Longevity Bonds and Other Mortality-Linked Securities', *British Actuarial Journal*, 12: 153-197.
- Blake, D., Cairns, A.J.G., Dowd, K. and MacMinn, R. (2006b) 'Longevity Bonds: Financial Engineering, Valuation and Hedging', *Journal of Risk and Insurance*, 73: 647-72.
- Blake, D., Dowd, K., and Cairns, A.J.G. (2008) 'Longevity Risk and the Grim Reaper's Toxic Tail: The Survivor Fan Charts', *Insurance: Mathematics and Economics*, 42:1062-1068.
- Blake, D., and Harrison, D. (2008) *And Death Shall Have No Dominion: Life Settlements and the Ethics of Profiting from Mortality*, Pensions Institute Report, July. Available at pensions-institute.org/DeathShallHaveNoDominion_Final_3July08.pdf.
- Blanchard, O., Furceri, D., and Pescatori, A. (2014) 'A Prolonged Period of Low Real Interest Rates?' In C. Teulings and R. Baldwin (Eds.) *Secular Stagnation: Facts, Causes, and Cures*. London: Centre for Economic Policy Research.
- Bohl, D. K., Hughes, B. B., and Johnson, S. (2016) Understanding and Forecasting Demographic Risk and Benefits, Report for the Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies, University of Denver.
- Bongaarts, J. (2005) 'Long-range Trends in Adult Mortality: Models and Projection Methods', *Demography*, 42(1): 23-49.
- Booth, H., Maindonald, J., and Smith, L. (2002a) 'Applying Lee-Carter under Conditions of Variable Mortality Decline', *Population Studies*, 56: 325-336.
- Booth, H., Maindonald, J., and Smith, L. (2002b) 'Age-Time Interactions in Mortality Projection: Applying Lee-Carter to Australia', Working Papers in Demography, Australian National University.

- Börger, M., Freimann, A., and Freimann, J. (2023) ‘On the Economics of the Longevity Risk Transfer Market’, *Journal of Risk and Insurance*; 10.1111/jori.12435
- Börger, M., Freimann, A., and Ruß, J. (2021a) ‘A Combined Analysis of Hedge Effectiveness and Capital Efficiency in Longevity Hedging’, *Insurance: Mathematics and Economics*, 99(C): 309-326.
- Börger, M., Ruß, J., and Schupp, J. (2021b) ‘It Takes Two: Why Mortality Trend Modeling is More Than Modeling One Mortality Trend’, *Insurance: Mathematics and Economics*, 99(C), 222-232.
- Börger, M., and Schupp, J. (2018) ‘Modeling Trend Processes in Parametric Mortality Models’, *Insurance: Mathematics and Economics*, 78: 369-380.
- Borio, C., and Disyatat, P. (2015) ‘Capital Flows and the Current Account: Taking Financing (More) Seriously’, *BIS Working Papers No. 525*; <https://www.bis.org/publ/work525.htm>
- Börsch-Supan, A. (2006) ‘Demographic Change, Saving and Asset Prices: Theory and Evidence’, Mannheim Research Institute (MEA)
- Boumezoued, A. (2021) ‘Improving HMD Mortality Estimates with HFD Fertility Data’, *North American Actuarial Journal*, 25(S1): S255-S279.
- Boumezoued, A., and Elfassihi, A. (2021) ‘Mortality Data Correction in the Absence of Monthly Fertility Records’, *Insurance: Mathematics and Economics*, 99(C): 486-508.
- Boumezoued, A., Hardy, H. L., El Karoui, N. and Arnold, S. (2018) ‘Cause-of-Death Mortality: What can be Learned from Population Dynamics?’, *Insurance: Mathematics and Economics*, 78: 301-315.
- Boumezoued, A., Hoffmann, M., and Jeunesse, P. (2019) ‘Nonparametric Adaptive Inference of Birth and Death Models in a Large Population Limit’, arXiv preprint, arXiv:1903.00673.
- Boumezoued, A., Hoffmann, M., and Jeunesse, P. (2020) ‘A New Inference Strategy for General Population Mortality Tables’, *ASTIN Bulletin*, 50(2):325-356.
- Bozikas, A., Badounas, I., and Pitselis, G. (2022) ‘Pricing Longevity Bonds under a Credibility Framework with Limited Available Data’, *Risks*, 10: 96.
- Bravo, J. M. (2011) ‘Pricing Longevity Bonds Using Affine-Jump Diffusion Models’, CEFAGE-UE Working Papers 2011_29, University of Evora.
- Bravo, J. M. (2022) ‘Pricing Participating Longevity-linked Life Annuities: A Bayesian Model Ensemble Approach’, *European Actuarial Journal*, 12: 125-159.
- Bravo, J. M., Ayuso, M., Holzmann, R., and Palmer, E. (2021) ‘Addressing the Life Expectancy Gap in Pension Policy’, *Insurance: Mathematics and Economics*, 99(C), 200-221.
- Bravo, J. M., Ayuso, M., Holzmann, R., and Palmer, E. (2023) ‘Intergenerational Actuarial Fairness when Longevity Increases: Amending the Retirement Age’, *Insurance: Mathematics and Economics*; 10.1016/j.insmatheco.2023.08.007
- Bravo, J. M., and El Mekkaoui de Freitas, N. (2018) ‘Valuation of Longevity-Linked Life Annuities’, *Insurance: Mathematics and Economics*, 78: 212-229.
- Bravo, J. M., and Nunes, J. P. V. (2021) ‘Pricing Longevity Derivatives via Fourier Transforms’, *Insurance: Mathematics and Economics*, 96(C): 81-97.
- Brockett, P. L., Chuang, S.-L., Deng, Y., and MacMinn, R. D. (2013) ‘Incorporating Longevity Risk and Medical Information into Life Settlement Pricing’, *Journal of Risk and Insurance*, 80: 799-826.

- Broeders, D., Mehlkopf, R., and van Ool, A. (2021) ‘The Economics of Sharing Macrolongevity Risk’, *Insurance: Mathematics and Economics*, 99(C): 440-458.
- Brouhns, N., Denuit, M., and Van Keilegom, I. (2005) ‘Bootstrapping the Poisson Log-Bilinear Model for Mortality Forecasting’, *Scandinavian Actuarial Journal*, 2005: 212–224.
- Brouhns, N., Denuit, M., and Vermunt, J. K. (2002a) ‘A Poisson Log-Bilinear Regression Approach to the Construction of Projected Lifetables’, *Insurance: Mathematics and Economics*, 31: 373–393.
- Brouhns, N., Denuit, M., and Vermunt, J. (2002b) ‘Measuring the Longevity Risk in Mortality Projections’, *Bulletin of the Swiss Association of Actuaries*, 2: 105–130.
- Brown, J., and Warshawsky, M. (2013) ‘The Life Care Annuity: A New Empirical Examination of an Insurance Innovation which Addresses Problems in the Markets for Life Annuities and Long-Term Care Insurance’, *Journal of Risk and Insurance*, 80: 677-704.
- Bruszas, S., Kaschützke, B., Maurer, R., and Siegelin, I. (2018) ‘Unisex Pricing of German Participating Life Annuities—Boon or Bane for Customer and Insurance Company?’, *Insurance: Mathematics and Economics*, 78: 230-245.
- Brynjolfsson, E., and McAfee, A. (2014) *The Second Machine Age*. New York: W. W. Norton & Company.
- Bugler, N., Maclean, K., Nicenko, V., and Tedesco, P. (2021) ‘Reinsurance Side-Cars: The Next Stage in the Development of the Longevity Risk Transfer Market’, *North American Actuarial Journal*, 25(S1): S25-S39.
- Buckner, D., Dowd, K., and Hulley, H. (2023) ‘A Market Consistent Approach to the Valuation of No Negative Equity Guarantees and Equity Release Mortgages’, *Journal of Demographic Economics*, 89(3):349-372.
- Cadena, M., and Denuit, M. (2023) ‘Mortality Projections for Higher Educational Attainment with Semi-Parametric Accelerated Hazard Relational Models’, *Decisions in Economics and Finance*; <https://www.springerprofessional.de/en/mortality-projections-for-higher-educational-attainment-with-sem/24676580>
- Cairns, A. J.G. (2011) ‘Modelling and Management of Longevity Risk: Approximations to Survivor Functions and Dynamic Hedging’, *Insurance: Mathematics and Economics*, 49(3): 438-453.
- Cairns, A.J.G. (2013) ‘Robust Hedging of Longevity Risk’, *Journal of Risk and Insurance*, 80: 621-648.
- Cairns, A.J.G., Blake, D., and Dowd K. (2006a) ‘Pricing Death: Frameworks for the Valuation and Securitization of Mortality Risk’, *ASTIN Bulletin*, 36: 79-120.
- Cairns, A.J.G., Blake, D., and Dowd K. (2006b) ‘A Two-Factor Model for Stochastic Mortality with Parameter Uncertainty: Theory and Calibration’, *Journal of Risk and Insurance*, 73: 687-718.
- Cairns, A.J.G., Blake, D., and Dowd, K. (2008) ‘Modelling and Management of Mortality Risk: A Review’, *Scandinavian Actuarial Journal*, 2-3, 79-113.
- Cairns, A.J.G., Blake, D., Dowd, K., Coughlan, G.D., Epstein, D., and Khalaf-Allah, M. (2011a) ‘Mortality Density Forecasts: An Analysis of Six Stochastic Mortality Models’, *Insurance: Mathematics and Economics*, 48: 355-367.
- Cairns, A. J. G., Blake, D., Dowd, K., Coughlan, G. D., Jones, O., and Rowney, J. (2022) A General Framework for Analysing the Mortality Experience of a Large Portfolio of

- Lives: With an Application to the UK Universities Superannuation Scheme, *European Actuarial Journal*, 12: 381–415.
- Cairns, A.J.G., Blake, D., Dowd, K., Coughlan, G.D. and Khalaf-Allah, M. (2011b) ‘Bayesian Stochastic Mortality Modelling for Two Populations’, *ASTIN Bulletin*, 41: 29-59.
- Cairns, A.J.G., Blake, D., Dowd, K., Coughlan, G.D., Epstein, D., Ong, A., and Balevich, I. (2009) ‘A Quantitative Comparison of Stochastic Mortality Models using Data from England & Wales and the United States’, *North American Actuarial Journal*, 13: 1-35.
- Cairns, A. J., Blake, D., Dowd, K., and Kessler, A. R. (2016) ‘Phantoms Never Die: Living with Unreliable Population Data’, *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 179(4):975-1005.
- Cairns, A.J.G., Blake, D., Kessler, A. R., and Kessler, M. (2020) ‘The Impact of Covid-19 on Future Higher-Age Mortality’, Pensions Institute Discussion Paper WP2007, 19 May; <http://www.pensions-institute.org/wp-content/uploads/wp2007.pdf>
- Cairns, A. J., Dowd, K., Blake, D., and Coughlan, G. D. (2014) ‘Longevity Hedge Effectiveness: A Decomposition’, *Quantitative Finance*, 14: 217-235.
- Cairns, A. J. G., and El Boukfaoui, G. (2021) ‘Basis Risk in Index Based Longevity Hedges: A Guide for Longevity Hedgers’, *North American Actuarial Journal*, 25(S1): S97-S118.
- Cannon, E., Tonks, I., and Yuille, R. (2016) ‘The Effect of the Reforms to Compulsion on Annuity Demand’, *National Institute Economic Review*, No. 237, August, R47-R54.
- Caraballo, T., Morillas, F., and Valero, J. (2022) ‘On a Stochastic Nonlocal System with Discrete Diffusion Modeling Life Tables’, *Stochastics and Dynamics*, 22(7), 2240017
- Carannante, M., D'Amato, V., and Haberman, S. (2022) ‘Covid-19 Accelerated Mortality Shocks and the Impact on Life Insurance: The Italian Situation’, *Annals of Actuarial Science*, 16(3): 478-497.
- Carannante, M., D'Amato, V., and Haberman, S. (2023a) ‘Effect of the Covid-19 Frailty Heterogeneity on the Future Evolution of Mortality by Stratified Weighting’, *Journal of Demographic Economics*, 89(3):513-532.
- Carannante, M., D'Amato, V., Haberman, S., and Menzietti, M. (2023b) ‘Frailty-based Lee-Carter Family of Stochastic Mortality Models’, *Quality & Quantity*; <https://doi.org/10.1007/s11135-023-01786-6>
- Carlson, C.J., Gregory F. Albery, G.F., Merow, C., Trisos, C. H., Zipfel, C. M., Eskew, E. A., Olival, K. J., Ross, N., and Bansal, S. (2022) ‘Climate Change Increases Cross-Species Viral Transmission Risk’, *Nature*, 607 555–562.
- Chan, W.-S., Li, J. S.-H., and Li, J. (2014) ‘The CBD Mortality Indexes: Modeling and Applications’, *North American Actuarial Journal*, 18(1): 38-58.
- Chandra, C. E., and Abdullah, S. (2022) ‘Forecasting Mortality Trend of Indonesian Old Aged Population with Bayesian Method’, *International Journal on Advanced Science, Engineering and Information Technology*, 12(2): 580-588.
- Chang, C.-K., Yue, J. C., Chen, C.-J., and Chen, Y.-W. (2021) ‘Mortality Differential and Social Insurance: A Case Study in Taiwan’, *North American Actuarial Journal*, 25(S1): S582-S592.
- Chang, L. and Shi, Y. (2023) ‘Forecasting Mortality Rates with a Coherent Ensemble Averaging Approach’, *ASTIN Bulletin*, 53(1): 2-28.

- Chen A., Hieber P., and Klein J. K. (2019) ‘Tonuity: A Novel Individual-Oriented Retirement Plan’, *ASTIN Bulletin*, 49(1): 5–30.
- Chen, A., Li, H., and Schultze, M. B. (2022a) ‘Tail Index-linked Annuity: A Longevity Risk Sharing Retirement Plan’, *Scandinavian Actuarial Journal*, 2022(2): 139-164.
- Chen, A., Li, H., and Schultze, M. B. (2022b) ‘Collective Longevity Swap: A Novel Longevity Risk Transfer Solution and its Economic Pricing’, *Journal of Economic Behavior & Organization*, 201(1): 227-249.
- Chen, A., Li, H., and Schultze, M. B. (2023a) ‘Optimal Longevity Risk Transfer under Asymmetric Information’, *Economic Modelling*, 120, 106179.
- Chen, A., and Rach, M. (2019) ‘Options on Tontines: An Innovative Way of Combining Tontines and Annuities’, *Insurance: Mathematics and Economics*, 89(C): 182-192.
- Chen, A., and Rach, M., and Sehner, T. (2020) ‘On the Optimal Combination of Annuities and Tontines’, *ASTIN Bulletin*, 50 (1): 95-129.
- Chen, B., Zhang, L. and Zhao, L. (2010) ‘On the Robustness of Longevity Risk Pricing’, *Insurance: Mathematics and Economics*, 47: 358-373.
- Chen, F.-Y, Yang, S. S., and Huang, H.-C. (2022) ‘Modeling Pandemic Mortality Risk and its Application to Mortality-Linked Security Pricing’, *Insurance: Mathematics and Economics*, 106: 341-363.
- Chen, H., and Cox, S. H. (2009) ‘Modeling Mortality with Jumps: Applications to Mortality Securitization’, *Journal of Risk and Insurance*, 76: 727–751.
- Chen, H., and Cummins, J. D. (2010) ‘Longevity Bond Premiums: The Extreme Value Approach and Risk Cubic Pricing’, *Insurance: Mathematics and Economics*, 46: 150-161.
- Chen, H., Gao, J., and Zhu, W. (2023) ‘A Unified Framework for Insurance Demand and Mortality Immunization’, *North American Actuarial Journal*; 10.1080/10920277.2023.2218465
- Chen, H., MacMinn, R. D., and Sun, T. (2015) ‘Multi-Population Mortality Models: A Factor Copula Approach’, *Insurance: Mathematics and Economics*, 63:135–146.
- Chen, H., MacMinn, R.D., and Sun, T. (2017) ‘Mortality Dependence and Longevity Bond Pricing: A Dynamic Factor Copula Mortality Model with the GAS Structure’, *Journal of Risk and Insurance*, 84(S1): 393-415.
- Chen, H., Sherris, M., Sun, T., and Zhu, W. (2013) ‘Living with Ambiguity: Pricing Mortality-Linked Securities with Smooth Ambiguity Preferences’, *Journal of Risk and Insurance*, 80: 705-732.
- Chen R.Y. and Millossovich P. (2018) ‘Sex-Specific Mortality Forecasting for UK Countries: A Coherent Approach’, *European Actuarial Journal*, 8(1): 69-95.
- Chen, Y., and Khaliq, A. Q. M. (2022) ‘Comparative Study of Mortality Rate Prediction Using Data-Driven Recurrent Neural Networks and the Lee–Carter Model’, *Big Data and Cognitive Computing*, 6(4):134.
- Chen, Z., Shi, L., and Shu, A. (2023b) ‘Managing Mortality and Aging Risks with a Time-Varying Lee–Carter Model’, *Healthcare*, 11(5):743.
- Cheng, Z., Si, W., Xu, Z., and Xiang, K. (2022) ‘Prediction of China’s Population Mortality under Limited Data’, *International Journal of Environmental Research and Public Health*, 19(19):12371.
- Choulli, T., Daveloose, C., and Vanmaele, M. (2021) ‘Mortality/Longevity Risk-Minimization with or without Securitization’, *Mathematics*, 9(14): 1-27.

- Christensen, K. and Vaupel, J. W. (1996) ‘Determinants of Longevity: Genetic, Environmental and Medical Factors’, *Journal of Internal Medicine*, 240(6): 333–341.
- Chuang, S.-L., and Brockett, P. L. (2014) ‘Modeling and Pricing Longevity Derivatives using Stochastic Mortality Rates and the Esscher Transforms’, *North American Actuarial Journal*, 18(1): 22-37.
- Clemente, G. P., Della Corte, F., and Nino, S. (2022) ‘A Stochastic Model for Capital Requirement Assessment for Mortality and Longevity Risk, Focusing on Idiosyncratic and Trend Components’, *Annals of Actuarial Science*, 16(3): 527-546.
- Cocco, J.F. and Gomes, F.J. (2008) ‘Hedging Longevity Risk’, Discussion Paper, London Business School.
- Cocco, J.F. and Gomes, F.J. (2012) ‘Longevity Risk, Retirement Savings, and Financial Innovation’, *Journal of Financial Economics*, 103: 507-529.
- Cochrane, J. (2021) ‘Low Interest Rates and Government Debt’, speech prepared for the IGIER policy seminar, 11 January.
- Coelho, E., and Nunes, L. C. (2011) ‘Forecasting Mortality in the Event of a Structural Change’, *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 174: 713–736.
- Coppola, M., Russolillo, M., and Simone, R. (2022) ‘On the Evolution of the Gender Gap in Life Expectancy at Normal Retirement Age for OECD Countries’, *Genus*, 78, 27.
- Coughlan, G. D., Epstein, D., Sinha, A., and Honig, P. (2007) *q-Forwards: Derivatives for Transferring Longevity and Mortality Risks*, J.P. Morgan, London.
- Coughlan, G. D., Khalaf-Allah, M. Ye, Y., Kumar, S., Cairns, A.J.G., Blake, D., and Dowd, K. (2011) ‘Longevity Hedging 101: A Framework for Longevity Basis Risk Analysis and Hedge Effectiveness’, *North American Actuarial Journal*, 15: 150-176.
- Cowley, A., and Cummins, J. D. (2005) ‘Securitization of Life Insurance Assets and Liabilities’, *Journal of Risk and Insurance*, 72: 193-226.
- Cox, S. H., and Lin, Y. (2007) ‘Natural Hedging of Life and Annuity Mortality Risks’, *North American Actuarial Journal*, 11: 1-15.
- Cox, S. H., Lin, Y., and Liu, S. (2021) ‘Optimal Longevity Risk Transfer and Investment Strategies’, *North American Actuarial Journal*, 25(S1): S40-S65.
- Cox, S. H., Lin, Y., and Pedersen, H. (2010) ‘Mortality Risk Modeling: Applications to Insurance Securitization’, *Insurance: Mathematics and Economics*, 46: 242-253.
- Cox, S. H., Lin, Y., and Shi, T. (2018) ‘Pension Risk Management with Funding and Buyout Options’, *Insurance: Mathematics and Economics*, 78: 183-200.
- Cox, S. H., Lin, Y., Tian, R., and Yu, J. (2013a) ‘Managing Capital Market and Longevity Risks in a Defined Benefit Pension Plan’, *Journal of Risk and Insurance*, 80: 585-620.
- Cox, S. H., Lin, Y., Tian, R., and Zuluaga, L. F. (2013b), ‘Mortality Portfolio Risk Management’, *Journal of Risk and Insurance*, 80: 853–890.
- Cupido, K., Jevtić, P., Paez, A. (2020) ‘Spatial Patterns of Mortality in the United States: A Spatial Filtering Approach’, *Insurance: Mathematics and Economics*, 95(C): 28-38.
- Currie, I.D. (2011) ‘Modelling and Forecasting Mortality of the Very Old’, *ASTIN Bulletin*, 41: 419-427.
- Currie, I. D. (2016) ‘On Fitting Generalized Linear and Non-Linear Models of Mortality’, *Scandinavian Actuarial Journal*, 2016: 356-383.
- Currie, I. D. (2020) ‘Constraints, the Identifiability Problem and the Forecasting of Mortality’, *Annals of Actuarial Science*, 14(2): 537–566.

- Currie, I. D. (2023) ‘A Black Box Approach to Fitting Smooth Models of Mortality’, *Statistical Modelling*; 10.1177/1471082X231181165
- Currie, I., Durbán, M., and Eilers, P. (2004) ‘Smoothing and Forecasting Mortality Rates’, *Statistical Modelling*, 4(4): 279–298.
- Czado, C., A. Delwarde, and M. Denuit (2005) ‘Bayesian Poisson Log-Linear Mortality Projections’, *Insurance: Mathematics and Economics*, 36: 260-284.
- Dagpunar, J. (2021) ‘Closed-form Solutions for an Explicit Modern Ideal Tontine with Bequest Motive’, *Insurance: Mathematics and Economics*, 100: 261-273.
- Dahl, M. (2004) ‘Stochastic Mortality in Life Insurance: Market Reserves and Mortality-Linked Insurance Contracts’, *Insurance: Mathematics and Economics*, 35: 113-136.
- Dahl, M., and Møller, T. (2006) ‘Valuation and Hedging of Life Insurance Risks with Systematic Mortality Risk’, *Insurance: Mathematics and Economics*, 39: 193-217.
- D’Amato, V., Di Lorenzo, E., Haberman, S., Russolillo, M., and Sibillo, M. (2011) ‘The Poisson Log-Bilinear Lee-Carter Model: Applications of Efficient Bootstrap Methods to Annuity Analyses’, *North American Actuarial Journal*, 15: 315-333.
- D’Amato, V., Di Lorenzo, E., Haberman, S., Sagoo, P., and Sibillo, M. (2018a) ‘De-Risking Strategy: Longevity Spread Buy-In’, *Insurance: Mathematics and Economics*, 79: 124-136.
- D’Amato, V., Di Lorenzo, E., Sibillo, M. (2018b) ‘Dread Disease and Cause-Specific Mortality: Exploring New Forms of Insured Loans’, *Risks*, 6, 13.
- D’Amato V., Haberman S., Piscopo G., and Russolillo M. (2012a) ‘Modelling Dependent Data for Longevity Projections’, *Insurance: Mathematics and Economics*, 51: 694-701.
- D’Amato, V., Haberman, S., Piscopo, G., Russolillo, M., and Trapani, L. (2014) ‘Detecting Common Longevity Trends by a Multiple Population Approach’, *North American Actuarial Journal*, 18(1): 139-149.
- D’Amato V., Haberman S., and Russolillo M. (2012b) ‘The Stratified Sampling Bootstrap: An Algorithm for Measuring the Uncertainty in Forecast Mortality Rates in the Poisson Lee-Carter Setting’, *Methodology and Computing in Applied Probability*, 14(1): 135-148.
- Danesi, I. L., Haberman, S., and Millossovich, P. (2015) ‘Forecasting Mortality in Subpopulations using Lee-Carter Type Models: A Comparison’, *Insurance: Mathematics and Economics*, 62, 151–161.
- Darkiewicz, G., and Hoedemakers, T. (2004) ‘How the Cointegration Analysis can Help in Mortality Forecasting’, Discussion Paper, Catholic University of Leuven.
- Dawson, P., Blake, D., Cairns, A.J.G., and Dowd, K. (2010) ‘Survivor Derivatives: A Consistent Pricing Framework’, *Journal of Risk and Insurance*, 77: 579-96.
- Dawson, P., Dowd, K., Cairns, A.J.G., and Blake, D. (2009) ‘Options on Normal Underlyings with an Application to the Pricing of Survivor Swaptions’, *Journal of Futures Markets*, 29(8): 757-774.
- Debón, A., Chaves, L., Haberman, S., and Villa. F. (2017) ‘Characterization of Between-group Inequality of Longevity in European Union Countries’, *Insurance: Mathematics and Economics*, 75:151-65.
- Debón, A., Haberman, S., and Piscopo, G. (2023) ‘Multipopulation Mortality Analysis: Bringing Out The Unobservable With Latent Clustering’, *Quality & Quantity*; 10.1007/s11135-023-01728-2

- Debonneuil, E. (2010) ‘Simple Model of Mortality Trends aiming at Universality: Lee Carter + Cohort’, *Quantitative Finance Papers* 1003:1802, arXiv.org.
- Debonneuil, E., Eyraud-Loisel, A., and Planchet, F. (2018a) ‘Can Pension Funds Partially Manage Longevity Risk by Investing in a Longevity Megafund?’, *Risks*, 6, 67.
- Debonneuil, E., Loisel, S., and Planchet, F. (2018b) ‘Do Actuaries Believe in Longevity Deceleration?’, *Insurance: Mathematics and Economics*, 78: 325-338.
- De Jong, P. and Tickle, L. (2006) Extending Lee–Carter Mortality Forecasting, *Mathematical Population Studies*, 13(1): 1–18.
- De Jong, P., Tickle, L., and Xu, J. (2016) ‘Coherent Modeling of Male and Female Mortality using Lee-Carter in a Complex Number Framework’, *Insurance: Mathematics and Economics*, 71: 130-137.
- De Jong, P., Tickle, L., and Xu, J. (2020) ‘A More Meaningful Parameterization of the Lee-Carter Model’, *Insurance: Mathematics and Economics*, 94(C): 1-8.
- Delwarde, A., Denuit, M., and Eilers, P. (2007) ‘Smoothing the Lee-Carter and Poisson Log-Bilinear Models for Mortality Forecasting: A Penalised Log-likelihood Approach’, *Statistical Modelling*, 7: 29-48.
- Deng, Y., Brockett, P., and MacMinn, R. (2011) ‘Pricing Life Settlements’, Working Paper, *Center for Risk Management and Insurance*, University of Texas.
- Deng, Y., Brockett, P., and MacMinn, R. (2012) ‘Longevity/Mortality Risk Modeling and Securities Pricing’, *Journal of Risk and Insurance*, 79: 697-721.
- Denuit, M. M. (2009) ‘An Index for Longevity Risk Transfer’, *Journal of Computational and Applied Mathematics*, 230: 411-417.
- Denuit, M. M., Devolder, P., and Goderniaux, A. (2007) ‘Securitization of Longevity Risk: Pricing Survivor Bonds with Wang Transform in the Lee-Carter Framework’, *Journal of Risk and Insurance*, 74: 87-113.
- Denuit, M. M., Haberman, S., and Renshaw, A. (2015) ‘Longevity-Contingent Deferred Life Annuities’, *Journal of Pension Economics and Finance*, 14(3): 315-327.
- Deprez, P., Shevchenko, P. V., and Wüthrich, M. V. (2017) ‘Machine Learning Techniques for Mortality Modeling’, *European Actuarial Journal*, 7(2): 337-352.
- De Rosa, C., Luciano, E., and Regis, L. (2021) ‘Geographical Diversification and Longevity Risk Mitigation in Annuity Portfolios’, *ASTIN Bulletin*, 51(2): 375-410.
- Diao, L., Meng, Y., and Weng, C. (2021) ‘A DSA Algorithm for Mortality Forecasting’, *North American Actuarial Journal*, 25(3): 438-458.
- Diao, L., Meng, Y., Weng, C., and Wirjanto, T. (2023) ‘Enhancing Mortality Forecasting through Bivariate Model-Based Ensemble’, *North American Actuarial Journal*, DOI: 10.1080/10920277.2023.2167832
- Diaz, G., Debón, A., and Giner-Bosch, V. (2018) ‘Mortality Forecasting in Colombia from Abridged Life Tables by Sex’, *Genus*, 74, 15.
- Di Lorenzo, E., Piscopo, G., Sibillo, M., Tizzano, R. (2022) ‘Reverse Mortgage and Risk Profile Awareness: Proposals for Securitization’, *Applied Stochastic Models in Business and Industry*, 38 (2): 353-369.
- Djeundje, V.B., Haberman, S., Bajekal, M., and Lu, J. (2022) ‘The Slowdown in Mortality Improvement Rates 2011–2017: A Multi-country Analysis’, *European Actuarial Journal*, 12: 839–878.
- Donnelly, C. (2014) ‘Quantifying Mortality Risk in Small Defined-Benefit Pension Schemes’, *Scandinavian Actuarial Journal*, 2014(1): 41–57.

- Dowd, K., Blake, D., and Cairns, A.J.G. (2011a) ‘A Computationally Efficient Algorithm for Estimating the Distribution of Future Annuity Values under Interest-rate and Longevity Risks’, *North American Actuarial Journal*, 15: 237-247.
- Dowd, K., Blake, D., Cairns, and A.J.G., Dawson, P. (2006) ‘Survivor Swaps’, *Journal of Risk and Insurance*, 73: 1-17.
- Dowd, K., Buckner, D., Blake, D., and Fry, J. (2019) ‘The Valuation of No-Negative Equity Guarantees and Equity Release Mortgages’, *Economics Letters*, 184, 108669.
- Dowd, K., Cairns, A. J. G., and Blake, D. (2020) ‘CBDX: A Workhorse Mortality Model from the Cairns-Blake-Dowd Family’, *Annals of Actuarial Science*, 14(2): 445–460.
- Dowd, K., Cairns, A. J. G., and Blake, D. (2021) ‘Hedging Annuity Risks with the Age-Period-Cohort Two-Population Gravity Model’, *North American Actuarial Journal*, 25(S1): S170-S182.
- Dowd, K., Cairns, A.J.G., Blake, D., Coughlan, G.D., Epstein, D., and Khalaf-Allah, M. (2010a) ‘Evaluating the Goodness of Fit of Stochastic Mortality Models’, *Insurance: Mathematics and Economics*, 47: 255-265.
- Dowd, K., Cairns, A.J.G., Blake, D., Coughlan, G.D., Epstein, D., and Khalaf-Allah, M. (2010b) ‘Backtesting Stochastic Mortality Models: An *Ex-Post* Evaluation of Multi-Period-Ahead Density Forecasts’, *North American Actuarial Journal*, 14: 281-298.
- Dowd, K., Cairns, A.J.G., Blake, D., Coughlan, G.D., and Khalaf-Allah, M. (2011b) ‘A Gravity Model of Mortality Rates for Two Related Populations’, *North American Actuarial Journal*, 15: 334-356.
- Dugravot, A., Fayosse, A., Dumurgier, J., Bouillon, K., Rayana, T., Schnitzler, A., Kivimaki, M., Sabia, S., and Singh-Manoux, A. (2019) ‘Social Inequalities in Multimorbidity, Frailty, Disability, and Transitions to Mortality: A 24-year Follow-up of the Whitehall II Cohort Study’, *The Lancet: Public Health*, 11 December, doi.org/10.1016/S2468-2667(19)30226-9.
- Dutton, L., Pantelous, A. A., and Seklecka, M. (2019) ‘The Impact of Economic Growth in Mortality Modelling for Selected OECD Countries’, *Journal for Forecasting*, 39(3): 533-550.
- Dyrting, S., and Taylor, A.J. (2023) ‘Estimating Age-specific Mortality using Calibrated Splines’, *Population Studies*; 10.1080/00324728.2023.2228297
- Ediev, D. M. (2011) ‘Robust Backward Population Projections Made Possible’, *International Journal of Forecasting*, 27(4): 1241–1247.
- Ediev, D. M. (2021) ‘On the Existence and Uniqueness of the Remaining Life Expectancy in the Model of a Stable Population’, *Mathematical Models and Computer Simulations*, 13(6): 964-970.
- Enchev, V., Kleinow, T., and Cairns, A. (2017) ‘Multi-Population Mortality Models: Fitting, Forecasting and Comparisons’, *Scandinavian Actuarial Journal*, 2017(4): 319-342.
- European Systemic Risk Board (2021) *Lower for Longer – Macroprudential Policy Issues arising from the Low Interest Rate Environment*, Joint Task Force of ESRB Advisory Technical Committee (ATC), ESRB Advisory Scientific Committee (ASC), and ESCB Financial Stability Committee (FSC).
- Feldstein, M., and Horioka, C. (1980) ‘Domestic Saving and International Capital Flows’, *Economic Journal*, 90 (358): 314–329.

- Feng, B. M., Siu, J. h., and Zhou, K. Q. (2022) ‘Green Nested Simulation via Likelihood Ratio: Applications to Longevity Risk Management’, *Insurance Mathematics and Economics*, 106: 285-301.
- Feng, R., Gan, G., and Zhang, N. (2022) ‘Variable Annuity Pricing, Valuation, and Risk Management: A Survey’, *Scandinavian Actuarial Journal*, 2022(10): 867-900.
- Ferrero, G., Gross, M., and Neri, S. (2019) ‘On Secular Stagnation and Low Interest Rates: Demography Matters’, *International Finance*, 22: 262-278.
- Fokeer, O. D., and Narsoo, J. (2022) ‘Evaluation of the Forecasting Accuracy of Stochastic Mortality Models: An Analysis of Developed and Developing Countries’, *Communications in Statistics: Case Studies, Data Analysis and Applications*, 8(4): 1-29.
- Ford, N., and Horioka, C. Y. (2016) ‘The ‘Real’ Explanation of the PPP Puzzle’, Institute of Social and Economic Research, Discussion Paper No. 969, Osaka University, Ibaraki, Osaka, Japan.
- Ford, N., and Horioka, C. Y. (2017) The ‘Real’ Explanation of the Feldstein–Horioka Puzzle, *Applied Economics Letters*, 24 (20): 95-97.
- Friedberg, L., and Webb, A. (2007) ‘Life is Cheap: Using Mortality Bonds to Hedge Aggregate Mortality Risk’, *B.E. Journal of Economic Analysis & Policy*, 7(1): Article 31.
- Gaille, S., and Sherris, M. (2011) ‘Modelling Mortality with Common Stochastic Long-Run Trends’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 595-621.
- Gao, G., and Shi, Y. (2021) ‘Age-Coherent Extensions of the Lee–Carter Model’, *Scandinavian Actuarial Journal*, 2021(10): 998-1016.
- Gao, H., Mamon, R., Liu, X., and Tenyakov, A. (2015) ‘Mortality Modelling with Regime-Switching for the Valuation of a Guaranteed Annuity Option’, *Insurance: Mathematics and Economics*, 63: 108–120.
- Gbari, S., Poulain, M., Dal, L., and Denuit, M. (2017) ‘Extreme Value Analysis of Mortality at the Oldest Ages: A Case Study Based on Individual Ages at Death’, *North American Actuarial Journal*, 21(3): 397-416.
- Gemmo, I., Rogalla, R., and Weinert, J.-H. (2020) ‘Optimal Portfolio Choice with Tontines under Systematic Longevity Risk’, *Annals of Actuarial Science*, 14(2): 302–315.
- Ghalehjooghi, A. S., and Lyu, P. (2021) ‘Socio-Economic Differentiation in Experienced Mortality Modelling and its Pricing Implications’, *European Actuarial Journal*, 12(1): 161-188.
- Gompertz, B. (1825) ‘On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contingencies’, *Philosophical Transactions of the Royal Society*, 115: 513–585.
- Gong, G. and Webb, A. (2010) ‘Evaluating the Advanced Life Deferred Annuity: An Annuity People Might Actually Buy’, *Insurance: Mathematics and Economics*, 46: 210-221.
- Goodhart, C., and Pradhan, M. (2020) *The Great Demographic Reversal: Ageing Societies, Waning Inequality, and an Inflation Revival*, London: Palgrave Macmillan.
- Gordon, R. J. (2016) *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War*, Princeton, NJ: Princeton University Press.
- Gourieroux, C., and Lu, Y. (2015) ‘Love and Death: A Freund Model with Frailty’, *Insurance: Mathematics and Economics*, 63: 191–203.

- Gourieroux, C. and Monfort, A. (2008) ‘Quadratic Stochastic Intensity and Prospective Mortality Tables’, *Insurance: Mathematics and Economics*, 43: 174-184.
- Gourinchas, P.-O., and Rey, H. (2019) ‘Global Real Rates: A Secular Approach’, Bank for International Settlements Working Paper No 793, June.
- Gowen, O., Fosse, E., and Winship, C. (2023) ‘Cross-Group Differences in Age, Period, and Cohort Effects: A Bounding Approach to the Gender Wage Gap’, *Sociological Science*, 10: 731-768.
- Gratton, L. and Scott, A. J. (2016) *The 100-Year Life – Living and Working in an Age of Longevity*, London: Bloomsbury.
- Guibert, Q., Lopez, O., and Piette, P. (2019) ‘Forecasting Mortality Rate Improvements with a High-dimensional VAR’, *Insurance: Mathematics and Economics*, 88: 255-272.
- Gungah, G., and Narsoo, J. (2022) ‘A Novel EVT-modified Lee-Carter Model for Mortality Forecasting: An Application to Extreme Mortality Events’, *Journal of Statistics and Management Systems*, 25(1): 211-243.
- Guo, G., and Bauer, D. (2021) ‘Different Shades of Risk: Mortality Trends Implied by Term Insurance Prices’, *North American Actuarial Journal*, 25(S1): S156-S169.
- Haberman, S. (2023) ‘A Rejoinder to “Thirty Years On: A Review of the Lee–Carter Method for Forecasting Mortality”’, *International Journal of Forecasting*, 39(3): 1050-1052.
- Haberman, S., and Renshaw, A. (2009) ‘On Age-Period-Cohort Parametric Mortality Rate Projections’, *Insurance: Mathematics and Economics*, 45: 255-270.
- Haberman, S., and Renshaw, A. (2011) ‘A Comparative Study of Parametric Mortality Projection Models’, *Insurance: Mathematics and Economics*, 48: 35-55.
- Haberman, S., and Renshaw, A. (2012) ‘Parametric Mortality Improvement Rate Modelling and Projecting’, *Insurance: Mathematics and Economics*, 50: 309–333.
- Haberman, S., and Renshaw, A. (2013) ‘Modelling and Projecting Mortality Improvement Rates using a Cohort Perspective’, *Insurance: Mathematics and Economics*, 53: 150–168.
- Hainaut, D. (2012) ‘Multidimensional Lee-Carter Model with Switching Mortality Processes’, *Insurance: Mathematics and Economics*, 50: 236-246.
- Hainaut, D. (2018) ‘A Neural-Network Analyzer for Mortality Forecast’, *ASTIN Bulletin*, 48: 481-508.
- Hainaut, D. (2023) ‘A Calendar Year Mortality Model in Continuous Time’, *ASTIN Bulletin*, 53(2): 351-376.
- Hanbali, H., Denuit, M., Dhaene, J., and Trufin, J. (2019) ‘A Dynamic Equivalence Principle for Systematic Longevity Risk Management’, *Insurance: Mathematics and Economics*, 86(C): 158-167.
- Hanewald, K. (2011) ‘Explaining Mortality Dynamics: The Role of Macroeconomic Fluctuations and Cause of Death Trends’, *North American Actuarial Journal*, 15: 290-314.
- Hari, N., De Waegenare, A., Melenberg, B., and Nijman, T. (2008) ‘Estimating the Term Structure of Mortality’, *Insurance: Mathematics and Economics*, 42: 492-504.
- Harrison, D., and Blake, D. (2013) ‘A Healthier Way to De-Risk: The Introduction of Medical Underwriting to the Defined Benefit De-risking Market’, Pensions Institute, London. Available at www.pensions-institute.org/reports/HealthierWayToDeRisk.pdf.

- Hatzopoulos, P., and Haberman, S. (2009) ‘A Parameterized Approach to Modeling and Forecasting Mortality’, *Insurance: Mathematics and Economics*, 44: 103-123.
- Hatzopoulos, P., and Haberman, S. (2011) ‘A Dynamic Parameterization Modeling for the Age-Period-Cohort Mortality’, *Insurance: Mathematics and Economics*, 49: 155–174.
- He, L., Huang, F., Shi, J., and Yang, Y. (2021) ‘Mortality Forecasting using Factor Models: Time-Varying or Time-Invariant Factor Loadings?’, *Insurance: Mathematics and Economics*, 98(C): 14-34.
- Heligman, L. and Pollard, J. H. (1980) ‘The Age Pattern of Mortality’, *Journal of the Institute of Actuaries*, 107(1): 49–80.
- Hilton, J., Dodd, E., Forster, J. J., and Smith, P. W. F. (2019) ‘Projecting UK Mortality by using Bayesian Generalized Additive Models’, *Journal of the Royal Statistical Society. Series C: Applied Statistics*, 68(1): 29–49.
- Hilton, J., Dodd, E., Forster, J. J., and Smith P.W.F. (2021) ‘Modelling Frontier Mortality using Bayesian Generalised Additive Models’, *Journal of Official Statistics*, 37(3): 569–589.
- Hobcraft, J., Menken, J., and Preston, S. H. (1982) ‘Age, Period and Cohort Effects in Demography: A Review’, *Population Index*, 48 (1): 4–43.
- Horioka, C. Y., and Ford, N. (2017) ‘A Possible Explanation of the ‘Exchange Rate Disconnect Puzzle’: A Common Solution to Three Macroeconomic Puzzles?’, *Applied Economics Letters*, 24 (13): 918-922.
- Horneff, V., Maurer, R., Mitchell, O. S., and Rogalla, R. (2015) ‘Optimal Life Cycle Portfolio Choice with Variable Annuities offering Liquidity and Investment Downside Protection’, *Insurance: Mathematics and Economics*, 63: 91–107.
- Horneff, W.J., Maurer, R.H., Mitchell, O.S., and Stamos, M.Z. (2009) ‘Asset Allocation and Location Over the Life Cycle with Investment-Linked Survival-Contingent Payouts’, *Journal of Banking and Finance*, 33: 1688-1699.
- Horneff, W. J., Maurer, R., and Rogalla, R. (2010) Dynamic Portfolio Choice With Deferred Annuities’, *Journal of Banking and Finance*, 34: 2652-2664.
- Horneff, W.J., Maurer, R.H., and Stamos, M.Z. (2008) ‘Life-Cycle Asset Allocation with Annuity Markets: Is Longevity Insurance A Good Deal?’, *Journal of Economic Dynamics and Control*, 32: 3590 -3612.
- Hsieh, M.-H., Tsai, J. C., and Wang, J. L. (2021) ‘Mortality Risk Management Under the Factor Copula Framework - With Applications to Insurance Policy Pools’, *North American Actuarial Journal*, 25(S1): S119-S131.
- Hsieh, M.-H., Wang, J. L., Chiu, Y.-F., and Chen, Y.-C. (2018) ‘Valuation of Variable Long-Term Care Annuities with Guaranteed Lifetime Withdrawal Benefits: A Variance Reduction Approach’, *Insurance: Mathematics and Economics*, 78: 246-254.
- Huang, H., Milevsky, M., and Salisbury, T. S. (2009) ‘A Different Perspective on Retirement Income Sustainability: The Blueprint for a Ruin Contingent Life Annuity (RCLA)’, *Journal of Wealth Management*, 11: 89–96.
- Huang, H., Milevsky, M., and Salisbury, T. S. (2012) ‘Optimal Retirement Consumption with a Stochastic Force of Mortality’, Papers 1205.2295, arXiv.org.
- Huang, H., Milevsky, M., and Salisbury, T. S. (2017) ‘Retirement Spending and Biological Age’, *Journal of Economic Dynamics & Control*, 84: 58-76’

- Huang, H.-C., Wang, C.-W., and Miao, Y.-C. (2011) ‘Securitization of Crossover Risk in Reverse Mortgages’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 622-647.
- Huang, Z., Sherris, M., Villegas, A. M., and Ziveyi, J. (2022) ‘Modelling USA Age-Cohort Mortality: A Comparison of Multi-Factor Affine Mortality Models’, *Risks*, 10(9): 183.
- Hunt, A., and Blake, D. (2014) ‘A General Procedure for Constructing Mortality Models’, *North American Actuarial Journal*, 18(1): 116-138.
- Hunt, A., and Blake, D. (2015) ‘Modelling Longevity Bonds: Analysing the Swiss Re Kortis Bond’, *Insurance: Mathematics and Economics*, 63, 12–29.
- Hunt, A., and Blake, D. (2016) *The Good, the Bad and the Healthy: The Medical Underwriting Revolution in the Defined Benefit De-risking Market*, Pensions Institute, January, www.pensions-institute.org/reports/GoodBadHealthy.pdf
- Hunt, A., and Blake, D. (2017) ‘Modelling Mortality for Pension Schemes’, *ASTIN Bulletin*, 47(2): 481-508.
- Hunt, A., and Blake, D. (2018) ‘Identifiability, Cointegration and the Gravity Model’, *Insurance: Mathematics and Economics*, 78: 360-368.
- Hunt, A., and Blake, D. (2020a) ‘Identifiability in Age/Period Mortality Models’, *Annals of Actuarial Science*, 14(2): 461–499.
- Hunt, A., and Blake, D. (2020b) ‘Identifiability in Age/Period /Cohort Mortality Models’, *Annals of Actuarial Science*, 14(2): 500–536.
- Hunt, A., and Blake, D. (2021a) ‘On the Structure and Classification of Mortality Models’, *North American Actuarial Journal*, 25(S1): S215-S234.
- Hunt, A., and Blake, D. (2021b) ‘A Bayesian Approach to Modelling and Projecting Cohort Effects’, *North American Actuarial Journal*, 25(S1): S235-S254.
- Hunt, A., and Blake, D. (2021c) ‘Forward Mortality Rates in Discrete Time I: Calibration and Securities Pricing’, *North American Actuarial Journal*, 25(S1): S482-S507.
- Hunt, A., and Blake, D. (2021d) ‘Forward Mortality Rates in Discrete Time II: Longevity Risk and Hedging Strategies’, *North American Actuarial Journal*, 25(S1): S508-S533.
- Hunt, A., and Villegas, A. M. (2023) ‘Mortality Improvement Rates: Modeling, Parameter Uncertainty, and Robustness’, *North American Actuarial Journal*, 27:1, 47-73.
- Huang, G., Guo, F., Zimmermann, K. F., Liu, L., Taksa, L., Cheng, Z., Tani, M., and Franklin, M. (2023a) ‘The Effect of the COVID-19 Pandemic on Life Expectancy in 27 Countries’, *Scientific Reports (Nature)*, 13, 8911.
- Huang, S., Tan, K. S., Zhang, J., and Zhu, W. (2023b) ‘Epidemic Financing Facilities: Pandemic Bonds and Endemic Swaps’, *North American Actuarial Journal*; 10.1080/10920277.2023.2256818
- Hwang, J., and Kim, S. K. (2023) ‘Unexpected Longevity, Intergenerational Policies, and Fertility’, *Journal of Population Economics*, 36(3): 1607-1640; <https://doi.org/10.1007/s00148-023-00943-3>
- Hyndman, R., Booth, H., and Yasmeen, F. (2013) ‘Coherent Mortality Forecasting the Product-Ratio Method with Functional Time Series Models’, *Demography*, 50: 261-283.
- Ignatieva, K., Song, A., Ziveyi, J. (2018) ‘Fourier Space Time-Stepping Algorithm for Valuing Guaranteed Minimum Withdrawal Benefits in Variable Annuities under Regime-Switching and Stochastic Mortality’, *ASTIN Bulletin*, 48(1): 139-169.

- International Monetary Fund (2012), *The Financial Impact of Longevity Risk*, Chapter 4 of *Global Financial Stability Report*, April, Washington DC.
- Jallbjørn, S., and Jarner, S. F. (2022) ‘Sex Differential Dynamics in Coherent Mortality Models’, *Forecasting*, 4(4):819-844.
- Jallbjørn, S., Jarner, S. F., and Hansen, N. R. (2023) ‘Forecasting, Interventions and Selection: The Benefits of a Causal Mortality Model’, *European Actuarial Journal*; 10.1007/s13385-023-00372-2
- Janssen, F., van Wissen, L. J. G., Kunst, A. E. (2013) ‘Including the Smoking Epidemic in Internationally Coherent Mortality Projections’, *Demography*, 50(4):1341-62.
- Jarner, S. r. F., and Kryger, E. M. (2011) ‘Modelling Adult Mortality in Small Populations: The SAINT Model’, *ASTIN Bulletin*, 41: 377-418.
- Jarner, S. r. F., and Jallbjørn, S. (2020) ‘Pitfalls and Merits of Cointegration-based Mortality Models’, *Insurance: Mathematics and Economics*, 90: 80-93.
- Jarner, S. r. F., and Jallbjørn, S. (2022) ‘The SAINT Model: A Decade Later’, *ASTIN Bulletin*, 52(2): 483-517.
- Jen, S. (2007) Demographic Trends and the Financial Markets, Morgan Stanley Fixed Income Research, 20 September.
- Jena, D., Swain, P. F., Tripathy, M. R., and Sarangi, P. K. (2023) ‘Modelling and Forecasting of Age Specific Mortality Rates in India’, *Demography India*, 52(1): 118-133.
- Jevtić, P., Kwak, M., and Pirvu, T. A. (2021) ‘Practical Partial Equilibrium Framework for Pricing of Mortality-linked Instruments in Continuous Time’, *European Actuarial Journal*, 12(1): 249-273.
- Jevtić, P., and Regis, L. (2019) ‘A Continuous-Time Stochastic Model for the Mortality Surface of Multiple Populations’, *Insurance: Mathematics and Economics*, 88: 181-195.
- Jevtić, P., Qin, C., and Zhou, H. (2023) ‘Multi-population Mortality Modeling with Lévy Processes’, *Decisions in Economics and Finance*; <https://www.springerprofessional.de/en/multi-population-mortality-modeling-with-levy-processes/25417714>
- Jiao, Y., Salhi, Y., and Wang, S. (2022) ‘Dynamic Bivariate Mortality Modelling’, *Methodology and Computing in Applied Probability*, 24(3): 917–938.
- Joint Forum (2013). *Longevity Risk Transfer Markets: Market Structure, Growth Drivers and Impediments, and Potential Risks*. Joint Forum of the Basel Committee on Banking Supervision, International Organization of Securities Commissions, and International Association of Insurance Supervisors, c/o Bank for International Settlements, Basel, Switzerland, December. Available at www.bis.org/publ/joint34.pdf.
- Jones, P. M., Minton, J., and Bell, A. (2023) Methods for Disentangling Period and Cohort Changes in Mortality Risk over the Twentieth Century: Comparing Graphical and Modelling Approaches, *Quality & Quantity*, 57: 3219–3239.
- Kallestrup-Lamb, M., Kjaergaard, S., and Rosenskjold, C. P. T. (2020) ‘Insight into Stagnating Adult Life Expectancy: Analyzing Cause of Death Patterns across Socioeconomic Groups’, *Health Economics*, 29(2): 1728-1743.
- Kallestrup-Lamb, M., and Laursen, N. S. (2023) ‘Longevity Hedge Effectiveness using Socioeconomic Indices’, *Insurance: Mathematics and Economics*; <https://doi.org/10.1016/j.insmatheco.2023.11.008>

- Kang, K., Liu, Y., Li J. S.-H., and Chan, W.-C. (2018) ‘Mortality Forecasting for Multiple Populations: An Augmented Common Factor Model with a Penalized Log-Likelihood’, *Communications in Statistics: Case Studies, Data Analysis and Applications*, 4 (3-4): 118-141.
- Karabarbounis, L., and Neiman, B. (2014) ‘Capital Depreciation and Labour Shares around the World: Measurement and Implications’, NBER Working Paper No. 20606.
- Katsiferis, A., Bhatt, S., Mortensen, L.H., Mishra, S., Jensen, M.K., Westendorp. R.G.J. (2023) ‘Machine Learning Models of Healthcare Expenditures Predicting Mortality: A Cohort Study of Spousal Bereaved Danish Individuals’, *PLoS One*, 18(8):e0289632.
- Katsiferis, A., Bhatt, S., Mortensen, L. H., Mishra, S., Westendorp, R. G. J. (2023) ‘Sex Differences in Health Care Expenditures and Mortality after Spousal Bereavement: A Register-Based Danish Cohort Study’, *PLoS One*, 18(3): e0282892.
- Kessler, A. (2021) ‘New Solutions to an Age-Old Problem: Innovative Strategies for Managing Pension and Longevity Risk’, *North American Actuarial Journal*, 25(S1): S7-S24.
- Kessler, A. (2023) ‘Resilience in a Time of Crisis: How Covid-19 Pandemic Insights are Supporting a Vibrant Longevity Risk Transfer Market’, *Journal of Demographic Economics*, 89(3):313-327.
- Kessy, S. R., Sherris, M, Villegas, A. M., and Ziveyi, J. (2022) ‘Mortality Forecasting using Stacked Regression Ensembles’, *Scandinavian Actuarial Journal*, 2022(7): 591-62.
- Kiley, M. T. (2020) ‘The Global Equilibrium Real Interest Rate: Concepts, Estimates and Challenges’, *Annual Review of Financial Economics*, 12: 305-326.
- Kleinow, T. (2015) ‘A Common Age Effect Model for the Mortality of Multiple Populations’, *Insurance: Mathematics and Economics*, 63: 147–152.
- Kleinow, T., and Cairns, A. (2013) ‘Mortality and Smoking Prevalence: An Empirical Investigation in Ten Developed Countries’ *British Actuarial Journal*, 18: 452-466.
- Kleinow, T., and Richards, S. J. (2017) ‘Parameter Risk in Time-Series Mortality Forecasts’, *Scandinavian Actuarial Journal*, 2017(9): 804-828.
- Kogure, A., Fushimi, T., and Kamiya, S. (2021) ‘Mortality Forecasts for Long-Term Care Subpopulations with Longevity Risk: A Bayesian Approach’, *North American Actuarial Journal*, 25(S1): S534-S544.
- Kogure, A., and Kurachi, Y. (2010) ‘A Bayesian Approach to Pricing Longevity Risk Based on Risk-Neutral Predictive Distributions’, *Insurance: Mathematics and Economics* 46: 162-172.
- Kogure, A., Li, J., and Kamiya, S. (2014) ‘A Bayesian Multivariate Risk-Neutral Method for Pricing Reverse Mortgages’, *North American Actuarial Journal*, 18(1): 242-257.
- Koijen, R.S.J., Nijman, T.E., and Werker, B.J.M. (2011) ‘Optimal Annuity Risk Management’, *Review of Finance*, 15: 799-833.
- Koissi, M., Shapiro, A., and Hognas, G. (2006) ‘Evaluating and Extending the Lee-Carter Model for Mortality Forecasting: Bootstrap Confidence Interval’, *Insurance: Mathematics and Economics*, 38: 1–20.
- Kuang, D., Nielsen, B., and Nielsen, J. (2008) ‘Forecasting with the Age-Period-Cohort Model and the Extended Chain-Ladder Model’, *Biometrika*, 95: 987-991.
- Kularatne, T. D., Li, J., and Shi, Y. (2022) ‘Forecasting Mortality Rates with a Two-Step LASSO-Based Vector Autoregressive Model’, *Risks*, 10(11):219.

- Kung, K.-L., Hsieh, M.-H., Peng, J.-L., Tsai, C. J., and Wang, J. L. (2021a) 'Explaining the Risk Premiums of Life Settlements', *Pacific-Basin Finance Journal*, 68: 101574.
- Kung, K.-L., Liu, I-C., and Wang, C.-W. Wang (2021b) 'Modeling and Pricing Longevity Derivatives using the Skellam Distribution', *Insurance: Mathematics and Economics*, 99: 341-354.
- Kung, K.-L., MacMinn, R. D., Kuo, W., and Tsai, C. J. (2022) 'Multi-Population Mortality Modeling: When the Data is Too Much and Not Enough', *Insurance: Mathematics and Economics*, 103: 41-55.
- Kurtbegu, E. (2018) 'Replicating Intergenerational Longevity Risk Sharing in Collective Defined Contribution Pension Plans using Financial Markets', *Insurance: Mathematics and Economics*, 78: 286-300.
- Lane, M. (2011) 'Longevity Risk from the Perspective of the ILS Markets', *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 501-515.
- Lee, C., Hong, J., and Kim, S. (2021) 'Feasibility Assessment of Longevity Swap for the Korean Life Annuity Market', *Communications for Statistical Applications and Methods*, 28:655-671.
- Lee, R. D. and Carter, L. R. (1992) 'Modeling and Forecasting U.S. Mortality', *Journal of the American Statistical Association*, 87(419): 659–671.
- Lee, Y.-T. Kung, K.-L., and Liu, I-C. (2018) 'Profitability and Risk Profile of Reverse Mortgages: A Cross-System and Cross-Plan Comparison', *Insurance: Mathematics and Economics*, 78: 255-266.
- Leng, X., and Peng, L. (2016) 'Inference Pitfalls in Lee-Carter Model for Forecasting Mortality', *Insurance: Mathematics and Economics*, 70: 58–65.
- Lesné, S., Koh, M.-T., Kotilinek, L., Kaye, R., Glabe, C. G., Yang, A., Gallagher, M., and Ashe, K. H. (2006) 'A Specific Amyloid- β Protein Assembly in the Brain Impairs Memory', *Nature*, 440: 352–357.
- Leung, M., Fung, M. C., and O'Hare, C. (2018) 'A Comparative Study of Pricing Approaches for Longevity Instruments', *Insurance: Mathematics and Economics*, 82, 95-116.
- Leung, M., Li, Y., Pantelous, A. A. and Vigne, S. A. (2021) 'Bayesian Value-at-Risk Backtesting: The Case of Annuity Pricing', *European Journal of Operational Research*, 293(2): 786-801.
- Levantesi, S., Lizzi, M. and Nigri, A. (2023) 'Enhancing Diagnostic of Stochastic Mortality Models Leveraging Contrast Trees: An Application on Italian Data', *Quality & Quantity*; 10.1007/s11135-023-01711-x
- Levantesi, S., Nigri, A., and Piscopo, G. (2020) 'Longevity Risk Management through Machine Learning: State of the Art', *Insurance Markets and Companies*, 11(1):11-20.
- Li, H. (2018) 'Dynamic Hedging of Longevity Risk: The Effect of Trading Frequency', *ASTIN Bulletin*, 48(1): 197-232.
- Li, H., and Chen, H. (2022) 'Hierarchical Mortality Forecasting with EVT Tails: An Application to Solvency Capital Requirement', *International Journal of Forecasting*; 10.1016/j.ijforecast.2022.08.007
- Li, H., De Waegenaere, A., and Melenberg, B. (2015a) 'The Choice of Sample Size for Mortality Forecasting: A Bayesian Learning Approach', *Insurance: Mathematics and Economics*, 63, 153–168.

- Li, H., De Waegenaere, A., and Melenberg, B. (2017a) ‘Robust Mean–Variance Hedging of Longevity Risk’, *Journal of Risk and Insurance*, 84(S1): 459-475.
- Li, H., and Hyndman, R. J. (2021) ‘Assessing Mortality Inequality in the US: What can be said about the Future?’, *Insurance: Mathematics and Economics*, 99(C): 152-162.
- Li, H., Li, H., Lu, Y., and Panagiotelis, A. (2019) ‘A Forecast Reconciliation Approach to Cause-of-Death Mortality Modeling’, *Insurance: Mathematics and Economics*, 86: 122-133.
- Li, H., Liu, H., Tang, Q., and Yuan, Z. (2023) ‘Pricing Extreme Mortality Risk in the Wake of the COVID-19 Pandemic’, *Insurance Mathematics and Economics*, 108(C): 84-106.
- Li, H., and Lu, Y. (2017) ‘Coherent Forecasting of Mortality Rates: A Sparse Vector-autoregression Approach’, *ASTIN Bulletin*, 47, 563-600.
- Li, H., Lu, Y., and Lyu, P. (2021) ‘Coherent Mortality Forecasting for Less Developed Countries’, *Risks*, 9: 151.
- Li, H., and O’Hare, C. (2017) ‘Semi-Parametric Extensions of the Cairns–Blake–Dowd Model: A One-Dimensional Kernel Smoothing Approach’, *Insurance: Mathematics and Economics*, 77, 166–176.
- Li, H., O’Hare, C., and Vahid, F. (2016) ‘Two Dimensional Kernel Smoothing of Mortality Surface: An Evaluation of Cohort Strength’, *Journal of Forecasting*, 35(6): 553-563.
- Li, H., O’Hare, C., and Vahid, F. (2017b) ‘A Flexible Functional Form Approach To Mortality Modeling: Do We Need Additional Cohort Dummies?’, *Journal of Forecasting*, 36, 357-367.
- Li, H., O’Hare, C., and Zhang, X. (2015b) ‘A Semi-Parametric Panel Approach to Mortality Modeling’, *Insurance: Mathematics and Economics*, 61, 264-270.]
- Li, H., and Shi, Y. (2021a) ‘Mortality Forecasting with an Age-Coherent Sparse VAR Model’, *Risks*, 9(2), 35.
- Li, H., and Shi, Y. (2021b) ‘Forecasting Mortality with International Linkages: A Global Vector-autoregression Approach’, *Insurance: Mathematics and Economics*, 100(C): 59-75.
- Li, H., Tan, K. S., Tuljapurkar, S., and Zhu, W. (2021a) ‘Gompertz Law Revisited: Forecasting Mortality with a Multi-factor Exponential Model’, *Insurance: Mathematics and Economics*, 99(C): 268-281.
- Li, H., and Tang, Q. (2019) ‘Analyzing Mortality Bond Indexes via Hierarchical Forecast Reconciliation’, *ASTIN Bulletin*, 49 (3): 823-846.
- Li, H., Zhou, R., and Ji, M. (2023) ‘Nonlinear Modeling of Mortality Data and Its Implications for Longevity Bond Pricing’, *Risks*, 11: 207.
- Li, J. (2013) A Poisson Common Factor Model for Projecting Mortality and Life Expectancy Jointly for Females and Males’, *Population Studies*, 67(1):111-26.
- Li, J. (2023) ‘A Model Stacking Approach for Forecasting Mortality’, *North American Actuarial Journal*, 27(3): 530-545.
- Li, J., and Kogure, A. (2021) ‘Bayesian Mixture Modelling for Mortality Projection’, *Risks*, 9(4), 76.
- Li, J., Lee, M., and Guthrie, S. (2021b) ‘A Double Common Factor Model for Mortality Projection Using Best-Performance Mortality Rates As Reference’, *ASTIN Bulletin*, 51(2): 349 – 374.
- Li, J., Li, J., Tan, C., and Tickle, L. (2019) ‘Assessing Basis Risk in Index-Based Longevity Swap Transactions’, *Annals of Actuarial Science*, 13(1), 166-197.

- Li, J., Tickle, L., and Parr, N. (2016) 'A Multi-population Evaluation of the Poisson Common Factor Model for Projecting Mortality Jointly for Both Sexes', *Journal of Population Research*, 33: 333–60.
- Li, J. S.-H. (2010) 'Pricing Longevity Risk with the Parametric Bootstrap: A Maximum Entropy Approach', *Insurance: Mathematics and Economics*, 47: 176-186.
- Li, J. S.-H., and Chan, W.-S. (2011) 'Time-Simultaneous Prediction Bands: A New Look at the Uncertainty involved in Forecasting Mortality', *Insurance: Mathematics and Economics*, 49: 81-88.
- Li, J. S.-H., Chan, W., and Cheung, S. (2011) 'Structural Changes in the Lee-Carter Mortality Indexes: Detection and Implications', *North American Actuarial Journal*, 15: 13–31.
- Li, J. S.-H., Chan, W., and Zhou, R. (2017c) 'Semicoherent Multipopulation Mortality Modeling: The Impact on Longevity Risk Securitization', *Journal of Risk and Insurance*, 84(3):1025-1065.
- Li, J. S.-H., and Hardy, M. R. (2011) 'Measuring Basis Risk involved in Longevity Hedges', *North American Actuarial Journal*, 15: 177-200.
- Li, J. S.-H., Hardy, M., and Tan, K. (2009) 'Uncertainty in Mortality Forecasting: An Extension to the Classic Lee-Carter Approach', *ASTIN Bulletin*, 39: 137–164.
- Li, J. S.-H., Li, J., Balasooriya, U., and Zhou, K. Q. (2021) 'Constructing Out-of-the-Money Longevity Hedges Using Parametric Mortality Indexes', *North American Actuarial Journal*, 25(S1): S341-S372.
- Li, J. S.-H., Liu, Y., and Chan, W.-C. (2023) 'Hedging Longevity Risk under Non-Gaussian State-Space Stochastic Mortality Models: A Mean-Variance-Skewness-Kurtosis Approach', *Insurance: Mathematics and Economics*;10.1016/j.insmatheco.2023.08.001
- Li, J. S.-H., and Luo, A. (2012) 'Key q-Duration: A Framework for Hedging Longevity Risk', *ASTIN Bulletin*, 42: 413–452.
- Li, J. S.-H., Zhou, K. Q., Zhu, X., Chan, W.-C., and Chan, F. W.-H. (2020) 'A Bayesian Approach to Developing a Stochastic Mortality Model for China', *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 182: 1523-1560.
- Li, J. S.-H., Zhou, R., and Hardy, M. R. (2015c) 'A Step-By-Step Guide To Building Two-Population Stochastic Mortality Models', *Insurance: Mathematics and Economics*, 63: 121–134.
- Li, N., and Lee, R. D. (2005) 'Coherent Mortality Forecasts for a Group of Populations: An Extension of the Lee-Carter Method', *Demography*, 42: 575–594.
- Li, N., Lee, R. D., and Gerland P. (2013) 'Extending the Lee-Carter Method to Model the Rotation of Age Patterns of Mortality Decline for Long-term Projections', *Demography*, 50: 2037–2051.
- Li, S., Hardy, H. L., Sherris, M. and Villegas, A. M. (2022) 'A Managed Volatility Investment Strategy for Pooled Annuity Products', *Risks*, 10: 121.
- Li, Z., and Kara, A. (2022) 'Pension De-risking Choice and Firm Risk: Traditional Versus Innovative Strategies', *International Review of Financial Analysis*, 81: 102064.
- Li, Z., Shao, A. W., and Sherris, M. (2017d) 'The Impact of Systematic Trend and Uncertainty on Mortality and Disability in a Multistate Latent Factor Model for Transition Rates', *North American Actuarial Journal*, 21 (4): 594-610.

- Lin, T., and Tsai, C. C.-L. (2014) ‘Applications of Mortality Durations and Convexities in Natural Hedges’, *North American Actuarial Journal*, 18(3), 417–442.
- Lin, T., and Tsai, C. C.-L. (2020a) ‘Natural Hedges with Immunization Strategies of Mortality and Interest Rates’, *ASTIN Bulletin*, 50 (1): 155-185.
- Lin, T., and Tsai, C. C.-L. (2020b) ‘Hedging Mortality/Longevity Risks for Multiple Years’, *North American Actuarial Journal*, 24(1): 118-140.
- Lin, T., and Tsai, C. C.-L. (2022) ‘Hierarchical Bayesian Modeling of Multi-country Mortality Rates’, *Scandinavian Actuarial Journal*, 2022(1):1-24.
- Lin, T., and Tsai, C. C.-L. (2023) ‘A New Option for Mortality-Interest Rates’, *Journal of Futures Markets*, 43(2):273-293.
- Lin, T., Tsai, C. C.-L., and Cheng, H.-W. (2023) ‘Asset Liability Management of Longevity and Interest Rate Risks: Using Survival–Mortality Bonds’, *North American Actuarial Journal*, 27(1): 74-95.
- Lin, T., and Tzeng, L. (2010) ‘An Additive Stochastic Model of Mortality Rates: An Application to Longevity Risk in Reserve Evaluation’, *Insurance: Mathematics and Economics*, 46: 423-435.
- Lin, T.-J. C, Lee, Y.-S., Li, M.-R., and Tzeng, J. (2021) ‘Applications of the Dynamic System and Differential Equations to Taiwan Mortality’, *International Journal of Computing Science and Mathematics*, 13(3): 245- 266.
- Lin, Y., and Cox, S. (2005) ‘Securitization of Mortality Risks in Life Annuities’, *Journal of Risk and Insurance*, 72: 227-252.
- Lin, Y., Liu, S., and Yu, J. (2013), ‘Pricing Mortality Securities with Correlated Mortality Indexes’, *Journal of Risk and Insurance*, 80: 921–948.
- Lin, Y., MacMinn, R. D., and Tian, R. (2015) ‘De-Risking Defined Benefit Plans’, *Insurance: Mathematics and Economics*, 63: 52–65.
- Lin, Y., MacMinn, R.D., Tian, R., and Yu, J. (2017a) ‘Pension Risk Management in the Enterprise Risk Management Framework’, *Journal of Risk and Insurance*, 84(S1): 345-365.
- Lin, Y., MacMinn, R.D., and Shi, T. (2023) ‘Do Pension Buyouts Help or Hurt Employees (Retirees)?’, *Journal of Risk and Insurance*, DOI: 10.1111/jori.12423
- Lin, Y., Shi, T., and Arik, A. (2017b) ‘Pricing Buy-Ins and Buy-Outs’, *Journal of Risk and Insurance*, 84(S1): 367-392.
- Lin, Y., Tan, K. S., Tian, R., and Yu, J. (2014) ‘Downside Risk Management of a Defined Benefit Plan Considering Longevity Basis Risk’, *North American Actuarial Journal*, 18(1): 68-86.
- Liu, C., and Shi, Y. (2023) ‘Extensions of the Lee-Carter Model to Project the Data-Driven Rotation of Age-Specific Mortality Decline and Forecast Coherent Mortality Rates’, *Journal of Forecasting*, 42(4): 813-834.
- Liu, J. J. (2021) ‘A Study on Link Functions for Modelling and Forecasting Old-Age Survival Probabilities of Australia and New Zealand’, *Risks*, 9(1), 11.
- Liu, Q., Ling, C., Li, D., and Peng, L. (2019) ‘Bias-Corrected Inference for a Modified Lee–Carter Mortality Model’, *ASTIN Bulletin*, 49 (2): 433-455.
- Liu, Y., and Li, J. S.-H. (2016) ‘It's All in the Hidden States: A Longevity Hedging Strategy with an Explicit Measure of Population Basis Risk’, *Insurance: Mathematics and Economics*, 70: 301-319.

- Liu, Y., and Li, J. S.-H. (2017) ‘The Locally Linear Cairns–Blake–Dowd Model: A Note on Delta–Nuga Hedging of Longevity Risk’, *ASTIN Bulletin*, 47 (1): 79-151.
- Liu, Y., and Li, J. S.-H. (2018) ‘A Strategy for Hedging Risks Associated with Period and Cohort Effects using q-Forwards’, *Insurance: Mathematics and Economics*, 78: 267-285.
- Liu, Y., and Li, J. S.-H. (2021) ‘An Efficient Method for Mitigating Longevity Value-at-Risk’, *North American Actuarial Journal*, 25(S1): S309-S340.
- Liu, Y., and Li, J. S.-H. (2023) ‘Disentangling Trend Risk and Basis Risk with Functional Time Series’, *Risks*, 11(12): 208.
- Lledó, J., Pavia, J. M., and Salas, J. S. (2023) ‘An Alternative Approach to Manage Mortality Catastrophe Risks under Solvency II’, *Risk Management*, 25: 16.
- Longevity Basis Risk Working Group (2014) ‘Longevity Basis Risk: A Methodology for Assessing Basis Risk’, Institute and Faculty of Actuaries (IFoA) and the Life and Longevity Markets Association (LLMA), London (Authors: Haberman, S., Kaishev, V., Villegas, A., Baxter, S., Gaches, A., Gunnlaugsson, S., and Sison, M.).
- Lourés, C. R., and Cairns, A. J. G. (2020) ‘Mortality in the US by Education Level’, *Annals of Actuarial Science*, 14(2): 384–419.
- Lourés, C. R., and Cairns, A. J.G. (2021) ‘Cause of Death Specific Cohort Effects In U.S. Mortality’, *Insurance: Mathematics and Economics*, 99(C): 190-199.
- Lu, Q., Hanewald, K., and Wang, X. (2021) ‘Subnational Mortality Modelling: A Bayesian Hierarchical Model with Common Factors’, *Risks*, 9(11), 203.
- Lu, Y., and Zhu, D. (2023) ‘Modelling Mortality: A Bayesian Factor-Augmented VaR (FAVaR) Approach’, *ASTIN Bulletin*, 53(1):29-61.
- Ludkovski, M., Risk, J., and Zail, H. (2018) ‘Gaussian Process Models for Mortality Rates and Improvement Factors’, *ASTIN Bulletin*, 48 (3): 1307-1347.
- Lyu, P., De Waegenare, A., and Melenberg, B. (2021) ‘A Multi-Population Approach to Forecasting All-Cause Mortality Using Causes-of-Death Mortality Data’, *North American Actuarial Journal*, 25(S1): S421-S456.
- Lyu, P., Li, J. S.-H., and Zhou, K. Q. (2023) ‘Socioeconomic Differentials in Mortality: Implications on Index-Based Longevity Hedges’, *Scandinavian Actuarial Journal*, 2023(4): 359-387.
- MacMinn, R., and Brockett, P. (2017) ‘On the Failure (Success) of the Markets for Longevity Risk Transfer’, *Journal of Risk and Insurance*, 84(S1): 273-277.
- MacMinn, R., Lin, Y., and Shi, T. (2023) ‘Buy-ins, Buy-outs, Longevity Bonds, and the Creation of Value’, *Journal of Demographic Economics*, 89(3):329-347.
- MacMinn, R., and Richter, A. (2018) ‘The Choice of Trigger in an Insurance Linked Security: The Mortality Risk Case’, *Insurance: Mathematics and Economics*, 78: 174-182.
- MacMinn, R. D., and Zhu, N. (2017) ‘Hedging Longevity Risk in Life Settlements Using Biomedical Research-Backed Obligations’, *Journal of Risk and Insurance*, 84(S1): 439-458.
- MacMinn, R. D., and Zhu, N. (2021) ‘Hedging Longevity Risk: Does the Structure of the Financial Instrument Matter?’, *North American Actuarial Journal*, 25(S1): S373-S364.
- Maffra, S. A., Armstrong, J., Pennanen, T. (2021) ‘Stochastic Modeling of Assets and Liabilities with Mortality Risk’, *Scandinavian Actuarial Journal*, 2021(8): 695-725.

- Mankiw, G. N., and Weil, D. N. (1989). ‘The Baby Boom, the Baby Bust and the Housing Market’, *Regional Science and Urban Economics*, 19: 235-258.
- Marino, M., Levantesi, S., and Nigri, A. (2023) ‘A Neural Approach to Improve the Lee-Carter Mortality Density Forecasts’, *North American Actuarial Journal*, 27(1): 148-165.
- Masters, R. K., Aron, L. Y., and Woolf, S. H. (2022) ‘Changes in Life Expectancy between 2019 and 2021 in the United States and 21 Peer Countries’, Medrxiv.org; <https://www.medrxiv.org/content/10.1101/2022.04.05.22273393v4>
- Mavros, G., Cairns, A. J. G., Streftaris G., and Kleinow, T. (2017) ‘Stochastic Mortality Modeling: Key Drivers and Dependent Residuals’, *North American Actuarial Journal*, 21 (3): 343-368.
- Maurer, R, Mitchell, O. S. Rogalla, R., and Kartashov, V. (2013) ‘Lifecycle Portfolio Choice with Systematic Longevity Risk and Variable Investment-Linked Deferred Annuities’, *Journal of Risk and Insurance*, 80: 649-676.
- Mayhew, L. (2023) ‘Counting the Cost of Inequality’, *Journal of Demographic Economics*, 89(3): 395-418.
- Mayhew, L., Harper, G., and Villegas, A. M. (2020) ‘An Investigation into the Impact of Deprivation on Demographic Inequalities in Adults’, *Annals of Actuarial Science*, 14(2): 358–383.
- Mayhew, L., Rickayzen, B., and Smith, D. (2021) ‘Flexible and Affordable Methods of Paying for Long-Term Care Insurance’, *North American Actuarial Journal*, 25(S1): S196-S214.
- Mayhew, L., and Smith, D. (2011) ‘Human Survival at Older Ages and the Implications for Longevity Bond Pricing’, *North American Actuarial Journal*, 15: 248-265.
- Mayhew, L., and Smith, D. (2014) ‘Gender Convergence in Human Survival and the Postponement of Death’, *North American Actuarial Journal*, 18(1): 194-216.
- Mayhew, L., and Smith, D. (2021) ‘An Investigation into Inequalities in Adult Lifespan’, *North American Actuarial Journal*, 25(S1): S545-S565.
- Mayhew, L., Smith, D., and Wright, D. (2018) ‘The Effect of Longevity Drift and Investment Volatility on Income Sufficiency in Retirement’, *Insurance: Mathematics and Economics*, 78: 201-211.
- Mazonas, P.M., Stallard, P. J. E., and Graham, L. (2011) ‘Longevity Risk in Fair Valuing Level-Three Assets in Securitized Portfolios’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 516-543.
- McCarthy, D. (2018) ‘A Cohort-based Analysis of US Mortality Rates Project Rapid Improvements in Old-age Mortality’, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3088688.
- McCarthy, D., and Wang, P.-L. (2021a) ‘An Analysis of Period and Cohort Mortality Shocks in International Data’, *North American Actuarial Journal*, 25(S1): S385-S409.
- McCarthy, D., and Wang, P.-L. (2021b) ‘Pooling Mortality Risk in Eurozone State Pension Liabilities: An Application of a Bayesian Coherent Multi-Population Cohort-Based Mortality Model’, *Insurance: Mathematics and Economics*, 99(C): 459-485.
- McCarthy, D., and Wang, P.-L. (2023) ‘Mortality Postponement and Compression at Older Ages in Human Cohorts’, *PLoS One*, 18(3): e0281752.
- McNown, R., and Rogers, A. (1992) ‘Forecasting Cause-Specific Mortality using Time Series Methods’, *International Journal of Forecasting*, 8(3): 413–432.

- Medford, A. (2021) 'Modeling Best Practice Life Expectancy Using Gumbel Autoregressive Models', *Risks*, 9(3), 51.
- Meese, R., and Rogoff, K. (1983) 'Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample?', *Journal of International Economics*, 14: 3-24.
- Menoncin, F. (2008) 'The Role of Longevity Bonds in Optimal Portfolios', *Insurance: Mathematics and Economics*, 42: 343-358.
- Michaelson, A., and Mulholland, J. (2014) 'Strategy for Increasing the Global Capacity for Longevity Risk Transfer: Developing Transactions that Attract Capital Markets Investors', *Journal of Alternative Investments*, 17 (1): 18-27.
- Mitchell, D., Brockett, P., Mendoza-Arriaga, R., and Muthuraman, K. (2013) 'Modeling and Forecasting Mortality Rates', *Insurance: Mathematics and Economics*, 52(2): 275-285.
- Milevsky, M. A. (2005) 'Real Longevity Insurance with a Deductible: Introduction to Advanced-life Delayed Annuities (ALDA)', *North American Actuarial Journal*, 9: 109-22.
- Milevsky, M. A. (2020) 'Calibrating Gompertz in Reverse: What is your Longevity-risk-adjusted Global Age?', *Insurance: Mathematics and Economics*, 92:147-161.
- Milevsky, M.A., and Promislow, S.D. (2001) 'Mortality Derivatives and the Option to Annuitize', *Insurance: Mathematics and Economics*, 29: 299-318.
- Milevsky, M. A., and Salisbury, T. S. (2015) 'Optimal Retirement Income Tontines', *Insurance: Mathematics and Economics*, 64: 91-105.
- Milevsky, M.A. and Young, V.R. (2007) 'Annuitization and Asset Allocation', *Journal of Economic Dynamics and Control*, 31: 3138-3177.
- Milidonis, A., and Efthymiou, M. (2017) 'Mortality Leads and Lags', *Journal of Risk and Insurance*, 84(S1): 495-514.
- Milidonis, A., Lin, Y., and Cox, S. H. (2011) 'Mortality Regimes and Pricing', *North American Actuarial Journal*, 15: 266-289.
- Mitchell, D., Brockett, P., Mendoza-Arriaga, R., and Muthuraman, K. (2013) 'Modeling and Forecasting Mortality Rates', *Insurance: Mathematics and Economics*, 52: 275-285.
- Miyata, A., and Matsuyama, N. (2022) 'Extending the Lee-Carter Model with Variational Autoencoder: A Fusion of Neural Network and Bayesian Approach', *ASTIN Bulletin*, 52(3): 789-812.
- Mrad, F., Hamdi, H., Naoui, K., and Abid, I. (2023) 'The GMWB guarantee embedded in Life Insurance Contracts: Fair Value Pricing Problem', *Finance Research Letters*, 51: 103327.
- Murphy, M. (2010) 'Re-Examining the Dominance of Birth Cohort Effects on Mortality', *Population and Development Review*, 36: 365-90.
- Murphy, M., and Di Cesare M. (2012) 'Use of an Age-Period-Cohort Model to Reveal the Impact of Cigarette Smoking on Trends in Twentieth Century Adult Cohort Mortality in England & Wales', *Population Studies*, 66: 259-77.
- Murray, R., Johnson, B., Hart, M., and Nawaz, S. (2022) Longevity Over The Next Decade, *Life Risk News*, 1(8): December; liferisk.news/longevity-over-the-next-decade
- Navarro, E., and Requena, P. (2023) 'Impact of Covid-19 on Spanish Mortality Rates in 2020 by Age and Sex', *Journal of Public Health*, DOI: 10.1093/pubmed/fdad023

- Neves, C., Fernandes, C., and Hoeltgebaum, H. (2017) ‘Five Different Distributions for the Lee–Carter Model of Mortality Forecasting: A Comparison using GAS Models’, *Insurance: Mathematics and Economics*, 75, 48-57.
- Nielsen, B., and Nielsen, J. (2014) ‘Identification and Forecasting in Mortality Models’, *The Scientific World Journal*, 2104: Article 347043.
- Ngai, A., and Sherris, M. (2011) ‘Longevity Risk Management for Life and Variable Annuities: The Effectiveness of Static Hedging using Longevity Bonds and Derivatives’, *Insurance: Mathematics and Economics*, 49: 100-114.
- Njenga, C.N., and Sherris, M. (2011) ‘Longevity Risk and the Econometric Analysis of Mortality Trends and Volatility’, *Asia-Pacific Journal of Risk and Insurance*, 5(2), 1-54.
- Njenga, C.N., and Sherris, M. (2020) ‘Modeling Mortality with a Bayesian Vector Autoregression’, *Insurance: Mathematics and Economics*, 94(C): 40-57.
- Nusselder, W. J., De Waegenaere, A. M. B., Melenberg, B., Lyu, P., and Valverde, J. R. R. (2022) ‘Future Trends of Life Expectancy by Education in the Netherlands’, *BMC Public Health*, 22: 1664.
- Obstfeld, M., and Rogoff, K. (2000) ‘The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?’, in Bernanke, B., and Rogoff, K. (eds.), *NBER Macroeconomics Annual 2000*, MIT Press, 15: 339–390.
- Odhiambo, J. (2023) ‘Deep Learning Incorporated Bühlmann Credibility in the Modified Lee-Carter Mortality Model’, *Mathematical Problems in Engineering*, 2023: 8543909
- Odhiambo, J., Weke, P., Ngare, P. (2021) ‘A Deep Learning Integrated Cairns-Blake-Dowd (CBD) Systematic Mortality Risk Model’, *Journal of Risk and Financial Management*, 14(6): 1-12.
- Odhiambo, J. O., Weke, P. G. O., Ngare, P., Naryongo, R., and Sewe, S. (2022) ‘Poisson Incorporated Credibility Regression Modelling of Systematic Mortality Risk for Populations with Finite Data’, *Mathematical Problems in Engineering*, 2022: 1753542.
- OECD (2022) ‘Strengthening Asset-backed Pension Systems in a Post-COVID World’, OECD Publishing, Paris; <https://doi.org/10.1787/288cb3cf-en>.
- O’Hare, C., and Li, Y. (2012) ‘Identifying Structural Breaks in Stochastic Mortality Models’, Discussion Paper, Monash University.
- O’Hare, C., and Li, Y. (2017) ‘Mortality Models of Mortality Rates: Analysing the Residuals’, *Applied Economics*, 49: 5309-5323.
- Olivieri, A., and Pitacco E. (2008) ‘Assessing the Cost of Capital for Longevity Risk’, *Insurance: Mathematics and Economics*, 42: 1013-1021.
- Olivieri, A., and Pitacco E. (2020) ‘Linking Annuity Benefits to the Longevity Experience: Alternative Solutions’, *Annals of Actuarial Science*, 14(2): 316–337.
- Olivieri, A., and Pitacco E. (2022) ‘Time Restrictions on Life Annuity Benefits: Portfolio Risk Profiles’, *Risks*, 10: 164.
- Olivieri, A., Thirurajah, S., and Ziveyi, J. (2022) ‘Target Volatility Strategies for Group Self-Annuity Portfolios’, *ASTIN Bulletin*, 52(2): 591-617.
- Ortiz, C. E., Stone, C. A., and Zissu, A. (2023) ‘The Shock of COVID-19 and the Shock of Rapid Vaccine Development on the Value of Senior Life Settlement Contracts’, *Risk Management and Insurance Review*; 10.1111/rmir.12251
- Orwat-Acedańska, A. (2023) ‘Accuracy of Small Area Mortality Prediction Methods: Evidence from Poland’, *Journal of Population Research*, 41: 6.

- Pascariu, M. D., Basellini, U., Aburto, J. M., and Canudas-Romo, V. (2020) ‘The Linear Link: Deriving Age-Specific Death Rates from Life Expectancy’, *Risks*, 8(4), 109.
- Pascariu, M. D., Canudas-Romo, V., and Vaupel, J. W. (2018) ‘The Double-Gap Life Expectancy Forecasting Model’, *Insurance: Mathematics and Economics*, 78: 339-350.
- Pavía, J. M., and Lledó, J. (2021) ‘Estimation of the Combined Effects of Ageing and Seasonality on Mortality Risk: An Application to Spain’, *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 185(2): 471–497.
- Pearson-Stuttard, J., Caul, S., McDonald, S., Whamond, E., and Newtone, J. N. (2024) ‘Excess Mortality in England Post COVID-19 Pandemic: Implications for Secondary Prevention’, *The Lancet Regional Health – Europe*, 36: 100802; <https://doi.org/10.1016/j.lanepe.2023.100802>
- Pedroza, C. (2006) ‘A Bayesian Forecasting Model: Predicting US Male Mortality’, *Biostatistics*, 7: 530–550.
- Pelkiewicz, A.J., Ahmed, S.W., Fulcher, P., Johnson, K.L., Reynolds, S.M., Schneider, R.J., and Scott, A.J. (2019) ‘A Review of the Risk Margin - Solvency II and Beyond’, Report from the Risk Margin Working Party, Institute & Faculty of Actuaries, 9 September; <https://www.actuaries.org.uk/system/files/field/document/Risk%20Margin%20Working%20Party%20Research%20Paper%20Final%2008082019.pdf>
- Perla, F., Richman, R., Scognamiglio, S., and Wüthrich, M. V. (2021) ‘Time-series Forecasting of Mortality Rates using Deep Learning’, *Scandinavian Actuarial Journal*, 2021(7): 572-598.
- Perla, F., and Scognamiglio, S. (2023) ‘Locally-Coherent Multi-Population Mortality Modelling via Neural Networks’, *Decisions in Economics and Finance*, 46(1): 157-176.
- Pichler, A., and Uhlig, D. (2023) ‘Mortality in Germany during the COVID-19 Pandemic’, *International Journal of Environmental Research and Public Health*, 20(20): 6942.
- Pitacco, E. (2019) ‘Heterogeneity in Mortality: A Survey with an Actuarial Focus’, *European Actuarial Journal*, 9: 3–30.
- Pitt, D., Li, J., and Lim T. K. (2018) ‘Smoothing Poisson Common Factor Model for Projecting Mortality Jointly for Both Sexes’, *ASTIN Bulletin*, 48 (2): 509-541.
- Plat, R. (2009a) ‘On Stochastic Mortality Modeling’, *Insurance: Mathematics and Economics*, 45: 393-404.
- Plat, R. (2009b) ‘Stochastic Portfolio Specific Mortality and the Quantification of Mortality Basis Risk’, *Insurance: Mathematics and Economics*, 45: 123-132.
- Poterba, J. M. (2001) ‘Demographic Structure and Asset Returns’, *Review of Economics and Statistics*, 83:565-584.
- Prudential Regulation Authority (2018) ‘Solvency II: Equity Release Mortgages’, Consultation Paper CP13/18, July.
- Qazvini, M. (2023) ‘Survival Analysis of Longitudinal Data: The Case of the English Population Aged 50 and Over’, *Journal of Demographic Economics*, 89(3): 419-463.
- Qiao, C., and Sherris, M. (2013) ‘Managing Systematic Mortality Risk with Group Self-Pooling and Annuitization Schemes’, *Journal of Risk and Insurance*, 80: 949-974.
- Rabbi, A. M. F., and Mazzuco, S. (2021) ‘Mortality Forecasting with the Lee-Carter Method: Adjusting for Smoothing and Lifespan Disparity’, *European Journal of Population*, 37(1): 97-120.

- Rachel, L., and Summers, L. H. (2019) 'On Falling Natural Real Rates, Fiscal Policy, and the Risk Of Secular Stagnation', *Brookings Papers on Economic Activity Conference Drafts*, March 7-8; <https://www.brookings.edu/wp-content/uploads/2019/03/On-Falling-Neutral-Real-Rates-Fiscal-Policy-and-the-Risk-of-Secular-Stagnation.pdf>
- Raftery, A. E., Lalic, N., and Gerland, P. (2014) 'Joint Probabilistic Projection of Female and Male Life Expectancy'. *Demographic Research*, 30: 795–822.
- Rakhmawan, S. A., Omar, M. H., Riaz, M., and Abbas, M. (2023) 'Hotelling T2 Control Chart for Detecting Changes in Mortality Models Based on Machine-Learning Decision Tree', *Mathematics*, 11(3): 566.
- Renshaw, A., and Haberman, S. (2003a) 'Lee-Carter Mortality Forecasting: A Parallel Generalized Linear Modelling Approach for England and Wales Mortality Projections', *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, 52: 119–137.
- Renshaw, A., and Haberman, S. (2003b) 'Lee-Carter Mortality Forecasting with Age-Specific Enhancement', *Insurance: Mathematics and Economics*, 33: 255–272.
- Renshaw, A. E., and Haberman, S. (2003c) 'On the Forecasting of Mortality Reduction Factors', *Insurance: Mathematics and Economics*, 32: 379–401.
- Renshaw, A. E., and Haberman, S. (2006) 'A Cohort-Based Extension to the Lee-Carter Model for Mortality Reduction Factors', *Insurance: Mathematics and Economics*, 38: 556–70.
- Renshaw, A., and Haberman, S. (2008) 'On Simulation-Based Approaches to Risk Measurement in Mortality with Specific Reference to Poisson Lee-Carter Modelling', *Insurance: Mathematics and Economics*, 42: 797–816.
- Richards, S. J. (2008) 'Detecting Year-of-Birth Mortality Patterns with Limited Data', *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 171(1):279-298.
- Richards, S. (2021) 'A Value-at-Risk Approach to Mis-Estimation Risk', *British Actuarial Journal*, 26: e13.
- Richards, S. J., Currie, I. D., Kleinow, T., and Ritchie, G. P. (2020) 'Longevity Trend Risk Over Limited Time Horizons', *Annals of Actuarial Science*, 14(2): 262–277.
- Richards, S. J., Currie, I. D., and Ritchie, G. P. (2014) 'A Value-at-risk Framework for Longevity Trend Risk', *British Actuarial Journal*, 19(1): 116-167.
- Richards, S. J., Kaufhold, K., and Rosenbusch, S. (2013) 'Creating Portfolio-Specific Mortality Tables: A Case Study', *European Actuarial Journal*, 3(2): 295-319.
- Richman, R., and Wüthrich, M.V. (2021) 'A Neural Network Extension of the Lee–Carter Model to Multiple Populations', *Annals of Actuarial Science*, 15(2): 346-366.
- Richter, A., and Weber, F. (2011) 'Mortality-Indexed Annuities: Managing Longevity Risk via Product Design', *North American Actuarial Journal*, 15: 212-236
- Rizzi, S., Kjærgaard, S., Bergeron Boucher, M.-P., Camarda, C. G., Lindahl-Jacobsen, R., and Vaupel, J.W. (2021) 'Killing Off Cohorts: Forecasting Mortality of Non-extinct Cohorts with the Penalized Composite Link Model', *International Journal of Forecasting*, 37 (1): 95-104.
- Robben, J., Antonio, K., and Devriendt, S. (2022) 'Assessing the Impact of the COVID-19 Shock on a Stochastic Multi-Population Mortality Model', *Risks*, 10(2): 26.
- Rogalla, R. (2021) 'Optimal Portfolio Choice in Retirement with Participating Life Annuities', *North American Actuarial Journal*, 25(S1): S182-S195.

- Rong, X., Tao, C., and Zhao, H. (2023) 'Target Benefit Pension Plan with Longevity Risk and Intergenerational Equity', *ASTIN Bulletin*; <http://10.1017/asb.2022.27>
- Roshani, A., Izadi, M., and Khaledi, B.-E. (2023) 'Bayesian Poisson Common Factor Model with Overdispersion for Mortality Forecasting in Multiple Populations', *Communication in Statistics-Simulation and Computation*; 10.1080/03610918.2023.2196381
- Russo, V., Giacometti, R., Ortobelli, S., Rachev, S., and Fabozzi, F. (2011) 'Calibrating Affine Stochastic Mortality Models using Term Assurance Premiums', *Insurance: Mathematics and Economics*, 49: 53-60.
- Russolillo, M., Giordano, G., and Haberman, S. (2011) 'Extending the Lee-Carter model: A Three-way Decomposition', *Scandinavian Actuarial Journal*, 2011 (2): 96–117.
- Salhi, Y., and Thérond, P. E. (2018) 'Age-Specific Adjustment of Graduated Mortality', *ASTIN Bulletin*, 48, 543-569.
- Santolino, M. (2020) 'The Lee-Carter Quantile Mortality Model', *Scandinavian Actuarial Journal*, 2020: 614–33.
- Santolino, M. (2023) 'Should Selection of the Optimum Stochastic Mortality Model be Based on the Original or the Logarithmic Scale of the Mortality Rate?', *Risks*, 11(10):170
- Orlova, N. (2021) 'Rising Inequality in Life Expectancy by Socioeconomic Status', *North American Actuarial Journal*, 25(S1): S566-S581.
- Schinzinger, E., Denuit, M. M., and Christiansen, M. C. (2016) 'A Multivariate Evolutionary Credibility Model for Mortality Improvement Rates', *Insurance: Mathematics and Economics*, 69: 70 – 81.
- Schmeck, M. D., and Schmidli, H. (2021) 'Mortality Options: The Point of View of an Insurer', *Insurance: Mathematics and Economics*, 96(C): 98-115.
- Schnürch, S., Kleinow, T., and Korn, R. (2021) 'Clustering-Based Extensions of the Common Age Effect Multi-Population Mortality Model', *Risks*, 9(3), 45.
- Schnürch, S., Kleinow, T., Korn, R., and Wagner, A. (2022) 'The Impact of Mortality Shocks on Modelling and Insurance Valuation as Exemplified by Covid-19', *Annals of Actuarial Science*, 16(3): 498-526.
- Schnürch, S., Kleinow, T., and Wagner, A. (2023) 'Accounting for Covid-19-Type Shocks in Mortality Modeling: A Comparative Study', *Journal of Demographic Economics*, 89(3): 483-512.
- Schnürch, S., and Korn, R. (2022) 'Point and Interval Forecasts of Death Rates using Neural Networks', *ASTIN Bulletin*, 52(1): 333-360.
- Schrager, D. F. (2006) 'Affine Stochastic Mortality', *Insurance: Mathematics and Economics*, 38: 81–97.
- Scognamiglio, S. (2022a) 'Calibrating the Lee-Carter and the Poisson Lee-Carter Models via Neural Networks', *ASTIN Bulletin*, 52(2): 519-561.
- Scognamiglio, S. (2022b) 'Longevity Risk Analysis: Applications to the Italian Regional Data', *Quantitative Finance and Economics*, 6(1): 138-157.
- Scognamiglio, S., and Marino, M. (2022) 'Backtesting Stochastic Mortality Models by Prediction Interval-based Metrics', *Quality & Quantity*, 57(4), 3825-3847.
- Sevčíková, H., and Raftery, A. E. (2021) 'Probabilistic Projection of Sub-National Life Expectancy', *Journal of Official Statistics*, 37(3): 591-610.

- Shang, H. L. (2012) 'Point and Interval Forecasts of Age-Specific Life Expectancies: A Model Averaging Approach', *Demographic Research*, 27 (21): 593-644.
- Shang, H. L. (2016) 'Mortality and Life Expectancy Forecasting for a Group of Populations in Developed Countries: A Multilevel Functional Data Method', *Annals of Applied Statistics*, 10(3): 1639-1672.
- Shang, H. L. (2019) 'Dynamic Principal Component Regression: Application to Age-Specific Mortality Forecasting', *ASTIN Bulletin*, 49 (3): 619-645.
- Shang, H. L., and Haberman, S. (2018) 'Model Confidence Sets and Forecast Combination: An Application to Age-Specific Mortality', *Genus*, 74, 19.
- Shang, H. L., and Haberman, S. (2020) 'Retiree Mortality Forecasting: A Partial Age-Range or a Full Age-Range Model?', *Risks*, 8(3): 69.
- Shang, H. L., Haberman, S., and Xu, R. (2022) 'Multi-Population Modelling and Forecasting Life-table Death Counts', *Insurance: Mathematics and Economics*, 106: 239-253.
- Shang, H. L., and Hyndman, R. (2017) 'Grouped Functional Time Series Forecasting: An Application to Age-Specific Mortality Rates', *Journal of Computational and Graphical Statistics*, 26(2): 330-343.
- Shang, Z., Goovaerts, M., and Dhaene, J. (2011) 'A Recursive Approach to Mortality-linked Derivative Pricing', *Insurance: Mathematics and Economics*, 49: 240-248.
- Shao, A. W., Hanewald, K., and Sherris, M. (2015) 'Reverse Mortgage Pricing and Risk Analysis allowing for Idiosyncratic House Price Risk and Longevity Risk', *Insurance: Mathematics and Economics*, 63: 76-90.
- Shapovalov, V., Landsman, Z., and Makov, U. (2021) 'Exchangeable Mortality Projection', *European Actuarial Journal*, 11(1): 113-133.
- Sharma, N., Selvamuthu, D., and Natarajan, S. (2022) 'Variable Annuities Valuation under a Mixed Fractional Brownian Motion Environment with Jumps Considering Mortality Risk', *Applied Stochastic Models in Business and Industry*, 38(6): 1019-1038.
- Shen Y., and Siu T. K. (2013) 'Longevity Bond Pricing under Stochastic Interest Rate and Mortality with Regime Switching', *Insurance: Mathematics and Economics*, 52: 114-123.
- Sherris, M., Xu, Y. and Ziveyi, J. (2020) 'Cohort and Value-Based Multi-Country Longevity Risk Management', *Scandinavian Actuarial Journal*, 2020 (7): 650-676.
- Shi J., Shi Y., Wang P., Zhu W. D. (2023) 'Multi-population Mortality Modelling: A Bayesian Hierarchical Approach', *ASTIN Bulletin*; 10.1017/asb.2023.29
- Shi, Y., Tang, S., and Li, J. (2020) 'A Two-Population Extension of the Exponential Smoothing State Space Model with a Smoothing Penalisation Scheme', *Risks*, 8(3): 67.
- Shimizu, Y., Minami, Y., and Ito, R. (2021) 'Why Does a Human Die? A Structural Approach to Cohort-Wise Mortality Prediction Under Survival Energy Hypothesis', *ASTIN Bulletin*, 51(1): 191-219.
- Shimizu, Y., Shirai, K., Kojima, Y., Mitsuda, D., and Inoue, M. (2023) 'Survival Energy Models for Mortality Prediction and Future Prospects', *ASTIN Bulletin*, 53(2): 377-391.
- Siu, J., and Liu, Y. (2021) 'Recent Declines in Life Expectancy: Implication on Longevity Risk Hedging', *Insurance: Mathematics and Economics*, 99: 376-394.

- Sliwka, P., and Socha, L. (2022) ‘Application of Continuous Non-Gaussian Mortality Models with Markov Switchings to Forecast Mortality Rates’, *Applied Sciences*, 12: 6203.
- Spreeuw, J., Owadally, I., and Kashif, M. (2022) ‘Projecting Mortality Rates Using a Markov Chain’, *Mathematics*, 10(7): 1162.
- SriDaran, D., Sherris, M., Villegas, A., and Ziveyi, J. (2022) ‘A Group Regularisation Approach for Constructing Generalised Age-Period-Cohort Mortality Projection Models’, *ASTIN Bulletin*, 52(1): 247-289.
- Stevens, R., De Waegenare, A., and Melenberg, B. (2010), ‘Longevity Risk in Pension Annuities with Exchange Options: The Effect of Product Design’, *Insurance: Mathematics and Economics*, 46: 222-234.
- Su, K. C., and Yue, J. C. (2021) ‘A Synthesis Mortality Model for the Elderly’, *North American Actuarial Journal*, 25(S1): S457-S481.
- Summers, L. H. (2013) Speech at the IMF Fourteenth Annual Research Conference in Honor of Stanley Fischer, Washington D.C.
- Summers, L. H. (2014) ‘US Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound’, *Business Economics*, 49(2): 65-73.
- Sweeting, P. J. (2011) ‘A Trend-Change Extension of the Cairns-Blake-Dowd Model’, *Annals of Actuarial Science*, 5: 143–162.
- Tan, C. I., Li, J., Li, J. S.-H., and Balasooriya, U. (2014) ‘Parametric Mortality Indexes: From Index Construction to Hedging Strategies’, *Insurance: Mathematics and Economics*, 59, 285–299.
- Tan, K. S., Weng, C., and Zhang, J. (2022) Optimal Dynamic Longevity Hedge with Basis Risk’ *European Journal of Operational Research*, 297(1): 325-337.
- Tang, S., and Li, J. (2021) ‘Market Pricing of Longevity-linked Securities’, *Scandinavian Actuarial Journal*, 2021(5): 408-436.
- Tang, S., Li, J., and Tickle, L. (2022) ‘A New Fourier Approach under the Lee-Carter Model for Incorporating Time-Varying Age Patterns of Structural Changes’, *Risks*, 10(8): 147.
- Tang, S., Li, J., and Tickle, L. (2023) ‘A Hermite Spline Approach for Modelling Population Mortality’, *Annals of Actuarial Science*, 17(2): 243-284.
- Thatcher, A. R., Kannisto, V., and Vaupel, J. W. (1998) *The Force of Mortality at Ages 80 to 120*, Odense, Denmark: Odense University Press.
- Thwaites, G. (2015) ‘Why are Real Interest Rates so Low? Secular Stagnation and the Relative Price of Investment Goods’, Bank of England Staff Working Paper No 564; <https://www.bankofengland.co.uk/working-paper/2015/why-are-real-interest-rates-so-low-secular-stagnation-and-the-relative-price-of-investment-goods>
- Tomas, J., and Planchet, F. (2015) ‘Prospective Mortality Tables: Taking Heterogeneity into Account’, *Insurance: Mathematics and Economics*, 63: 169–190.
- Torri, T. and Vaupel, J. W. (2012) ‘Forecasting Life Expectancy in an International Context’, *International Journal of Forecasting*, 28(2): 519–531.
- Tsai, C. C.-L., and Cheng, E. S. (2021) ‘Incorporating Statistical Clustering Methods into Mortality Models to Improve Forecasting Performances’, *Insurance: Mathematics and Economics*, 99(C): 42-62.
- Tsai, C. C.-L., and Liang, X. (2018) ‘Application of Relational Models in Mortality Immunization’, *North American Actuarial Journal*, 22(4): 509-532.

- Tsai, C. C.-L., and Lin, T. (2017a) 'A Bühlmann Credibility Approach to Modeling Mortality Rates', *North American Actuarial Journal*, 21(2): 204-227.
- Tsai, C. C.-L., and Lin, T. (2017b) 'Incorporating the Bühlmann Credibility into Mortality Models to Improve Forecasting Performances', *Scandinavian Actuarial Journal*, 2017: 419-440..ca
- Tsai, J., Wang, J., and Tzeng, L. (2010) 'On the Optimal Product Mix in Life Insurance Companies using Conditional Value at Risk', *Insurance: Mathematics and Economics*, 46: 235-241.
- Tzeng, L. Y., Wang, J. L., and Tsai, J. T. (2011) 'Hedging Longevity Risk when Interest Rates are Uncertain', *North American Actuarial Journal*, 15: 201-211.
- Ungolo, F., Garces, L. P. D. M., Sherris, M., and Zhou, Y. (2023) 'Estimation, Comparison, and Projection of Multifactor Age-Cohort Affine Mortality Models', *North American Actuarial Journal*; 10.1080/10920277.2023.2238793
- United Nations (2007). *World Population Prospects: The 2006 Revision*, New York: United Nations.
- van Berkum, F., Antonio, K., and Vellekoop, M. H. (2016) 'The Impact of Multiple Structural Changes on Mortality Predictions', *Scandinavian Actuarial Journal*, 2016(7): 581-603.
- van Berkum, F., Antonio, K., and Vellekoop, M. H. (2017) 'A Bayesian Joint Model for Population and Portfolio-Specific Mortality', *ASTIN Bulletin*, 47(3): 681-713.
- van Berkum, F., Antonio, K., and Vellekoop, M. H. (2021) 'Quantifying Longevity Gaps Using Micro-level Lifetime Data', *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 184(2): 548-570.
- Venter, G., and Şahin, S. (2018) 'Parsimonious Parameterization of Age-Period-Cohort Models by Bayesian Shrinkage', *ASTIN Bulletin*, 48(1):1-22.
- Venter, G., and Şahin, Ş. (2022) 'Semiparametric Regression for Dual Population Mortality', *North American Actuarial Journal*, 26(3): 403-427.
- Villegas, A. M., and Haberman, S. (2014) 'On the Modelling and Forecasting of Socio-Economic Mortality Differentials: An Application to Deprivation and Mortality in England', *North American Actuarial Journal*, 18(1): 168-193.
- Villegas, A. M., Haberman, S., Kaishev, V. K., and Millossovich, P. (2017) 'A Comparative Study of Two-Population Models for the Assessment of Basis Risk in Longevity Hedges', *ASTIN Bulletin*, 47(3): 631-679.
- Villegas, A. M., Kaishev, V. K., and Millossovich (2018) 'StMoMo: An R Package for Stochastic Mortality Modeling', *Journal of Statistical Software*, 84: 1-38.
- Wan, C., and Bertschi, L. (2015) 'Swiss Coherent Mortality Model as a Basis for Developing Longevity De-Risking Solutions for Swiss Pension Funds: A Practical Approach', *Insurance: Mathematics and Economics*, 63: 66-75.
- Wang, C.-W., Huang, H.-C., and Liu, I.-C. (2011a) 'A Quantitative Comparison of the Lee-Carter Model under Different Types of Non-Gaussian Innovations', *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 675-696.
- Wang, C.-W., Huang, H.-C., and Liu, I.-C. (2013) 'Mortality Modeling with Non-Gaussian Innovations and Applications to the Valuation of Longevity Swaps', *Journal of Risk and Insurance*, 80: 775-798.

- Wang, C.-W., and Yang, S. (2013) ‘Pricing Survivor Derivatives with Cohort Mortality Dependence under the Lee–Carter Framework’, *Journal of Risk and Insurance*, 80: 1027–1056.
- Wang, C.-W., Yang, S., and Huang H.-C. (2015) ‘Modeling Multi-Country Mortality Dependence and its Application in Pricing Survivor Index Swaps – A Dynamic Copula Approach’, *Insurance: Mathematics and Economics*, 63: 30–39.
- Wang, C., Zhang, J., and Zhu, W. (2021a) ‘Neighbouring Prediction for Mortality’, *ASTIN Bulletin*, 51(3), 689–718.
- Wang, D., and Chan, W.-S. (2022) ‘Backcasting Mortality in England and Wales, 1600–1840’, *North American Actuarial Journal*, 26(1): 102–122.
- Wang, H., and Preston, S. H. (2009) ‘Forecasting United States Mortality using Cohort Smoking Histories’, *Proceedings of the National Academy of Sciences of the United States of America* 106: 393–8.
- Wang, H.-C., Yue, C.-S. J., Chang, T.-C., and Chang, T.-C. (2023a) ‘Morbidity Compression and Cancer Insurance’, *Journal of Demographic Economics*, 89(3): 465–482.
- Wang, H.-C., Yue, C.-S. J., and Chong, C.-T. (2018) ‘Mortality Models and Longevity Risk for Small Populations’, *Insurance: Mathematics and Economics*, 78: 351–359.
- Wang, J., Wen, L., Xiao, L., and Wang, C. (2023b) ‘Time-series Forecasting of Mortality Rates using Transformer’, *Scandinavian Actuarial Journal*; 10.1080/03461238.2023.2218859
- Wang, J. L., Hsieh, M., and Chiu, Y. (2011b) ‘Using Reverse Mortgages to Hedge Longevity and Financial Risks for Life Insurers: A Generalized Immunization Approach’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 697–717.
- Wang, J.L., Huang, H.-C., Yang, S.S., and Tsai, J.T. (2010) ‘An Optimal Product Mix for Hedging Longevity Risk in Life Insurance Companies: The Immunization Theory Approach’, *Journal of Risk and Insurance*, 77: 473–497.
- Wang, L., Chiu, M. C., and Wong, H. Y. (2021b) ‘Volterra Mortality Model: Actuarial Valuation and Risk Management with Long-range Dependence’, *Insurance: Mathematics and Economics*, 96(C): 1–14.
- Wang, L., Valdez, E., and Piggott, J. (2008) ‘Securitization of Longevity Risk in Reverse Mortgages’, *North American Actuarial Journal*, 12: 345–371.
- Wang, P., Pantelous, A. A., and Vahid, F. (2023c) ‘Multi-Population Mortality Projection: The Augmented Common Factor Model with Structural Breaks’, *International Journal of Forecasting*, 39(1): 450–469.
- Wang, Z., and Li, J. S.-H. (2016) ‘A DCC-GARCH Multi-population Mortality Model and its Applications to Pricing Catastrophic Mortality Bonds’, *Finance Research Letters*, 16(C): 103–111.
- Weinert, J. H., and Gründl, H. (2021) ‘The Modern Tontine’, *European Actuarial Journal*, 11: 49–86.
- Wen, J., Cairns, A.J.G., and Kleinow, T. (2021) ‘Fitting Multi-Population Mortality Models to Socio-Economic Groups’, *Annals of Actuarial Science*, 15: 144–172.
- Wen, J., Kleinow, T., and Cairns, A.J.G. (2020) ‘Trends in Canadian Mortality by Pension Level: Evidence from the CPP and QPP’, *North American Actuarial Journal*, 24: 533–561.
- Wen, J., Cairns, A.J.G., and Kleinow, T. (2023) ‘Modelling Socio-economic Mortality at Neighbourhood Level’, *ASTIN Bulletin*, 53: 285–310.

- Wills, S., and Sherris, M. (2010) ‘Securitization, Structuring and Pricing of Longevity Risk’, *Insurance: Mathematics and Economics*, 46: 173-185.
- Wilmoth, J. R. and Horiuchi, S. (1999) ‘Rectangularization Revisited: Variability of Age at Death within Human Populations’, *Demography*, 36(4): 475–495.
- Wilmoth, J. R., Zureick, S., Canudas-Romo, V., Inoue, M., and Sawyer, C. (2012) ‘A Flexible Two Dimensional Mortality Model for Use in Indirect Estimation’, *Population Studies*, 66(1): 1–28.
- Wong, J. S. T., Forster, J. J., and Smith, P. W. F. (2018) ‘Bayesian Mortality Forecasting with Overdispersion’, *Insurance: Mathematics and Economics*, 83:206-221.
- Wong, J. S. T., Forster, J. J., and Smith, P. W. F. (2023) ‘Bayesian Model Comparison for Mortality Forecasting’, *Journal of the Royal Statistical Society Series C Applied Statistics*; DOI: 10.1093/jrssc/qlad021
- Wong, K., Li, J., and Tang, S. (2020) ‘A Modified Common Factor Model for Modelling Mortality Jointly for Both Sexes’, *Journal of Population Research*, 37: 181–212.
- Wong, T., Chiu, M., Wong, H. (2017) ‘Managing Mortality Risk with Longevity Bonds when Mortality Rates are Cointegrated’, *Journal of Risk and Insurance*, 84(3): 987-1023.
- Xiao, H., Zhao, M., Li, X., and Bai, A. (2023) ‘An Innovation Mortality Prediction Model with Cohort Effect’, *Communications in Statistics-Theory and Methods*; 10.1080/03610926.2023.2264998
- Xu, Y., Sherris, M., and Ziveyi, J. (2020) ‘Market Price of Longevity Risk for a Multi-Cohort Mortality Model with Application to Longevity Bond Option Pricing’, *Journal of Risk and Insurance*, 87(3): 571-595.
- Yan, H., Peters, G., and Chan, J. (2021) ‘Mortality Models Incorporating Long Memory for Life Table Estimation: A Comprehensive Analysis’, *Annals of Actuarial Science*, 15(3): 567-604.
- Yang, B., Li, J., and Balasooriya, U. (2015) ‘Using Bootstrapping to Incorporate Model Error for Risk-Neutral Pricing of Longevity Risk’, *Insurance: Mathematics and Economics*, 62, 16–27.
- Yang, B., Li, J., and Balasooriya, U. (2016) ‘Cohort Extensions of the Poisson Common Factor Model for Modelling Both Genders Jointly’, *Scandinavian Actuarial Journal*, 2016(2), 93-112.
- Yang, S., and Zhou, K. Q. (2023) ‘On Risk Management of Mortality and Longevity Capital Requirement: A Predictive Simulation Approach’, *Risks*, 11(12):206.
- Yang, S. S. (2011) ‘Securitization and Tranching Longevity and House Price Risk for Reverse Mortgage Products’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 648-674.
- Yang, S. S., Huang, H.-C., and Yeh, Y.-Y. (2019) ‘Optimal Longevity Hedging Framework for Insurance Companies Considering Basis and Mispricing Risks’, *Journal of Risk and Insurance*, 86 (3): 783-805.
- Yang, S. S., and Wang, C.-W. (2013) ‘Pricing and Securitization of Multi-Country Longevity Risk with Mortality Dependence’, *Insurance: Mathematics and Economics*, 52: 157-169.
- Yang, S. S., Yeh, Y.-Y., Yue, J. C., and Huang, H.-C. (2021) ‘Understanding Patterns of Mortality Homogeneity and Heterogeneity across Countries and Their Role in

- Modelling Mortality Dynamics and Hedging Longevity Risk', *North American Actuarial Journal*, 25(S1): S132-S155.
- Yang, S. S., Yue, J., and Huang, H.-C. (2010) 'Modeling Longevity Risks using a Principal Component Approach: A Comparison with Existing Stochastic Mortality Models', *Insurance: Mathematics and Economics*, 46: 254-270.
- Yang, S. S., Yueh, M.-L., and Tang, C.-H. (2008) 'Valuation of the Interest Rate Guarantee Embedded in Defined Contribution Pension Plans', *Insurance: Mathematics and Economics*, 42: 920-934.
- Yue, J. C., and Huang, H.-C. (2011) 'A Study of Incidence Experience for Taiwan Life Insurance', *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 718-733.
- Yue, J. C., Wang, H.-C., Leong, Y.Y., and Su W.-P. (2018) 'Using Taiwan National Health Insurance Database to Model Cancer Incidence And Mortality Rates', *Insurance: Mathematics and Economics*, 78: 316-324.
- Yue, J. C., Wang, T.-Y., and Wang, H.-C. (2021) 'Using Graduation to Modify the Estimation of Lee-Carter Model for Small Populations', *North American Actuarial Journal*, 25(S1): S410-S420.
- Zeddouk, F., and Devolder, P. (2020a) 'Longevity Modelling and Pricing under a Dependent Multi-Cohort Framework', *Risks*, 8: 121.
- Zeddouk, F., and Devolder, P. (2020b) 'Mean Reversion in Stochastic Mortality: Why and How?', *European Actuarial Journal*, 10(2): 499–525.
- Zeddouk, F., and Devolder, P. (2023) 'Pricing and Hedging of Longevity Basis Risk through Securitisation', *ASTIN Bulletin*; 10.1017/asb.2023.37
- Zelenko, I. (2014) 'Longevity Risk and the Stability of Retirement Systems: The Chilean Longevity Bond Case', *Journal of Alternative Investments*, 17 (1): 35–54
- Zhang, X., Huang, F., Hui, F.K.C., and Haberman, S. (2023) 'Cause-of-Death Mortality Forecasting Using Adaptive Penalized Tensor Decompositions', *Insurance: Mathematics and Economics*, 111: 193-213.
- Zhou, H., Zhou, K. Q., and Li, X. (2022) 'Stochastic Mortality Dynamics Driven by Mixed Fractional Brownian Motion', *Insurance: Mathematics and Economics*, 106(C): 218-238.
- Zhou, K. Q., and Li, J. S.-H. (2017) 'Dynamic Longevity Hedging in the Presence of Population Basis Risk: A Feasibility Analysis from Technical and Economic Perspectives', *Journal of Risk and Insurance*, 84(S1): 417-437.
- Zhou, K. Q., and Li, J. S.-H. (2019) 'Delta-Hedging Longevity Risk under the M7–M5 Model: The Impact of Cohort Effect Uncertainty and Population Basis Risk', *Insurance: Mathematics and Economics*, 84:1-21.
- Zhou, K. Q., and Li, J. S.-H. (2020) 'Asymmetry in Mortality Volatility and its Implications on Index-based Longevity Hedging', *Annals of Actuarial Science*, 14(2): 278–301.
- Zhou, K. Q., and Li, J. S.-H. (2021) 'Longevity Greeks: What do Insurers and Capital Market Investors Need to Know?', *North American Actuarial Journal*, 25(S1): S66-S96.
- Zhou, K. Q., and Li, J. S.-H. (2023) 'The Impact of Long Memory in Mortality Differentials on Index-based Longevity Hedges', *Journal of Demographic Economics*, 89(3):533-552.

- Zhou, R. (2019) ‘Modelling Mortality Dependence with Regime-Switching Copulas’, *ASTIN Bulletin*, 49 (2): 373-407.
- Zhou, R., and Ji, M. (2021) ‘Modelling Mortality Dependence: An Application of the Dynamic Vine Copula’, *Insurance: Mathematics and Economics*, 99(C): 241-255.
- Zhou, R., and Li, J. S.-H. (2013) ‘A Cautionary Note on Pricing Longevity Index Swaps’, *Scandinavian Actuarial Journal*, 2013(1): 1-23.
- Zhou, R., and Li, J. S.-H. (2022) ‘A Multi-parameter-level Model for Simulating Future Mortality Scenarios with COVID-alike Effects’, *Annals of Actuarial Science*, 16(3): 453-477.
- Zhou, R., Li, J. S.-H., and Tan, K. S. (2011) ‘Economic Pricing of Mortality-Linked Securities in the Presence of Population Basis Risk’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 544-566.
- Zhou, R., Li, J. S.-H., and Tan, K. S. (2013) ‘Pricing Standardized Mortality Securitizations: A Two-Population Model with Transitory Jump Effects’, *Journal of Risk and Insurance*, 80: 733-774.
- Zhou, R., Li, J. S.-H., and Tan, K. S. (2015) ‘Modeling Longevity Risk Transfers as Nash Bargaining Problems: Methodology and insights’, *Economic Modelling*, 51:460-472.
- Zhou, R., Wang, Y., Kaufhold, K., Li, J. S.-H., and Tan, K. S. (2014) ‘Modeling Period Effects in Multi-Population Mortality Models: Applications to Solvency II’, *North American Actuarial Journal*, 18(1): 150-167.
- Zhu, N., and Bauer, D. (2011) ‘Applications of Forward Mortality Factor Models in Life Insurance Practice’, *Geneva Papers on Risk and Insurance – Issues and Practice*, 36: 567-594.
- Zhu, N., and Bauer, D. (2013) ‘Coherent Pricing of Life Settlements under Asymmetric Information’, *Journal of Risk and Insurance*, 80: 827-851.
- Zhu, N., and Bauer, D. (2014) ‘A Cautionary Note on Natural Hedging of Longevity Risk’, *North American Actuarial Journal*, 18(1): 104-115.
- Zhu, N., and Bauer, D. (2022) ‘Modeling the Risk in Mortality Projections’, *Operations Research*, 70(4):2069-2084.
- Zhu, W., Tan, K. S., and Wang, C.-W. (2017) ‘Modeling Multicountry Longevity Risk With Mortality Dependence: A Lévy Subordinated Hierarchical Archimedean Copulas Approach’, *Journal of Risk and Insurance*, 84(S1): 477-493.
- Zhu, X., and Zhou, K.Q. (2023) ‘Smooth Projection of Mortality Improvement Rates: A Bayesian Two-Dimensional Spline Approach’, *European Actuarial Journal*, 13: 277–305.