Longevity Risk and Capital Markets: The 2019-20 Update

David Blake and Andrew J. G. Cairns[+]

3 April 2021

This Special Issue of the *Insurance: Mathematics and Economics* contains 16 contributions to the academic literature all dealing with longevity risk and capital markets. Draft versions of the papers were presented at *Longevity 15: The Fifteenth International Longevity Risk and Capital Markets Solutions Conference* that was held in Washington DC on 12-13 September 2019. It was hosted by 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. 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 Cass Business School 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.

[+] David Blake [D.Blake@city.ac.uk] is Professor of Pension Economics and Director of the Pensions Institute, City, University of London, UK. Andrew J. G. Cairns [A.J.G.Cairns@hw.ac.uk] is Professor of Financial Mathematics at Heriot-Watt University, Edinburgh. 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 Sharmila Harris for their superb organization of the conference.

[1] Blake et al. (2013).

Longevity 2: 2006

The second conference (*L2*) was held in April 2006 in Chicago and hosted by the Katie School at Illinois State University.[2] 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 of UK corporations.[3] Goldman Sachs announced it was setting up such a buy-out company itself (Rothesay 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.[4] 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.[5] 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;[6] 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.[7] 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

---

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

[3] 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.

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

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

[6] www.lifemetrics.com

[7] 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.

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 clearing house for onward distribution of life settlement assets, whether individually or in structured form.[8]

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 contract[9] 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, covering £16bn of pension liabilities, was the longevity swap for the British Telecom Pension Scheme, arranged by the Prudential Insurance Co of America (PICA)[10] 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.[11]

Longevity 4: 2008

The fourth conference (*L4*) was held in Amsterdam on 25-26 September 2008. It was hosted by Netspar Network for Studies on Pensions, Aging and Retirement and the Pensions Institute.[12] 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. In 2009, survivor swaps began to be offered to the market based on Deutsche Börse's Xpect Cohort Indices.

Longevity 5: 2009

The fifth conference (*L5*) was held in New York on 25-26 September 2009.[13] On 1 February 2010, the Life and Longevity Markets Association (LLMA)[14] was established in London. Its current members are Aviva, AXA, Deutsche Bank, J.P. Morgan, Morgan Stanley, Prudential

[8] In 2010, National Financial Partners became the sole owner of ILS/ILA.
[9] Coughlan et al. (2007).
[10] 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).
[11] 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.
[12] The conference proceedings for *L4* were published in the February 2010 issue of *Insurance: Mathematics and Economics*.
[13] The conference proceedings for *L5* were published in the *North American Actuarial Journal* (Volume 15, Number 2, 2011).
[14] www.llma.org

(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.

Longevity 6: 2010

The sixth conference (*L6*) was held in Sydney on 9-10 September 2010.[15] 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 are 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.

In January 2011, the Irish government announced that it would issue bonds that allow the creation of sovereign annuities.[16] This followed a request from the Irish Association of 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 have 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)[17] formed a life settlement and derivatives committee and announced that it was developing a life

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

[16] 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 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.

[17] www.islsp.org

settlement index. The purpose of the index is 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 is 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.

The first international longevity reinsurance 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 7: 2011

The seventh conference (*L7*) was held at the House of Finance, Goethe University, Frankfurt, Germany on 8-9 September 2011.[18]

In February 2012, Deutsche Bank executed a massive €12 billion index-based longevity solution 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 swap[19] is out of the money, the amount of longevity risk actually transferred is far less than that suggested by the €12 billion notional amount. 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 has been passed to investors in the form of private bonds and swaps.

In June 2012, General Motors Co. (GM) announced a huge deal to transfer up to $26 billion 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 December 1, 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.[20] 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

[18] The conference proceedings for *L7* were published in the September 2013 issue of the *Journal of Risk and Insurance*.
[19] It is structured as a bull call option spread – see Michaelson and Mullholland (2014).
[20] In fact, the lump sum was only being offered to limited cohorts of plan members.

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 $3.6 billion buy-out of the pension obligations of its white-collar retirees. Also in October 2012, Verizon Communications executed a $7.5 billion bulk annuity buy-in with PICA. The buy-out deals in the U.S. in 2012 amounted to $36 billion.

Longevity 8: 2012

The eighth conference (*L8*) was held at the University of Waterloo, Ontario, Canada on 7-8 September 2012.[21]

In February 2013, the first medically underwritten bulk annuity (MUBA) transaction was executed in the UK by the UK insurer Partnership.[22] 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.[23] In April 2016, the two largest UK medical underwriters, Partnership and Just Retirement merged to form the Just Group valued at £16bn.

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.

Longevity 9: 2013

The ninth conference (*L9*) was held in Beijing, China on 6-7 September 2013.[24]

[21] The conference proceedings for *L8* were published in the *North American Actuarial Journal* (Volume 18(1), 2014).
[22] Harrison and Blake (2013).
[23] Hunt and Blake (2016).
[24] The conference proceedings for *L9* were published in *Insurance: Mathematics and Economics* (Volume 63, July, 2015).

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 risk's 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 LLMA longevity indices. LEOs will be traded over-the-counter under a standard ISDA[25] 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 longevity risk transfer to capital markets investors and reinsurers, including SCOR. Société Générale was the intermediary in the €1.4 billion 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)).

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.[26] 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 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.

[25] International Swaps and Derivatives Association; https://www.isda.org/
[26] Towers Watson (2015) *Corporate Briefing*, April.

Longevity 10: 2014

The tenth conference (*L10*) was held at Universidad Diego Portales in Santiago, Chile on 3-4 September 2014.[27]

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 the Longevity Direct platform was the £1.5bn longevity swap executed by the Merchant Navy Officers Pension Fund (MNOPF) in January 2015 which was insured by MNOPF 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. For example, in 2014, Warren Buffett's Berkshire Hathaway agreed to a £780m quota-reinsurance deal with the Pension Insurance Corporation (PIC), a specialist UK buy-out insurer.[28] Similarly, in August 2014, AXA France executed a €750m longevity swap with Hannover Re.

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 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 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. 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).

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

[28] Reported in *Financial News*, 14 July 2014.

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 II[29] 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%.[30]

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 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,[31] 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.[32] 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.[33] 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'.

---

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

[30] *Financial News*, 28 March–3 April 2016.

[31] Sun Life Financial uses the RMS Longevity Risk Model, which RMS describes as a 'structural meta-model of geroscience advancement'.

[32] Eckler Consultants (2017) *Pension Risk Transfer Report*, November.

[33]http://www.artemis.bm/blog/2015/06/26/delta-lloyd-rga-in-second-e12-billion-longevity-swap-deal/

Longevity 11: 2015

The eleventh conference (*L11*) was hosted by Université Lyon 1, Lyon, France on 7-8 September 2015.[34]

In April 2016, Willis Towers Watson (WTW) 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 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 too high.

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)[35] 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.[36]

2016 saw the beginning of a trend towards consolidation amongst insurance companies involved in the longevity risk transfer business in the UK. For example, 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. Similarly, 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 programme 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

---

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

[35] This is the regulatory authority for insurance companies in the UK.

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

inadequate return on capital and to transfer that capital to its growing businesses in Asia.[37] 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.

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.[38] 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).[39] Figure 1 shows the growth of the global market in longevity risk transfer between 2007 and 2020. A total of $620bn in transactions have been completed during this period in the UK, the US and Canada alone.

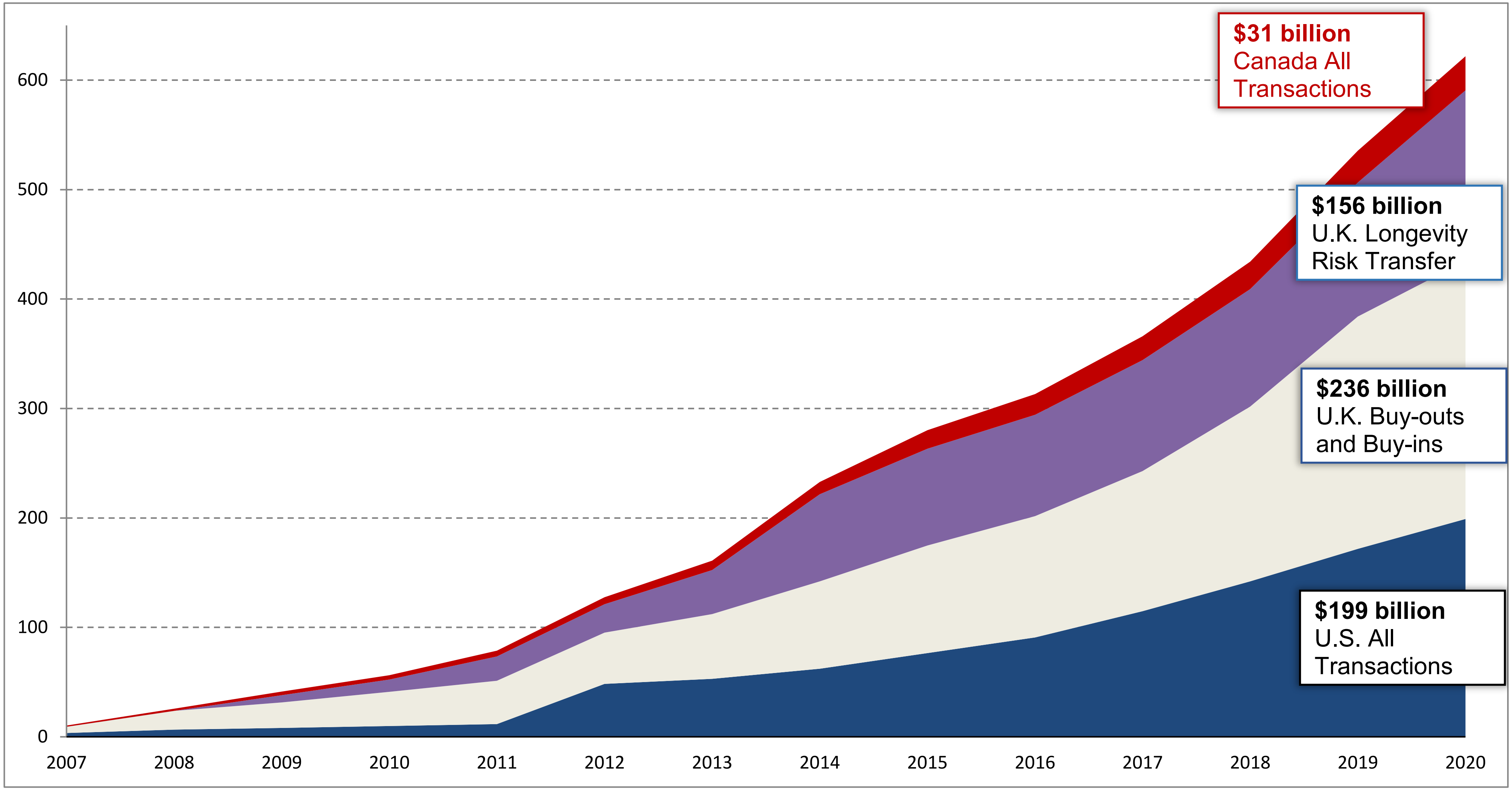
Longevity 12: 2016

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]

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 are PIC and L&G, with market shares of 37% and 30%, respectively. The others are 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'.[41]

[37] https://www.ftadviser.com/pensions/2016/12/05/prudential-seeks-buyers-for-45bn-annuity-business/
[38] LCP, *Professional Pensions* (15 December 2016 and 26 January 2017). Since 2007, some 92 buy-ins have been completed.
[39] www.artemis.bm/library/longevity_swaps_risk_transfers.html.
[40] The conference proceedings for *L12* were published in volume 25(S1) of the *North American Actuarial Journal* in 2021.
[41] 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*.

Figure 1: Cumulative Pension Risk Transfers by Product and Country, $bn, 2007-2020



Data in USD billions. Cumulative totals. Sources: LIMRA, Hymans Robertson, LCP, WTW and Prudential Financial, Inc. (PFI) analysis of EY, 31 December 2020.

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 Reinsurance 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.[42] 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.[43] In November 2017, PIC executed a £900m longevity swap with PICA, while in December 2017, L&G executed a £600m longevity swap with PICA.[44]

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 structure is similar to the 2013 Aegon tail-risk deal arranged by Société Générale and builds on subsequent work including Michaelson and Mulholland (2015) and Cairns and El Boukfaoui (2018). While the term of the transaction is 20 years, NN Life is protected over a longer time period via a commutation function[45] 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 relief and effective risk transfer over time.[46, 47]

In order to reduce the costs of de-risking, pension plans are encouraged to perform some liability reduction exercises, the key ones being:[48]

---

42 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.

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

44 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.

45 The role of the 'commutation function' is to 'compress' the risk period. As explained in Michaelson and Mulholland (2015, 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'.

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

47 https://www.nn-group.com/Investors/Capital-Markets-Day-2017.htm

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

- 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 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.[49] 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.[50]
- 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.

Innovation is a continuing feature of this market. Some examples include (see, e.g., Legal & General and Engaged Investor, 2016):[51]

- 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.[52]
- 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.
- 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

[49] Hannah Godfrey (2017) DB transfer values back on the rise in August, *Professional Adviser*, 7 September.
[50] Sophie Smith (2019) DB transfer values in record fall – XPS, *Pensions Age*, 7 November.
[51] Legal & General and Engaged Investor (2016) *De-risking Journeys of Mid-sized Pension Schemes*, June.
[52] 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.

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.[53]

- Automated bulk plan transfers – to reduce risks (introduced in November 2017 by Scottish Widows and Standard Life).[54]
- 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 or 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.[55]
- 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.[56]
- 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 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.

---

[53] 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'.

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

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

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

- 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.[57]
- 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.[58] 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.[59] Third, their longevity risk is greater, because the longevity improvement assumption used for pricing has greater reliance on the assumed long-run trend.[60] 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 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.[61]

---

[57] 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.

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

[59] 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.

[60] 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.

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

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 is, 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'.[62]

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.[63] In particular, there was no longer a requirement to purchase an annuity.[64] 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 yields (which led to a corresponding fall in annuity rates) arising from the government's quantitative easing programme 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.[65] 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 enhanced), Hodge Lifetime (standard only), Just Group (enhanced only), L&G (standard and enhanced) and Scottish Widows (standard and enhanced).[66]

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

---

[62] 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 of writing, there were significant human resource bottlenecks in some parts of the transaction chain, in particular, a shortage of qualified lawyers.

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

[64]https://www.pensionsadvisoryservice.org.uk/about-pensions/pension-reform/freedom-and-choice

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

[66] *Source: Hargreaves Lansdown, August 2017.* Scottish Widows introduced a standard annuity in September 2019.

before they die. A recent study by Just Group found that UK men aged 40-54 expect to live until 78.9 years on average, whereas official estimates of their life expectancy is 87.5; the figures for women are 80.5 and 90.1.[67]

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)[68] 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,[69] Mutual of America, and CUNA Mutual. Athene wrote more than $2bn of business in 2017. A total of $24.7bn pension risk transfers were 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 are 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.[70]

---

[67] 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.
[68] See Dowd et al. (2019).
[69] Athene is majority owned by private equity company Apollo Global Management, LLC.
[70] Navigating you through your de-risking journey: Overseas, *Aon Risk Settlement Market Review 2018*.

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 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.[71]

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 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 PPF, this leaves leaves potentially 2,000 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.[72]

The business models of the two consolidators is 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

[71] The conference proceedings for *L13* were published in volume 25(S1) of the *North American Actuarial Journal* in 2021.
[72] Quoted in Mona Dohle (2020) Superfunds - New entrants to the DB consolidation market, *Portfolio Institutional*, 17 August.

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 intends 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.[73]

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.[74] Both the Pension Superfund and Clara-Pensions aim to undercut insurance buy-out pricing by up to 10-15%.[75] The two consolidators justify themselves as filling a gap between a full insurance buy-out and schemes entering into the Pension Protection Fund (PPF) following the insolvency of their sponsor.[76] 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 of writing still considering an authorization, supervision and solvency regime.[77]

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

---

[73] 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).

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

[75] *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

[76] 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. 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/

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

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:[78]

- 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.[79] 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.[80]
- 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

[78] 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*).

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

[80] 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 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. The proposed transfer was part of Prudential's demerging its asset management and UK/European life insurance businesses under the M&G brand.

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.[81] 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.[82]
- 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 Zurich[83] 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, '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

[81] 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.

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

[83] 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.

15,000 pensioners and 7,200 deferred members, thereby avoiding entering the UK Pension Protection Fund.

- In December, PIC executed another longevity swap, this time with SCOR, covering 8,000 pensioners and valued at £1.2bn.[84]

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.[85]

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.[86]

A total of £43.8bn longevity risk transfer deals were announced for the UK in 2019.[87] XPS reported that for a buy-out for a medium-sized scheme, pensioner member transfers used a

---

[84] This brought the total value of the deals between the two companies to £2.2bn.

[85] 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/

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

[87] *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 (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 £100mn and £1bn, and 6% of deals were below £100mn.

Total assets and asset allocations of the main UK PRT providers 2019

	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	-	25	-	-		-	-	-

'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.'.[88] Willis Towers Watson reported an average buy-in price at 0.15% p.a. above gilts.[89] Highlights included:

- In January, PIC invested £125m in Exeter University accommodation in order to generate index 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).
- 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

residential mortgages (%)								
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*								

88 *XPS Risk Transfer News*, issue 10/19.
89 Figure 2 in Willis Towers Watson *De-risking Report 2020*, January.

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'.[90]
- 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.[91]
- 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 maintain this arrangement, allowing deferred members to 'consider their options' prior to a full buy-out.[92]
- 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 – 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, spilt 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 will convert to a full buy-out in 2020 or 2021 at an additional cost of £800m.

[90] Susanna Rust (2019) HSBC pension scheme strikes £7bn longevity risk transfer, *IPE*, 6 August.
[91] https://www.artemis.bm/news/prudential-in-longevity-reinsurance-deal-for-pension-insurer-phoenix/
[92] Nick Reeve (2019) L&G backs 'innovative' buy-in for Hitachi UK pension scheme, *IPE*, 14 August.

- 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.[93] 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 intermediary and there will be greater transparency since all parties will have access to the latest version of the ledger database.[94]
- 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

---

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

[94] https://www.professionalpensions.com/news/3077264/-deploys-blockchain-technology-streamline-pension-reinsurance

was advised in this deal by Willkie Farr & Gallagher, while Phoenix was advised by CMS and Eversheds Sutherland.[95]

- 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 and fulfilled by L&G. Prudential (UK), while remaining a UK-registered company, is closing down its UK operations in favour of growing its business 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 2017 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.[96]
- 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.
- 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%, which although low by historical standards, exceeded the 3% that a lower-risk fund recommended as a sustainable withdrawal rate.[97]

There are a number of reasons explaining the strength of the UK longevity risk transfer market in 2018 and 2019. First, funding levels have improved as a result of 1) deficit reduction contributions and strong equity returns, which have increased asset values, and 2) lower liability values due to a combination of higher interest rates and lower mortality improvements since 2011;[98] UK funds exhibited the first surplus in aggregate since 2011.[99] Second, there has been an increase in capital and competition from insurers which

[95] Holly Roach (2019) PICA launches reinsurance counterparty to back UK bulk annuities, *Professional Pensions*, 5 August.
[96] Susanna Rust (2019) Energy scheme completes rare longevity swap to buy-in conversion, *IPE*, 13 November.
[97] Greg Nielson (2019) Glimmers of an annuity market renaissance, *Retirement Planner*, 7 November.
[98] This is discussed later.
[99] 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,

have recruited heavily and so have more staff to model pension scheme mortality, provide price quotations and implement transactions. Third, there has been 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 has been increasing standardization of the models used to execute transfers, with three dominant examples: intermediated, pass through, and captive. Fifth, insurers have been increasing their investment in high yielding illiquid matching assets, such as infrastructure, housing and urban regeneration, and equity release, and have 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 has 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 tends 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 helps to reduce the capital an insurer is required to hold.[100] Mercer have 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.[101]

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

- RGA Life Reinsurance Company of Canada, covering 45,000 Manulife Canadian annuitants (February).
- PartnerRe, covering 25,000 Manulife annuitants (March and May).
- Canada Life Re, €5.5bn, covering 150,000 in-payment and deferred pensioners liabilities of Dutch firm VIVAT (March).
- Canada Life Re, €12bn, for Dutch insurer Aegon (December).[102]

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.

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, were 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

---

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).

[100] Attractive pricing opportunities for buy-in/buy-out, XPS Pensions, Briefing Note No, 2, June 2018.

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

[102] https://www.artemis.bm/news/aegon-gets-e12bn-longevity-reinsurance-cover-from-canada-life-re/

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 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 categories of risk. Liability is limited to assets of the SPV and the vehicle is unrated. The benefit to insurers is that sidecars can provide protection against exposure to peak longevity risks,[103] 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

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

supplied mainly by private equity investors, including Apollo, Athene's parent company, Crestview Partners and Reverence Capital Partners.[104]

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.[105]

In February, the $400m Leo Re Ltd. 2018-1 collateralized reinsurance sidecar was executed 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 with a reinsurer, for a proportion of the counterparties' underwriting book, thereby sharing in the cedents' risks and underwriting returns.[106]

In July, 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.[107]

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

---

[104] 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/

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

[106] 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/

[107] 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/

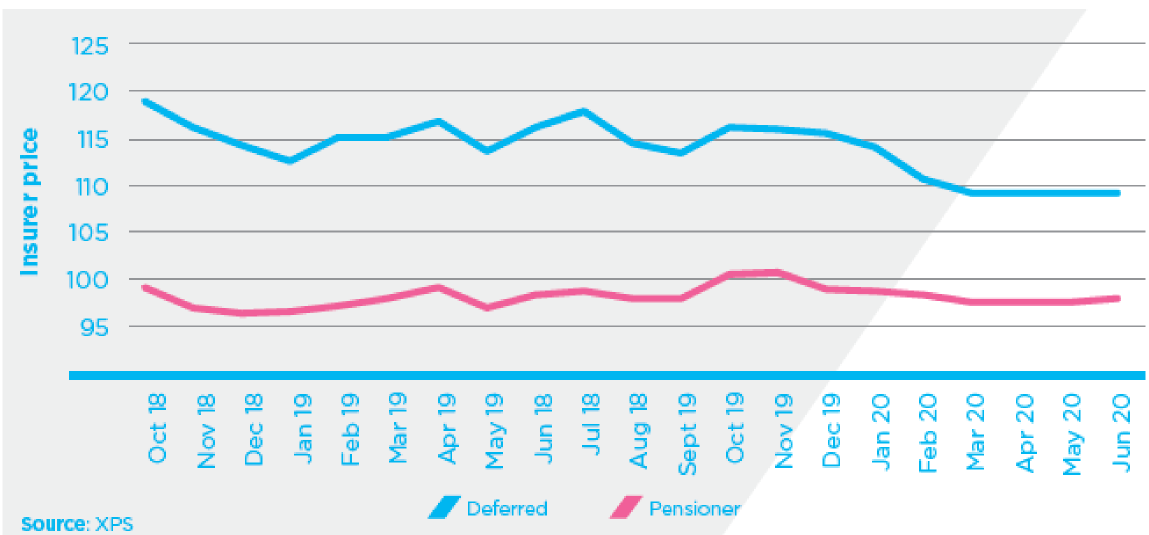
too many insurance companies in a market which is consolidating..[and the acquisition will] give us the opportunity to capture significant cost and capital synergies'.[108]

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 costs and time efficient – in a similar manner as the ISDA Master Agreement.[109]

2020 was also a near record year for the longevity risk transfer market in the UK. 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 Pension Insurance Corporation both on 19%.[110]

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, while the pricing of deferred pensioner liabilities was based on a 'gilts – 0.35% p.a.' liability. 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 2.[111]

Figure 2: Bulk annuity pricing 2018-2020 – buy-out price relative to £100 liability on a gilts flat basis



108 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.

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

110 UK. Pension longevity risk transfers reach record-breaking £55.8bn in 2020, *Pension Policy International*, 19 March 2021. The full list of UK longevity swaps since 2009 is given in Appendix 2.

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

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'.112
- 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.[113]
- 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 Scheme No.1, Lloyds Bank Pension Scheme No.2 and 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 reinsurancer.[114]
- 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.[115]
- 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.[116]
- In February, PICA executed a $6bn reinsurance transaction with Rothesay Life.[117]
- 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). The APP hedges the scheme's investment risk by protecting

[112] 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

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

[114] 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.

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

[116] 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.

[117] Ditto.

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.[118]

- In March, the Xylem UK Pension Plan completed a £255m bulk annuity transaction with Rothesay Life, covering around 2,500 final salary section members.[119]
- In March, L&G announced that it executed eight PRT deals worth £261m, ranging in size between £2.2m and £80m.[120]
- 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.[121]
- Also in May, L&G completed a £70m buy-in for the ICI Pension Fund, the fund's 17th de-risking deal.[122]
- 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.[123]
- In June, PIC executed a £280m longevity reinsurance deal with MetLife.[124]
- 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 Reinsurance.125
- 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'.[126]
- 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

---

[118] AIB UK scheme completes £1.1bn de-risking deal, *IPE*, 13 February 2020.
[119] Xylem UK Pension Plan secures £255m bulk annuity deal, *Pensions Age,* 2 March 2020.
[120] L&G completes £261mn of pension risk transfer deals in March, *Pension Policy International*, 3 April 2020.
[121] L&G agrees £650m buy-in with 3i scheme, *Professional Pensions*, 27 May 2020.
[122] ICI fund teams up with Legal & General for 17th buy-in, *IPE*, 13 August 2020.
[123] Willis pension scheme strikes £1bn longevity hedge with Munich Re, *IPE*, 30 June 2020.
[124] https://www.artemis.bm/news/metlife-enters-uk-longevity-reinsurance-market-with-pic-transaction/
[125] UBS UK pension scheme enters into £1.4bn longevity hedge, *IPE*, 7 July 2020.
[126] £5m deal shows small schemes' ability to access bulk annuity market, *IPE*, 22 July 2020.

712 retirees. The scheme had entered the Pension Protection Fund assessment 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 benefits compared with those available from the PPF, but less than those available from a full buy-out.[127]

- Also in July, UBS executed a £1.4bn longevity swap with Zurich.[128]
- 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.[129]
- 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.[130]
- In October, the Old British Steel Pension Scheme agreed a £2bn buy-in covering 30,000 members with Pension Insurance Corporation, with a buy-out expected in 2021.[131]
- In October, Rothesay executes a $320m longevity reinsurance deal with MetLife.[132]
- 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.[133]
- In November, the Prudential 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.[134]
- Also in November, the £1.4bn Baker Hughes UK pension plan completed a £100m buy-in with Just Group.
- Smiths Group completes a £290m buy-in with Aon as consultant in the August-December period.[135]
- In December, the Barclays Bank UK Retirement Fund completed a £5bn longevity swap transaction with Reinsurance Group of America. 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

---

[127] Pension scheme of collapsed rural retailer agrees £100m bulk annuity, *IPE*, 30 July 2020.
[128] *Aon's Risk Settlement Market Review 2020.*
[129] Littlewoods scheme completes de-risking with £930m buy-in, *IPE*, 12 August 2020.
[130] Louron Pratt (2020) Hitachi UK completes £275 million pensions buy-in transaction, Employee Benefits, 26August; https://employeebenefits.co.uk/hitachi-pensions-buy-in-transaction/
[131] Pension Insurance Corporation buys British Steel pension fund in £2bn deal, *Financial News,* 22 October 2020.
[132] https://www.artemis.bm/news/metlife-reinsures-320m-of-pension-longevity-risk-for-rothesay-life/
[133] M&S tops up de-risked pensioner liabilities with £750m set of buy-ins, *IPE*, 4 November 2020.
[134] Prudential Staff Pension Scheme agrees £3.7bn longevity swap, *IPE*, 11 November 2020.
[135] *Aon's Risk Settlement Market Review 2020.*

appetite of the global reinsurance market to take on pension fund longevity risk, even in these challenging times'.[136]

- 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 Reinsurance. The swap covers around one-third of the scheme's pensioner and dependant members.[137]
- In December, L&G executed a $2bn longevity reinsurance deal with MetLife.[138]
- In December, the National Grid UK Pension Scheme completed an £800m buy-in with Rothesay.[139]
- 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.[140]
- Finally, Willis Towers Watson completed a £3.3bn buy-in with an unnamed company, the market's largest bulk annuity to date.[141]

Mercer UK head of risk transfer, Andrew Ward, predicted £60bn in bulk annuities, longevity swaps and new risk transfer solutions in 2021. This would be driven by better affordability as more schemes mature and innovation to meet the challenges faced by DB schemes.[142]

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 asset risk and longevity risk associated with pension and annuity liabilities. The reinsurer contracts to reimburse the insurer for monthly benefits for as long as people live. Before this, Prudential 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, head of International Reinsurance for Prudential, 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 U.K. market to continue to grow in new ways in the years to come'.[143]

---

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

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

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

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

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

141 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

142 UK. Pension risk transfer market to hit up to £60bn in 2021, *Pension Policy International*, 10 December 2020; https://pensionpolicyinternational.com/uk-pension-risk-transfer-market-to-hit-up-to-60bn-in-2021/

143 Prudential Retirement enters funded reinsurance business, 30 October 2020; https://news.prudential.com/prudential-retirement-enters-funded-reinsurance-business.htm#.X5wS1QIIOSE.linkedin

In June, the Pension Insurance Corporation (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.[144] 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'.[145]

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.[146]

The most significant pension event of 2020 was the introduction in June by the Pension Regulator (TPR) of an interim regulatory regime for the superfund pension consolidation market.[147] This is the market where pension schemes are consolidated into a larger fund, while remaining legally classified as pension schemes.[148] 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 Pension Protection Fund 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

---

144 UK housing association Trident secures £75m funding from PIC, *IPE*, 19 June 2020.
145 PIC invest a further £65m in Welsh housing association Pobl, *IPE*, 26 November 2020.
146 PRTs could help plug UK infrastructure 'mega-gap' – L&G, *Pension Policy International*, 9 July 2020.
147 https://www.thepensionsregulator.gov.uk/en/media-hub/press-releases/2020-press-releases/tpr-launches-tough-new-interim-regime-for-emerging-superfund-pension-market
148 This contrasts with buy-outs where the liability for paying pensions is transferred to an insurance company.

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 members relative to the Pension Protection Fund (PPF). In the near term, superfund transactions are likely to take place only where the employer is distressed or insolvent'.[149]

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,[150] insurers can cut members' benefits unilaterally in securing them, but superfunds cannot'.

---

[149] UK regulator delivers superfund guidance for trustees, sponsors, *IPE*, 21 October 2020.
[150] That is, being considered for inclusion in the PPF due sponsor insolvency.

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, 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 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.[151]

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

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

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.[152]

Another innovation in 2020 was the introduction of 'third-party capital solutions' (TPCSs).[153] 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 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 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 get 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 liabilites 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, 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

[152] New DB consolidator targets UK's small schemes, *IPE*, 20 October 2020.
[153] 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

p.a., although the ongoing longevity reinsurance premiums will reduce the IFRS operating result before tax by approximately €30m p.a.[154]

- 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 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.[155]
- The launch in August by Australian annuity provider Challenger 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.[156]
- 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 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 such as Pension Benefit Guaranty Corporation (PBGC) premiums, investment management and administration fees, and the risk associated with fixed-income defaults and downgrades.[157]

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

[155] 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.

[156] Australia. Challenger launches floating rate annuity, *Pension Policy International*, 24 August; https://pensionpolicyinternational.com/challenger-launches-floating-rate-annuity/

[157] 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-mercer-u-s-pension-buyout-index-methodology-shows-that-costs-of-annuity-buyouts-could-be-less-than-accounting-liability/

- In November, Milliman's US Pension Buy-out Index (MPBI) 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 accumulated benefit obligation (ABO) basis. Annuity purchase costs were even lower at 100.2% (down from 101.0% in August). The MPBI uses the FTSE Above Median AA Curve, along with annuity purchase composite interest rates from eight insurers, to estimate the average and competitive costs of a PRT annuity de-risking strategy.[158]

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.[159] 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.[160]

Covid-19

The most significant global event of 2020 was, of course, the Covid-19 pandemic. Here we discuss the implications for pension schemes and the PRT market.

A study 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. Liabilities would fall since some pensioners would die, especially those in care homes, and that would be offset by a small increase in 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%.[161] 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 (DB) 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 total UK DB liabilities are around £2.2trn, excess deaths in 2020 due to Covid-19 could reduce liabilities by less than £5bn.

---

[158] 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/

[159] *Insurance Asset Management*, 3 February 20121.

[160] https://www.pensionpolicy.net/uk-roundup-1trn-of-db-pension-risk-to-be-insured-by-2031-says-hymans/

[161] *Daily Telegraph*, 25 November 2020; https://www.statista.com/statistics/283917/uk-state-pension-costs/

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 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'.[162]

Willis Towers Watson (WTW) found that 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 recent 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'.[163]

WTW's *Emerging Trends in DB Pensions Survey 2020*[164] 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 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.*[165] 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

[162] 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

[163] 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

[164] https://www.willistowerswatson.com/en-GB/Insights/2020/10/emerging-trends-in-db-pensions-survey-2020; October 26, 2020.

[165] 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 ability to fund state pensions in the future.

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 – see Appendix 1. Swiss Re has been the most active participant in the market, issuing the first security in 2003, known as Vita I.[166] 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 Libor 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 RMS which developed an indemnity trigger on loss ratios.[167]

Guy Carpenter (GC), the global risk and reinsurance specialist, argues that risk transfer, reinsurance and insurance-linked securities (ILS) sectors are well-placed to assist in dealing with climate change.[168] 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.[169] Pension funds might consider diversifying into these catastrophe bonds.

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

---

[166] 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

[167] https://www.insurancebusinessmag.com/asia/news/breaking-news/rms-collaborates-on-new-mortality-catastrophe-bond-239994.aspx

[168] Climate change is discussed in more detail below.

[169] 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/

life settlements.[170] 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 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 that 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%), Government of Singapore Investment Corporation (GIC) (28.5%), and MassMutual (7%), due to the new regulatory capital requirements faced by banks and insurers.[171] In October 2020, Blackstone sold its 36% stake in Rothesay Life to GIC and 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.[172]

[170] 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.

[171] 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

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

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 Ruβ (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), D'Amato et al. (2018), Leung et al. (2018), MacMinn and Richter (2018), Li and Tang (2019), Bahl and Sabanis (2021), Mayhew et al. (2021))
- 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)) and specifically survivor/longevity swaps (e.g., Dowd et al. (2006), Wang et al. (2013, 2015)), survivor/longevity forwards and swaptions (e.g., Dawson et al. (2009, 2010)), *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)), guaranteed annuity options (e.g., Gao et al. (2015)) and longevity bond options (e.g., Xu et al. (2020))
- Pricing longevity risk (e.g., Olivieri and Pitacco (2008), Bayraktar et al. (2009), Chen et al. (2010), Li (2010)).
- 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))
- Longevity and mortality indices (e.g., Denuit (2009), Li et al. (2011), Chan et al. (2014), Tan et al. (2014))
- 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 (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. (2017), MacMinn and Brockett (2017), Bugler et al. (2021))
- 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), 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), Cairns (2013), 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. (2018), Li (2018), Tsai and Liang (2018), Hanbali et al. (2019), Zhou and Li (2019, 2020), Sherris et al. (2020), Cairns and El Boukfaoui (2021), Hsieh et al. (2021), Kessler (2021), Li et al. (2021), MacMinn and Zhu (2021))

- Mortality modelling, mortality term structure[173] modelling, 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, 2006, 2008), Currie et al. (2004), Biffis (2005), Bongaarts (2005), Czado et al. (2005), Cairns et al. (2006b, 2008a,b, 2009, 2011a), De Jong and Tickle (2006), Delwarde et al. (2007), Koissi et al (2006), Pedroza (2006), 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), Lin and Tzeng (2010), Murphy (2010), Yang et al. (2010), Coelho and Nunes (2011), Currie (2011, 2016), D'Amato et al. (2011, 2012a,b), Ediev (2011), 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), Alai and Sherris (2014b), Aleksic and Börger (2012), Hainaut (2012), O'Hare and Li (2012, 2017), Wilmoth et al. (2012), Hyndman et al. (2013), Kleinow and Cairns (2013), Mitchell et al. (2013), Nielsen and Nielsen (2014), Hunt and Blake (2014, 2020a,b, 2021a,b,c,d), Villegas and Haberman (2014), Danesi at al. (2015), Tomas and Planchet (2015), Leng and Peng (2016), Schinzinger 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), 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), Hainaut (2018), Ludkovski et al. (2018), McCarthy (2018), Salhi, and Thérond (2018), Venter and Şahın (2018), Wong et al. (2018), Apicella et al. (2019), Guibert et al. (2019), Hilton et al. (2019), Liu et al. (2019), Shang (2019), Yang et al. (2019), Zhou (2019), Balland et al. (2020), Basellini et al. (2020), Currie (2020), Dowd et al. (2020), Li et al. (2020), Milevsky (2020), Njenga et al. (2020), Richards et al. (2020), Zeddouk and Devolder (2020), Rizzi et al. (2021), Boumezoued (2021), Guo and Bauer (2021), McCarthy and Wang (2021), Rabbi and Mazzuco (2021), Su and Yue (2021), Yue et al. (2021), Wang et al. (2021)).
- Multi-population mortality modelling (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), D'Amato et al. (2014), Raftery et al. (2014), Zhou et al. (2014), Antonio et al. (2015), Chen et al.(2015), Kleinow (2015), Biffis et al. (2017), Li et al. (2015c, 2017), De Jong et al. (2016, 2020), Enchev et al. (2017), van Berkum et al. (2017), Villegas et al. (2017), Zhu

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

et al. (2017), 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), Chang et al. (2021), Yang et al. (2021))

- Mortality modelling by cause-of-death, educational attainment, social class, special patterns, 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), Alai et al. (2014), Gourieroux and Lu (2015), Alai et al. (2018), Boumezoued et al. (2018), Yue et al. (2018), Li et al. (2019), Dutton et al. (2019), Cupido et al. (2020), Lourés and Cairns (2020), Lyu et al. (2021))
- Population, births and deaths data (e.g., Richards (2008), Cairns et al. (2016), Boumezoued et al. (2019, 2020), Boumezoued (2020))
- Longevity inequality (e.g., Mayhew and Smith (2014, 2021), Debón et al. (2017), Mayhew et al. (2020), Sanzenbacher et al. (2021)).
- Longevity risk and financial innovation (improvements in the analysis and design of longevity-linked products) (e.g., Gong and Webb (2010), Stevens at al. (2010), Richter and Weber (2011), Cocco and Gomes (2012), Brown and Warshawsky (2013), Bernhardt and Donnelly (2019))
- Reverse or equity release mortgages (e.g., Wang et al. (2008), Huang et al. (2011), Yang (2011), Alai et al. (2014a), Kogure et al. (2014), Shao et al. (2015), Lee et al. (2018), Dowd et al. (2019))
- Longevity risk in investment portfolios (e.g., Milevsky and Young (2007), Menoncin (2008), Horneff et al. (2008, 2009, 2010, 2015), Huang et al. (2012), Maurer et al. (2013), Aro and Pennanen (2017), Gemmo et al. (2020), Rogalla (2021))
- Longevity risk in pension plans, pension systems, annuities and long-term care (e.g., 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 and Siegelin (2018), Cox et al. (2018), Debonneuil et al. (2018a), Hsieh et al. (2018), Ignatieva et al. (2018), Kurtbegu (2018), Mayhew et al. (2018), Chen and Rach (2019), Balter et al. (2020), Chen et al. (2020), Olivieri and Pitacco (2020), Cox et al. (2021), Dowd et al. (2021), Kogure et al. (2021)).

Looking into the future

The reliability of of life expectancy projections

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 service 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,[174] 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 improvements.[175] 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.[176]

This prompted a debate in the UK about the reliability of life expectancy projections. 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.[177] 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 (CMI) – which covers England & Wales – published in March 2019 showed 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%).[178] US male life expectancy has also been declining between 2015 and 2016 from 76.3 to 76.1 years. The main causes were unintentional injuries (due to drug, mainly opioid, overdoses), death from Alzheimer's and suicides. Female life expectancy remained constant at 81.1 years.

Time will tell if this is indeed a permanent change in trend 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

---

[174] 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

[175] 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.

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

[177] 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

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

compared with the S2 series mortality tables for the period 2004-11.[179] One year's increase in life expectancy can raise a pension scheme's liabilities by 4%,[180] 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%.[181] 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.[182]

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 (LDI) 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 prepartion 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,

[179] XPS Pensions (2019), New 'SAPS3' mortality tables – a confusing message?, *Briefing Note No.3*, January.
[180] Mark Dunne (2020) Breaking free: Bulk annuities, *Portfolio Institutional*, 24 January; https://www.portfolio-institutional.co.uk/features/breaking-free/
[181] Willis Towers Watson *De-risking Report 2020*, January (p.9).
[182] Susanna Rust (2020) Highest reduction in mortality rates in England and Wales since 2011, *IPE*, 2 March.

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 the Eurozone and US corporate bond markets and then hedge the currency risk.[183]

In August 2020, Legal & General Investment Management 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.[184]

Population aging

These developments are part of 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 reason for declining fertility is the choice made by women in developed countries to have fewer children than previous generations. Another 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.[185]

Another aspect of population aging is the differential impact on the rich and poor, i.e., health inequalities due to differences in wealth. A recent 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 was 7.2 years in 2001, but this had increased to 8.4 years in 2015[186] and to 9 years in 2020.[187] 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, depression, arthritis, cancer, dementia, and

---

[183] 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/
[184] LGIM launches secure income range for DB plans, *IPE*, 3 August 2020.
[185] India Sturgis (2018) Prepare for Spermageddon, *Daily Telegraph Magazine*, 27 January.
[186] Life expectancy gap between rich and poor widens, *BBC News*, 15 February 2018.
[187] 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 Aging, while the US results come from the US Health and Retirement Study.

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.[188]

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 response to increasing life expectancy. In response to these inequalities, the 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.[189]

Climate change and sustainable development

While climate change has been in the news for around 30 years, only in the last couple of years has it begun to impact the pensions industry. For example, UK listed companies and asset managers, such as pension funds, will be 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). The UK Pensions Regulator and Department for Work and Pensions has 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 will be required to report publicly on how they manage climate risks.

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 (environmental, social, and corporate governance) 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

---

[188] Amelia Hill (2020) Health inequality greater than previously thought, report finds, *Guardian*, 12 February.

[189] https://www.gov.uk/government/news/experts-to-help-uk-champion-ageing-society-opportunities

to adhere to on ESG generally, or specifically with regard to climate.[190] 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.[191]

There are 17 global Sustainable Development Goals (SDGs), including ending poverty, fighting inequality and addressing climate change.[192] According to Schroders' 2020 *Global Investment Survey*, 'increasingly clients are using the Sustainable Development Goals as a common language' and estimates global ESG assets under management in excess of $1trn.[193] 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 of sources of revenue) and impact investing (investing in a measurable sustainable outcome in addition to financial returns).[194]

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' or 'social' bonds ($500bn). Many of these bonds are issued by inter-governmental organizations (e.g, the EU's SURE 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%).[195]

The UK government also announced it would fund a new Green Finance Institute 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'. 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'.[196] SDG/ESG considerations have begun to impact the investments held by PRT providers in the UK. For example, they

---

[190] Richard Butcher (2020) The PLSA is here to help overcome barriers as industry embraces climate-aware investment, *portfolio institutional*, November.
[191] Romil Patel (2020) Spinning on a sustainable axis, *funds-europe*, November 2020.
[192] The Global Goals for Sustainable Development; https://www.globalgoals.org. These were adopted by the United Nations in 2015.
[193] The power of measurement: Schroders approach to sustainability, *funds-europe*, November 2020.
[194] Five reasons to choose indexing for sustainable, *portfolio institutional*, November 2020.
[195] ESG News, *portfolio institutional*, November 2020 (p26).
[196] 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

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 investment that generates higher returns than UK government bonds.

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 7.5bn 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 20 years. 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 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'.[197]

A report on climate change and health published in December 2020 by *The Lancet*[198] estimates that global warming has already caused a 50% increase in heat-related deaths of

[197] Steven Running (2019) The biosphere: Global limits of human habitability, 30 October; https://www.openaccessgovernment.org/biosphere-human-habitability/75469/

[198] Reported in the *New York Times*, 3 December 2020.

people older than 65, especially in Japan, China, India and parts of Europe. 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'.

On 4 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.[199] 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.

There are other global developments that could affect life expectancy – some positively, others negatively.

The aging process and anti-aging treatments

Life expectancy is strongly linked to the aging process.[200] 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 cancer, diabetes, cardiovascular disorders, and neurodegenerative diseases. López-Otín et al. (2013) show that there are nine candidate hallmarks of aging:[201] genomic instability,[202] telomere attrition,[203] epigenetic alterations,[204] loss of proteostasis,[205] deregulated nutrient

[199] 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

[200] See, e.g., Andrew Steele (2020) *The New Science of Getting Older Without Getting Old*, Bloomsbury, London; https://www.bloomsbury.com/uk/ageless-9781526608277/

[201] 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

[202] A high frequency of mutations within a cell's genome.

[203] 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.

[204] Non-genetic (i.e., heritable) changes in gene expression that do not affect the DNA sequence.

[205] 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/

sensing,[206] mitochondrial dysfunction,[207] cellular senescence,[208] stem cell exhaustion,[209] and altered intercellular communication.[210]

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 Aging[211] 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

[206] 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 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

[207] Mitochondria are organelles – specialised 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

[208] 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 neverthless destabilise 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

[209] 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/

[210] 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

[211] https://www.buckinstitute.org/

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'.[212]

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 rapamycin[213] 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 age[214]
- The finding that rapamycin, administered to middle aged mice, increased survival significantly in both male and female mice.[215]
- Potential reversal of aging using a younger person's blood, following successful experiments with mice.[216]
- Professor Tony Wyss-Coray (Stanford) has identified circulating factors in plasma that can rejuvenate or restore function in the aging brain, leading to the development of anti-aging therapies based on the plasma proteome, suitable for treating age-related macular degeneration and neurodegenerative disorders.[217]
- Development of inhibitors for the protein 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.[218]
- 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.[219]

---

[212] Interview in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[213] A bacterial antifungal compound discovered in the soil of Easter Island in the 1970s.

[214] http://mypharmacynews.com/health-problems/rapamycin-retards-epigenetic-ageing-of-keratinocytes/

[215] Randy Strong, Richard A. Miller, Molly Bogue, Elizabeth Fernandez, Martin A. Javors, Sergiy Libert, Paul Anthony Marinez, 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/acel.13269

[216] Undulating changes in human plasma proteome profiles across the lifespan, *Nature Medicine*, 5 December 2019.

[217] Steven Braithwaite, Chief Scientific Officer, Alkahest, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[218] Joan Mannick, Chief Medical Officer, resTORbio, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[219] 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.

- Identification of an inflammatory marker called sCD14 which is linked to cognitive decline and dementia, allowing early intervention.[220]
- 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.[221]
- The development of protein-destroying drugs, capable of degrading the MYC cancer-fuelling protein or the tau protein responsible for Alzheimer's.[222]
- 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.[223]
- The discovery that higher levels of humanin, a peptide[224] encoded in the small genome of mitochondria, are associated with longer lifespans, better health, and a lower risk for diseases such as Alzheimer's.[225]
- 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.[226]
- 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.[227]
- The introduction of rejuvenation medicine that turns back biological age, 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.[228] Another example is organ regeneration using lymph nodes to regrow functioning organs within a patient's own body, eradicating the

[220] Inflammatory marker linked to dementia, *EurakAlert! Science News*, 9 December 2019.
[221] https://medicine.wustl.edu/news/bateman-receives-potamkin-award-for-alzheimers-research/
[222] Protein-slaying drugs could be the next blockbuster therapies, *Nature Feature*, 20 March 2019.
[223] Carla Heyworth (2020) Targeting mitochondria to fight aging, *Longevity Technology*, 22 January; https://www.longevity.technology/targeting-mitochondria-to-fight-aging/
[224] 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/
[225] Protein in mitochondria appears to regulate health and longevity, *Science Daily*, 24 June 2020; https://www.sciencedaily.com/releases/2020/06/200624151613.htm
[226] Stimulating immune cells to protect against Alzheimer's, *Neuroscience News*, 10 March 2020.
[227] 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,
[228] Aubrey de Grey, Co-Founder and Chief Scientific Officer,SENS Research Foundation, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

problem of organ rejection in transplant patients and solving the problem of organ supply scarcity.[229, 230]

- 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 pressurised 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%.[231]
- 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, known as 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.[232]
- The identification of 10 genomic loci which influence three key phenotypes[233] (years lived in good health (healthspan), total years lived (lifespan), and survival 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 metabolises iron, with too much iron in the blood appearing to increase risk of dying earlier. Professor 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'.[234]

---

[229] *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[230] 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.

[231] Anthony Cuthbertson (2020) Human ageing 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

[232] 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

[233] 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 as height, eye colour and blood type (https://www.britannica.com/science/phenotype; https://www.genome.gov/genetics-glossary/Phenotype).

[234] 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 ageing, *Nature Communications* volume 11,

- The identification of proteins associated with aging and increased frailty.235 A study of 4265 proteins measured in plasma found that 55 were positively associated with fraility, in particular, fatty acid-binding protein FABP and ANTR2.[236]
- 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.[237]
- By increasing the amount of 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.[238]
- The discovery that pro-inflammatory cytokines[239] induce cellular senescence and hence aging by activating EGFR (Epidermal Growth Factor Receptor) signaling. The activity of five senescence-inducing cytokines (IL-1β, IL-13, MCP-2, MIP-3α, and SDF-1α) 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).[240]
- The discovery that lysine glycation in collagen appears to contribute to tendon stiffening with age and in diabetes.[241]
- 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

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, Sicence Alert, 17 July; https://www.sciencealert.com/a-study-of-1m-people-finds-a-strange-link-between-iron-levels-and-long-life

[235] 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.

[236] 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/acel.13193

[237] 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

[238] 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

[239] 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

[240] 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/acel.13145

[241] 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

compared with those whose body mass index is normal. The risk is particularly high for women.[242]

- 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.[243] Identification of a biomarker for tumour initiating (or cancer stem) cells.[244]
- Early diagnosis of certain cancers (e.g., ovarian and brain) by identifying genetic errors in DNA.[245]
- 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.[246]
- 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.[247]
- The importance of selenium in antioxidant mixtures designed to reduce all-cause mortality, in particular, from cardiovascular disease and cancer.[248]
- The development of technology by Bit.Bio to reprogram stem cells to make any human cell desired.[249]

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

---

242 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

243 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.

244 Labmedica.com, 28 November 2019.

245 Rhys Blakely (2020) Cancer code offers hope of treatment decades early, *The Times*, 6 February.

246 Katy Rezvani, Marco Ruella, and Robbie Majzner (2020) Advances in Adoptive Cell Therapies, Cell Press webinar, 16 July.

247 University of Bonn. "Receptor makes mice strong and slim: Molecule that regulates two side effects of aging identified." ScienceDaily. ScienceDaily, 25 June 2020; www.sciencedaily.com/releases/2020/06/200625115916.htm

248 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

249 Tom Whipple (2020) Bit.Bio: British firm cracks code for stem cells, *The Times*, 27 October.

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'.[250] 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'.[251] Joan Mannick, Chief Medical Officer of resTORbio, goes further: 'In the future we may be able to personalise 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 how cholesterol became a biomarker for the use of statins.[252]

Preventative health care and later life wellness

This 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. 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 programme is focusing on understanding why we age and developing treatments that, if successful, could lead to dramatic changes in the malleability of age'[253] 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.[254] It showed that two years of caloric restriction could slow biological aging and reduce age-related markers, such as oxidative stress.[255]
- Diets and food supplements designed to treat age-related disorders. Dr Verdin from the Buck Institute 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

[250] Interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.
[251] Steven Braithwaite, Chief Scientific Officer, Alkahest, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.
[252] Joan Mannick, Chief Medical Officer, resTORbio, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.
[253] 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.
[254] https://calerie.duke.edu/
[255] Carla Heyworth (2020) Metabolic aging, fasting and metformin, *Longevity Technology*, 10 March; https://www.longevity.technology/metabolic-aging-fasting-and-metformin/

TAME (Targeting Aging with Metformin) trial.[256] 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, memory and decision-making performance.[257] Food companies are promoting 'future food' which combines healthier eating and leveraging agricultural gene editing.[258]

- 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.[259]

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 Eric 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'.[260]
- 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, including the Seattle area and the region around Pullman, Washington. Existing research estimates that heritable factors such as genes only explain about 20% to 35% of an individual's chances of reaching centenarian age.[261]

---

[256] Carla Heyworth (2020) Metabolic aging, fasting and metformin, *Longevity Technology*, 10 March; https://www.longevity.technology/metabolic-aging-fasting-and-metformin/

[257] 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

[258] Aging Analytics Agency, *Advancing Financial Industry: Longevity/AgeTech /WealthTech*

[259] Jane Wakefield (2020) Wearable to spot Alzheimer's being developed, *BBC News*, 13 February.

[260] Interview in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[261] 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/

- 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. Agetech[262] in the form of digital health platforms and telemedicine is providing access to cost-effective healthcare, in combination with medical software and apps.[263] Agetech also targets other aspects of well-being, such as education and financial wellness.[264]
- 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, gender, education, depression, negative affect, and extraversion. This result adds to a growing body of research on positive affect's role in healthy aging.[265]
- Exploiting the so-called 'longevity dividend', where companies 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 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.[266] Mercer's Next Stage research programme, 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:

---

262 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.

263 Angela Tyrrell (2020) Eight sectors to be disrupted by longevity, *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

264 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., personalised 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 programmes (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.

265 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*, 2020; 095679762095388 DOI: 10.1177/0956797620953883

266 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.

- 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'[267] by the OECD, the World Economic Forum, and AARP.[268] 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.[269] Society also benefits from the increase in healthspan associated with the longevity dividend as a result of lower later-life healthcare costs.[270]

These developments led Bank of America to conclude that the human lifespan could soon pass 100 years, 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.[271] As Dr Barzilai argues that 'Death is inevitable but aging is not'.[272] This is a key message that needs to be taken into account when quantifying longevity risk going forward.

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.[273]
- 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.274

---

[267] https://www.aarpinternational.org/initiatives/future-of-work/living-learning-and-earning-longer

[268] American Association of Retired Persons.

[269] Yvonne Sonsino, Global Co-Leader of Next Stage, Mercer, interviewed in *Longevity Trends 2020*, published by Longevity Leaders, January 2020.

[270] 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

[271] https://www.cnbc.com/2019/05/08/techs-next-big-disruption-could-be-delaying-death.html

[272] 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

[273] Haroon Siddique (2019) UK heart disease fatalities rise for first time in 50 years, *Guardian*, 13 May.

[274] U.S. Deaths of despair - Not everyone benefits from the 'longevity economy', *Pension Policy International*, 14 October 2020;

- 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.275
- The World Economic Forum's *Global Risks Report 2019* warns 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.[276] And within a year this came to pass.

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 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.[277]

Artificial intelligence and machine learning

There have been a number of significant developments:

- Using artificial intelligence (AI) for many health-related purposes, such as the early detection of heart disease, reading retinal scans with as much accuracy as experienced junior doctors (using Google's DeepMind), correcting faults in the human nervous system, e.g., robotic arms controlled by brain signals replacing lost human arms.[278]
- 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

https://pensionpolicyinternational.com/us-deaths-of-despair-not-everyone-benefits-from-the-longevity-economy/

[275] Antibiotic resistance, World Health Organization, 5 February 2018; https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance

[276] https://cirmagazine.com/cir/epidemic-risks-pose-as-big-a-business-threat-as-climate-change.php

[277] Glowing bacteria to help tackle antibiotic resistance, Open Access Government, 3 July 2020; https://www.openaccessgovernment.org/glowing-bacteria/89771/

[278] 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.

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 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.[279]

- The use of machine learning 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 developing cell replacement therapies to treat blindness and conducting research into new drugs. The method could be adapted to create other human artificial organs.[280]
- The use of machine learning, in particular, matrix factorization, deep learning, and topological data analysis, to improve understanding of the complex relationships between diseases or multimorbidities.[281]
- The use of digital technologies, such as predictive analytics, by life companies for product innovation.[282] Predictive analytics makes use of data mining, predictive modelling and machine learning 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 machine learning 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.[283]

Implications of global aging for economic growth and financial markets

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.

Jen (2007)[284] argues that there are four important economic and financial implications of these demographic trends:

---

[279] Emin Shinmaz (2020) Could Musk 's microchip really boost brainpower, *Daily Mail*, 29 August.
[280] Machine learning will help to grow artificial organs, Open Access Governement, 7 July 2020; https://www.openaccessgovernment.org/grow-artificial-organs/89945/
[281] 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
[282] Demand for predictive analytics rises among life insurers, *The Actuary*, 26 November 2020.
[283] PRNewswire, 7 January 2021.
[284] Drawn from Jen (2007) – with updated data.

- 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.[285] 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.[286] The end result is a shrinking tax base 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.

- 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. This implies a flatter yield curve in the US. Similar logic suggests that the accelerating potential growth rates in younger countries 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 altemative 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

[285] 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).
[286] In theory, investment to enhance total factor productivity could keep output growth high, even with a shrinking population.

from assets with low credit risk. In contrast to the first hypothesis, this altemative 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.[287] If demographic trends drive the savings patterns in countries, then C/A imbalances should also be affected. The permanent income 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 pattem.

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 (3.6% of GDP in 2019), 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 (2.3% of GDP in 2019), the US does not seem to have a great deal of scope to dis-save further. Three of the largest capital surplus countries in the world (Japan, China and Germany) 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'.

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 saving rates and the rate of return on capital. On the other hand, it is possible that

[287] 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.

imperfections in international capital and traded goods markets could well contribute to international asset price volatility arising from differential aging across countries.[288]

The bottom line, according to Jen (2007) is that 'demographic trends have important economic and financial implications. Without remedial action, global aging in the developed world tends to raise the level of real interest rate, flatten the yield curves, benefit equities at the expense of bonds, and lower the value of the dollar'. In addition, population aging could lead to an increase in stock market volatility.

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 in which pension funds and PRT providers need to inves to achieve their objectives.

Longevity 15: 2019

As with the previous conferences, *Longevity 15 (L15)* 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 - Mortality Trends and Forecasts

    - Professor Moshe Milevsky (Professor of Finance, Schulich School of Business York University, Toronto) discussed 'Biological age vs Chronological Age and Retirement Policy'. Chronological age – the number of years lived since birth – is the standard measure of how old someone is. Biological (or physiological) age can differ from chronological age due to differing biological and physiological factors that result in cumulative damage to the body's cells and tissues. These factors include lifestyle, diet, exercise, stress, genetics (e.g., how fast it takes for a body's antioxidant defences to respond) and diseases. To

[288] 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. The first study argues 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'. The latter two studies 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.

illustrate, the biological age of a 55 year-old Scandinavian male is 48, whereas a 55 year-old Russian male is closer in age to 67. The reason this is important is because it can be used to influence retirement policy. We need to convince consumers to take longevity risk seriously and get those with a biological age below their chronological age to take action, e.g., work longer, delay social security, and annuitize a greater proportion of their retirement assets.

- Paul Kitson (Actuary and Partner at PwC and part of part of PwC's global longevity risk team) talked about '<u>Using Technology to Monitor Longevity Trends</u>'. He began by discussing the factors that might disrupt life expectancy improvements:

	Environment	*Health intervention*	*Lifestyle*
Highest income decile	Electric/autonomous vehicles and air quality improvements	Gene editing and therapy Regenerative medicine Nanomedicine Stem cell medicine Immunotherapy Telemere extension 3D printing	Obesity reduction
Lowest income decile	Isolation and depression Public healthcare investment crisis	Antibiotic resistance Increased costs of preventive medicine	Smoking/vaping

Analysis for a large UK pension plan showed that the impact of these disruptors could increase liabilities by up to 40%, even after allowing for the diminishing marginal impact on life extension from each technology. However, there is material uncertainty around both the likelihood and impact of a number of the disruptive technologies. Also, by definition, this analysis excludes 'unknown unknowns' (both positive and negative). Never before has the possible range of life expectancy outcomes been so great and so uncertain.

Technologies can help us better predict longevity changes. Of the 12 that may emerge in the next 5 years, four – management of lifestyle using real time technology, including wearables, smoking cessation, 3D printing of replacement organs, and technology enabled access to care – have the potential to have a moderate to material positive impact on life expectancy (greater than one year life extension); and one may have a material negative impact – increased isolation and reduced access to care.

Artificial intelligence techniques are making possible the analysis of vast quantities of data, enabling new levels of topic modelling, pattern identification and prediction.

- Dr Georgina Pascutiu (Vice President and Medical Director, Global Medical Support, RGA Re) gave a presentation entitled '<u>Marijuana is now legal: What will the future hold?</u>'. She pointed out that cannabis was the world's most widely used drug (with 188m users) well ahead of opioids (53m), amphetamines (29m), ecstasy (21m), and cocaine (18m). Around 25% of cannabis users are 15-24, 50% are 25-44 and the rest are above 45. The two main cannabinoids from the marijuana plant that are of medical interest are THC and CBD (phytocannabinoids). THC is the main mind-altering ingredient that makes people 'high'. CBD has beneficial effects (e.g., anti-inflammatory, muscle relaxant). THC in low doses can be calming, while high dose gives anxiety. THC may cause more damage to a young brain (until age 25). There has been no death epidemic in countries where it has been legal for a while. Marijuana legalization causes a significant decline in opioid mortality (especially deaths from synthetic opioids). The legalized sale of marijuana will create new opportunities to gather more evidence about the impact of its usage on life expectancy.

- Plenary Session 2 - Financial Wellness and its Importance in an Aging Society

  - Yanela Frias (Senior Vice President and Head of Investment and Pension Solutions, Prudential Retirement) opened this session with a talk entitled '<u>Preparing for Longevity: Defining the Financial Wellness Challenge</u>'. She reminded us that we have never faced a world where so few would support so many. The World Economic Forum estimates a current $70trn global retirement savings gap which is projected to grow to $400trn by 2050. On average, Americans are prepared for nearly 10 years in retirement, but this leaves a gap of 8 years for men and 11 years for women. The obstacles standing in the way of individuals achieving retirement readiness are grounded in a lack of financial wellness:

The reality	*Some solutions*
25% spend their full paycheck or more every month	Income planning and budgeting

60% don't have enough savings to cover $1,000 emergency	Emergency savings account
28% of non-retired adults have no retirement savings or pension	Auto-enrollment and auto-escalation in a 401(k) retirement plan
62% say that student loans impact their ability to save for retirement	Student loan benefit
33% of millennials dipped into 401(k) retirement plans to finance home purchase	Long-term savings for buying a home or saving for a college
36% of Health Savings Accounts (HSAs) have no contributions; 13% contribute the maximum	Maximize HSA accounts as long-term savings for health care

Since 2008, Prudential has been tracking key indicators of both health and financial wellness in its own workforce. The percentage of Prudential employees who reported feeling financial stress or anxiety has fallen from 31% to 16% from 2008 to 2017.

- Michael Knowling (Head of Client Relations and Business Development, Prudential Retirement) moderated a panel session 'The Business Case for Financial Wellness in an Aging Society: How Employers and Employees Both Gain, with panellists Jill Vaslow (Director of Global Health and Wellness, CIGNA) and Carolyn Kennedy (Vice President of Employee Benefits, Chubb).

- This was followed by another panel on the topic of 'Policy Perspectives on Longevity, Aging and Retirement Readiness' moderated by Karen Andres (Director of Policy and Market Solutions, Project Director of the Retirement Savings Initiative, Aspen Institute Financial Security Program) with panellists Steve Goss (Chief Actuary, Social Security Administration), Lori Lucas (President and CEO, Employee Benefit Research Institute), and Professor Angela M. Antonelli (Executive Director of the Center for Retirement Initiatives, Georgetown University McCourt School of Public Policy).

- The session was closed by Phil Waldeck (President, Prudential Retirement) with a talk entitled 'From Crisis to Opportunity: A Call to Action for Financial Wellness in the Age of Increased Longevity'.

- Plenary Session 3 - Market Developments

  - Dale Hall (Managing Director of Research, Society of Actuaries) discussed 'Trends in US Population and Insured Morality Improvement'. The key finding was a slowing/declining trend of mortality improvement across many different causes of death and the SOA was beginning to investigate why this was happening. Part of the investigation included an insurance company practice survey about the assumptions insurers/reinsurers were using for future mortality improvement for life insurance and annuities, and how these assumptions might vary assumptions by product, birth cohort, gender or other characteristics. Another SOA theme was mortality modeling research on cause of death, which involved supporting the development and enhancement of the US Mortality Database and the Human Mortality Database. A further SOA theme was public interest mortality research, a key example of which was an investigation into the economic impact of opioid abuse.

- Douglas Anderson (Actuary and Founder of Club Vita) gave a talk on 'Some Animals are More Equal than Others: Latest Insights into Longevity Inequality from UK, Canada and US'. He opened by pointing out that we are all born pretty equal. The evidence on twins suggests that only 20% of lifespan variation is explained by our genetic make-up. This implies that lifespan variation is driven more by nurture than nature. He then discussed the importance of good and bad habits: 1) smoking levels have halved over a generation, more at higher levels of educational attainment, 2) 54% of the fall in deaths from heart disease is attributable to decline in smoking, 3) the harmful use of alcohol is a causal factor in more than 200 disease and injury conditions, and 4) exercise rises while obesity declines sharply with educational attainment, 5) growing obesity over time at all ages, and 6) eradicating prolonged sedentary behaviour might avoid around10% of UK deaths. It is also important to monitor changes over time. There is possible evidence of 'eras' linked to economic policies and/or flu epidemics. For example, in the UK, there is narrowing of the socioeconomic gap during 2000-2005, strong stable improvements for all during 2005-2011, and resilience of the higher socio-economic groups and worsening mortality in the lower ones during 2011-2017.[289] On top of this, there is short-term volatility of winter flu epidemics in the UK in 2014-15, 2016-17 and 2017-18. In the US, there has also been a widening of the gap between top and bottom quartiles by around one year a decade. If these differences are sustained, over the remaining lifetime of a typical 50-year-old DB plan participant a four-year gap will open up. If US plan sponsors use national population mortality data, this leads to an over/under valuation of pension liabilities of the order of +/-5% relative to the central best estimate. This is a sobering thought for the sponsors of white collar plans, but better news for blue collar plans.

- Michael Fasano (Founder and CEO Fasano Associates) spoke about 'Life and Structured Settlement Underwriting'. A life settlement is the sale of an individual life insurance policy to an investor in the secondary (or tertiary) market. By contrast, a structured settlement is an annuity given to an individual who has suffered damages (injury, wrongful death of a spouse, etc.) through a court proceeding. A secondary structured settlement transaction is the conversion of a structured settlement annuity into a lump sum because the individual needs money now. The role of the medical underwriter is to estimate the life expectancy of the individual whose life insurance policy is being sold

[289] Club Vita and Pensions and Lifetime Savings Association (2017) *Longevity Trends: Does one size fit all?,* June; https://www.clubvita.co.uk/assets/images/general/170623_16_PLSA-Longevity-model.pdf

in a life settlement or whose structured settlement is being converted to a lump sum. Typically, life expectancy (LE) is estimated by assigning debits associated with the individual's medical and behavioural conditions; the debits are added to generate a mortality ratio which is then applied to an appropriate mortality table. The ratio of actual to expected (A/E) deaths is used to assess the reliability of the medical underwriting. The underwriting tools used include: paramedical exams with related lab work, medical records, prescription drug reports, crime/motor vehicle reports, questionnaires and telephone interviews.

Life settlement underwriting involves mainly a higher income, well-educated demographic that goes to the doctor, has nothing to hide and wants a short life expectancy. Medical records and paramedical exams are the gold standard. By contrast, structured settlement underwriting involves a low income, largely unemployed (52%), and poorly educated demographic that receives any medical treatment via emergency rooms or walk-in clinics and has an incentive to conceal medical conditions. Behavioural issues, like criminal history and drug abuse, are as important as medical issues. A targeted questionnaire can expose some of the behavioural issues, although this must be corroborated and supplemented with prescription and crime reports, and telephone interviews.

There are two A/E methodologies: the mortality distribution approach and difference in life expectancies (DLE) approach. With the former approach, projected deaths are based on the mortality distribution embedded in the LE estimates. The projected deaths are aggregated for each LE estimate and then compared to actual deaths to give an A/E ratio. This is a good approach for portfolios of 3 to 12 years duration. However, for short durations, the small number of deaths make results less reliable and more subject to the slope assumptions of the mortality curve, while for long durations, once the number of deaths exceeds 50% of portfolio, the A/E is mechanically pulled towards 100% – as pointed out by Bauer et al (2018) – giving a spurious accuracy to all LE estimates.

The DLE approach is based on the idea that the difference between the actual and expected lifetime of an individual is a random variable which should have an expected value of zero in the case of an accurate LE estimate. The DLE is the gold standard, but is not available until all lives have died. There are two alternatives: 1) the difference in temporary life expectancies (DTLE) is based on experience to date and is a good option that avoids the 'pull to 100%' problem, but does not discriminate bad from good underwriting in early durations, and 2) implied difference in life expectancies (IDLE) which takes DTLE and projects to ultimate maturity assuming survival pattern remains steady – a good alternative to DTLE, although with wide confidence bands in early durations.

- Plenary Session 4 - Longevity Products and the Regulatory Dimension

  - Tim Gordon (Actuary and Partner in Aon's UK Risk Settlement Group) spoke about 'The Longevity Swap Market a Decade on - Lessons Learned and Future Prospects'.

  - Robert Diefenbacher (Senior Vice President, Retrocession, Pacific Life Re) discussed 'The Evolution of the Canadian Longevity Market - Successes and Lessons Learned'. The Canadian PRT market is growing, but lags the UK. In the UK, there are eight insurers competing for a £30bn per annum market, while in Canada, eight insurers compete for a C$5bn annual market. There are key differences across the two markets, mainly arising from their different maturities.

    First, data. The UK market is mature with widely available sources of data to help determine longevity (and spouse demographic) assumptions, third-party pension plan experience data can be purchased (e.g., Club Vita), and as a robust longevity market has existed for more than a decade, re/insurers used their own experience data. Canadian data analyses are much more recent (e.g., Canadian Pensioners Mortality Study (February 2014) and Task Force Report on Mortality Improvement (September 2017), although third-party data sources (e.g., Club Vita) are becoming available.

    Second, capital requirements. The UK market operates under Solvency II.[290] Most players in the market (both insurers and reinsurers) using internal models. This involves stresses on base mortality and mortality improvements use best estimate assumptions. Some – non-EU-based – reinsurers active in the market are not subject to Solvency II. The Canadian market is subject to the Life Insurance Capital Adequacy Test (LICAT). Stresses on base mortality use best estimate assumptions. Stress on mortality improvement is a prescribed multiple of 75% of the best estimate assumption. This results in a more conservative base assumption leading to higher capital. Offshore reinsurers must collaterize reserves and use LICAT.

    Third, transaction splitting. The Canadian PRT market will tend to chop up larger opportunities into tranches to spread among multiple insurers. The reasons for this include: asset availability, credit risk exposure, less dependency on a single provider, to increase competitiveness by increasing participation in a plan sponsor's request for proposals.

    Fourth, lack of standard processes and terms in the Canadian market. By contrast, there is a recognized set of structures used within the UK market, e.g., intermediated, pass-throughs and captive arrangements. Further, a number of concepts are well established and contracts are now more streamlined: 1)

[290] https://www.bankofengland.co.uk/prudential-regulation/key-initiatives/solvency-ii

counterparty risk – experience-based collateral provisions in place to manage counterparty risk, 2) data errors – provision to adjust the contract to allow for gender and date of birth errors, 3) transaction models – use of models to simplify administration and ensure consistent modelling, and 4) termination events – agreed events and process for contract termination, e.g., payment default.

- Thomas Olunloyo (CEO, Legal & General Reinsurance) discussed 'Longevity on the Blockchain' and why blockchain is the perfect technology for transacting longevity risk. He opened by explaining that blockchain is a series of blocks and hashes, where the hashes are a unique and time stamped identifier for a given block and also identify the previous block. Data of any kind can be stored in the blocks, as agreed by the users. The hashes make it possible to build up a perfect record.

  The blocks can also store a 'smart contract' which is a programme that executes using the data in the blocks. It allows the performance of a contract without third parties, i.e., the contract is self executing. The contract can be to carry out a sequence of checks on the data, or to calculate, and pay, amounts based on the data. The smart contract is visible to all users of the blockchain.

  The use of blockchain for longevity risk transfers overcomes the disadvantages of the current system which embodies a decentralized view of the data. This leads to different versions throughout the system, timing delays and lags as the data are processed, duplication of effort for all users, and inefficiency leading to additional costs and friction across the system. All this applies both before and after execution. By contrast, blockchain gives a 'single version of the truth' for all users. Every user sees the same data in real time. The chain is built as the data evolves with a perfect history for the duration of the contract.

  Blockchain can also be used for: 1) pricing – the data on the blockchain will enable real time pricing for all participants, 2) execution – pricing can be offered and accepted, and transactions completed on the blockchain, 3) experience – once transacted, the blockchain can support real time monitoring of emerging experience, and 4) speed - all points of friction are removed.

  In short, blockchain will transform the longevity risk transfer market. Smart contracts automatically execute every aspect of the value chain in real time. Trust security is in the DNA of blockchain. It provides a perfect audit for buyers and sellers. The future is a global market place for the transacting of longevity risk built on a blockchain ecosystem.

- Patrick F. Tedesco and Kirsty Maclean (respectively, Associate and Senior Associate in the Corporate & Financial Services Department, Willkie Farr &Gallagher) discussed 'Regulatory Issues Impacting the Longevity and Pension Risk Transfer Market - A Global Perspective'.

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 *Insurance: Mathematics & Economics*. They cover the following themes: longevity hedging and capital efficiency; pricing longevity derivatives; macro-longevity risk; longevity insurance; pension policy, the life expectancy gap and mortality inequality arising from unequal lifespans; cause-specific mortality; modelling mortality trends; multi-population modelling and forecasting; and mortality data correction. We briefly discuss each of the 16 papers selected.

In 'A Combined Analysis of Hedge Effectiveness and Capital Efficiency In Longevity Hedging', Matthias Börger, Arne Freimann and Jochen Ruβ show that by hedging longevity exposures, annuity providers can reduce both the uncertainty in future cashflows and capital charges in a cost efficient manner. They argue that a separate analysis of these two aspects cannot provide a full picture of the implications of longevity hedging, in particular when using index-based instruments. Hence, they propose a stochastic modeling framework for a joint analysis of the risk reducing effect and the economic impact of longevity hedges in terms of hedge effectiveness and capital efficiency, respectively. In an economic capital model under Solvency II, a wide selection of customized and index-based instruments is analyzed. The authors show that different hedging objectives require different instruments on different index populations and discuss the accompanying trade-off between hedge effectiveness and capital effciency. While customized hedges naturally outperform their index-based counterparts in terms of hedge effectiveness, the authors show that cost efficient index-based designs may be more capital efficient.

An article published in the *British Medical Journal* in 2018 revealed that a number of developed countries have experienced a decline in life expectancy in recent years. In 'Recent Declines in Life Expectancy: Implication on Longevity Risk Hedging', Johnny Siu-Hang Li and Yanxin Liu argue that in the classical framework of stochastic mortality modeling, the observed decline in life expectancy may be attributed to noises around the fitted log-linear trends in age-specific death rates. However, the patterns in the mortality heat maps for these countries suggest that this is likely to be a result of a fading of waves of high mortality improvement, which previously contributed to a linear rise in life expectancy in the developed world. In this paper, the authors introduce an improved version of the heat wave mortality model, which has the potential to capture the cessation of the waves of high mortality improvement. The proposed model is then used to examine the impact of declines in life expectancy on index-based longevity hedges. It is found that if life expectancy declines, a simple delta hedge still performs reasonably well in the sense that the over-hedging problem is only modest.

In 'Modeling and Pricing Longevity Derivatives using the Skellam Distribution', Ko-Lun Kung, I-Chien Liu, and Chou-Wen Wang propose a novel mortality improvement model with the difference of death counts following the Skellam distribution. They extend Mitchell et al. (2013) by considering the difference in Poisson death counts instead of the ratio of subsequent mortality rate, which does not have a known distribution. They derive the iterative estimators of the model from the Skellam distribution. Their model employs maximum likelihood estimation for estimation issues such as missing data and provides a better fit than Mitchell et al. (2013). Using English and Wales data on mortality rates for ages 0-89 between 1950-2016, the model estimate suggests that the age-dependent mortality improvement is slower than the benchmark, which coincides with a recent observation by Office for National Statistics (2018).[291] The forecasting performance outperforms the Poisson and M10 models. The study concludes by making inferences on the price of longevity swaps and analyzes how the volatility shock of mortality improvement affects the premium of longevity swaps.

In 'The Economics of Sharing Macro-longevity Risk', Dirk Broeders, Roel Mehlkopf and Annick van Ool, recognizing that pension funds face macro-longevity risk or uncertainty about future mortality rates, analyze macro-longevity risk sharing between cohorts in a pension scheme as a risk management tool. They show that the optimal risk-sharing rule and the welfare gains from risk sharing largely depend on the retirement age policy. In the case of a fixed retirement age, welfare gains from sharing macro-longevity risk measured on a 10-year horizon are between 0.1 and 0.3 percent of certainty equivalent consumption after retirement for each cohort. By contrast, if the retirement age is fully linked to changes in life expectancy, welfare gains are substantially higher. In this case, the risk bearing capacity of workers is particularly large because their labour supply acts as a hedge against macro-longevity risk. As a result, workers absorb risk from retirees in the optimal risk-sharing rule, thereby increasing the welfare gain for each cohort up to 1.8 percent in the Lee-Carter mortality model and up to 2.9 percent in the Cairns-Blake-Dowd model.

In 'The Role of Longevity Insurance in Defined Contribution Pension Systems', Solange Berstein and Marco Morales analyze longevity insurance for defined-contribution systems, using the case of Chile to evaluate its potential implementation. In the current context of increasing longevity and low interest-rates, it has become important to find the most efficient formulas for both funding pensions and covering longevity risk, not only for countries with mandatory DC systems, but for pension systems in general. The proposed longevity insurance, in addition to covering the risk of surviving longer than expected, it is also able to increase the level of pensions paid to insured workers by allowing the use of savings to fund retirement ages where the probability of being alive is high, and using income from deferred annuities at ages where the surviving probability is low for most pensioners.

In 'Macro Longevity Risk and the Choice between Annuity Products: Evidence from Denmark', Anne G. Balter, Malene Kallestrup-Lamb and Jesper Rangvid study a unique data set containing individuals who were given the opportunity to substitute a guaranteed pension product with relatively low levels of risk for a market-sensitive pension product with both a higher degree of financial risk and exposure to macro longevity risk. Implicitly there is a longevity hedge built into the guaranteed product that is abolished when one switches to the market-sensitive product. The analysis shows that situations might arise where expected pension payments in the market-sensitive product fall below expected pension payments in the guaranteed product, despite the fact that the former has a higher

[291] Office for National Statistics (2018) 'Changing Trends in Mortality: A Cross-UK Comparison, 1981 to 2016. Analysis of Age-specific and Age-standardized Mortality Rates for the UK, England, Wales, Scotland and Northern Ireland from 1981 to 2016'. Office for National Statistics, London.

expected return from financial assets. The authors find that young male residents of Copenhagen with a degree in economics who are guaranteed a low return on their pension savings and have moderate pension wealth are more likely to switch to the market-sensitive pension product.

In 'Pooling Mortality Risk in Eurozone State Pension Liabilities: An Application of a Bayesian Coherent Multi-Population Cohort-based Mortality Model', David McCarthy and Po-Lin Wang design a coherent cohort-based multi-population mortality model, calibrate it to national mortality rates in the Eurozone using Human Mortality Database data, and use it to project developments in national mortality across the Eurozone. Combining this model with a stylized model of social security pensions in each country allows the authors to calculate the pension mortality risk in these systems and estimate the benefits of pooling it across the Eurozone. They examine three risk pools, which are all actuarially fair, but differ in how undiversifiable risk is allocated across countries. The first naïve approach allocates undiversifiable risk in proportion to GDP, a second according to a CAPM-based measure of the undiversifiable risk each country contributes to the pool and a third ensures that the aggregate benefits of diversification are shared equitably across countries using a particular measure adopted by the authors. In all cases, the benefits of risk pooling increase over time as mortality uncertainty accumulates, but fall over time as cross-country correlation increases due to the long-term dominance of the mortality trend, which by assumption is shared between countries. The peak benefit occurs around 2050, with an aggregate reduction in the standard deviation of pension expenditures of around 0.11% of GDP, or 3% of pension expenditure at the 99th percentile. The authors find that allocating undiversifiable risk proportional to GDP does not ensure an efficient allocation of undiversifiable risk across countries, given that different countries have markedly different pension mortality risk due to different pension system generosities as well as different mortality correlation with the Eurozone. Based on these results, the authors propose a contract design that surmounts most of the moral hazard risks created by the pool.

In 'Addressing the Life Expectancy Gap in Pension Policy', Jorge M. Bravo, Mercedes Ayuso, Robert Holzmann and Edward Palmer argue that understanding the systematic relationship between period and cohort life expectancy and how the relationship evolves over time are critical issues in formulating the design of retirement income products, evaluating the actuarial balance of pension schemes, and more generally for all analyses where demographic projections are involved. In this paper, estimates of the life expectancy gap at all ages are performed using data for 1960-2018 from the Human Mortality Database and projections are generated through 2050 for the 42 national populations, disaggregated by gender. Contrary to previous research that often uses a single deemed to be 'best' model to forecast mortality rates, the authors use a novel adaptive Bayesian Model Ensemble of heterogeneous parametric generalized age-period-cohort stochastic mortality models, principal component methods, and smoothing approaches. The procedure involves both the selection of the model confidence set and the determination of optimal weights. Model-averaged Bayesian credible prediction intervals are derived, accounting for both the uncertainty arising from model error and parameter uncertainty. With intergenerational actuarial fairness and neutrality as the guiding principles, the study then explores potential policy interventions to address the consequences of the life expectancy gap – spanning over adjustments in the accumulation, benefit determination, and payout stages. Comprehensive numerical results are provided for two policy options: 1) introducing a sustainability factor, and 2) conditional pension indexation. The results show that: 1) the life expectancy gap is positive and significant for almost all countries and years studied, 2) it will continue to increase, 3) the magnitude of the subsidy rates between generations can be sizeable demanding important initial pension benefit reduction and/or a gradual diminution in the annual indexation rate of pensions to correct them.

In 'Linking retirement age to life expectancy does not lessen the demographic implications of unequal lifespans', Jesús-Adrián Álvarez, Malene Kallestrup-Lamb, and Søren Kjærgaard argue that the fact that individuals are living longer and thus spending more time in retirement challenges the sustainability of pension systems. This has forced policy makers to rethink the design of pension plans to mitigate the burden of increased longevity. Countries such as the Netherlands, Estonia, Denmark and Finland have implemented reforms that link retirement age to changes in life expectancy. However, the demographic and financial implications of such linkages are not well understood. This paper analyzes the Danish case, using high-quality data from population registers during the period 1985-2016. The authors identify trends in demographic and actuarial measures after retirement by sex and socio-economic group. They also introduce a new decomposition method to disentangle the demographic sources of socio-economic disparities in pension costs per year of expected benefits. There are two main results. First, linking retirement age to life expectancy increases uncertainty about length of life after retirement, with the financial cost becoming more sensitive to changes in mortality. Second, socio-economic disparities in lifespans persist regardless of the age at which individuals retire. Males from lower socio-economic groups are at a greater disadvantage, because they spend fewer years in retirement, pay higher pension costs per year of expected benefits and are exposed to higher longevity risk than the rest of the population. This disadvantageous setting is magnified when retirement age is linked to life expectancy.

In 'Assessing Mortality Inequality in the US: What can be said about the Future?', Han Li and Rob J Hyndman investigate mortality inequality across US states by modelling and forecasting mortality rates via a forecast reconciliation approach. Understanding the heterogeneity in state-level mortality experience is of fundamental importance, as it can assist decision making for policymakers, health authorities, as well as local communities which are seeking to reduce inequalities and disparities in life expectancy. A key challenge of multi-population mortality modeling is high dimensionality, and the resulting complex dependence structures across sub-populations. Moreover, when projecting future mortality rates, it is important to ensure that the state-level forecasts are coherent with the national-level forecasts. The authors address these issues by first obtaining independent state-level forecasts based on classical stochastic mortality models, and then incorporating the dependence structure in the forecast reconciliation process. Both traditional bottom-up reconciliation and the cutting-edge trace minimization reconciliation methods are considered. Based on US total mortality data for the period 1969-2017, the authors project the 10-year-ahead mortality rates at both national-level and state-level up to 2027. They find that the geographical inequality in the longevity levels is likely to continue in the future, and the mortality improvement rates will tend to slow down in the coming decades.

In ‘Cause of Death Specific Cohort Effects in US Mortality’, Christian Redondo Lourés and Andrew Cairns use a stochastic age-period-cohort mortality model to analyse US data for years 1989-2015 and ages, separated by sex, educational attainment, and cause of death. The paper focuses, in particular, on the fitted cohort effect for each sub-population and cause of death with two key findings. First, causes of death with a strong or distinctively-shaped cohort effect are also causes of death with significant, controllable risk factors, and that the fitted cohort effect provides insight into the underlying prevalence of specific risk factors (such as smoking prevalence). Second, although each sub-population and cause of death has its own distinctive model fit, there are sufficient similarities between cohort effects to allow the authors to postulate that there is a relatively small number of underlying controllable risk factors that drive these cohort effects. The analysis then provides insight into the modelled cohort effect for all-cause mortality.

In ‘Cause-Specific Mortality Rates: Common Trends and Differences’, Séverine Arnold and Viktoriya Glushko work with cause-of-death mortality data for two sexes from five developed countries (USA, Japan, France, England and Wales, and Australia) and split the mortality rates into five main groups of causes of death (Infectious & Parasitic, Cancer, Circulatory diseases, Respiratory diseases, and External causes). As was shown in Arnold and Sherris (2016), these time series of cause-specific mortality rates are cointegrated and so there exist long-run equilibrium relationships between them. In essence, this means that although the death probabilities evolve stochastically over time, the relationships existing between them are constant and that the past developments of the cause-specific mortality rates are affected by common stochastic trends. In the present paper, the authors explicitly extract these common stochastic trends and compare them across the different datasets. By testing cointegration assumptions about these trends, the authors are able to get a better representation and understanding of how cause-specific death rates are evolving. They believe that common patterns emerging from such analysis could indicate a link to more fundamental biological processes such as aging.

In ‘It Takes Two: Why Mortality Trend Modeling is more than modeling one Mortality Trend’, Matthias Börger, Jochen Russ and Johannes Schupp point out that increasing life expectancy and thus decreasing mortality rates constitute a global trend that can be observed in almost all countries worldwide. Estimating the current rate at which mortality rates decrease and modeling the future rate of decrease is important for, e.g., demographers and actuaries. This task is commonly referred to as mortality trend modeling. In many applications, however, one needs to carefully distinguish between two different mortality trends: the actual (but unobservable) mortality trend (AMT) prevailing at a certain point in time and the estimated mortality trend (EMT) that an observer would estimate given the (observable) realized mortality up to that point in time. Since the AMT is not observable, an actuary or demographer might misestimate the AMT at any point in time. In particular, he or she would typically not be able to distinguish between a recent change in the actual trend and a ‘normal’ random fluctuation around the previous long term trend. Depending on the question at hand, the AMT or the EMT or both need to be considered and modeled in analyses. This paper provides a clear definition of and distinction between the actual mortality trend and the estimated mortality trend, discusses their connection, and explains which of the two is relevant for which kind of question. Moreover, a numerically efficient combined model for both trends is specified and calibrated to mortality data. The model component for the actual mortality trend builds on recent findings that mortality appears to evolve log-linearly over time with random changes in slope. The model component for the estimated mortality trend is specified such that, given the assumed dynamics for the actual mortality trend, the estimated mortality trend matches the actual trend as closely as possible. This provides valuable information on how best estimate mortality assumptions should be derived from the available data in general. Finally, the authors apply the combined model in practical examples and illustrate the importance of distinguishing between AMT and EMT. They show that, if the AMT is wrongfully assumed observable, the hedge effectiveness of a longevity hedge or the Solvency Capital Requirement (SCR) for longevity risk will typically be misestimated significantly.

In 'Modelling Mortality Dependence: An Application of the Dynamic Vine Copula', Rui Zhou and Min Ji show that the vine copula, constructed from bivariate copulas, provides great flexibility in modelling complex high-dimensional dependence. When applied to multi-population mortality modelling, the vine copula yields significant improvements over traditional multivariate copulas. The study captures time-varying features in mortality dependence with a dynamic regular vine (R-vine) copula which is built from bivariate copulas with time-varying dependence parameters. The authors develop two dependence dynamics for R-vine copulas and illustrate the selection and estimation of dynamic R-vine copulas using mortality data from eight populations. The estimated R-vine copulas using the proposed dependence dynamics are shown to yield a better goodness of fit than both static and regime-switching vine copulas. The paper goes on to demonstrate the simulation of mortality paths using dynamic R-vine copulas and examine the impact of vine copula choice on the assessed effectiveness of longevity hedges.

In 'Gompertz Law Revisited: Forecasting Mortality with a Multi-factor Exponential Model', Hong Li, Ken Seng Tan, Shripad Tuljapurkar.and Wenjun Zhu provide a flexible way to address some ongoing challenges in mortality modeling, with a special focus on the mortality curvature and possible mortality plateau for extremely old ages. In particular, they extend the Gompertz law (1825) by proposing a multi-factor exponential model, a framework that is able to capture flexible mortality patterns, and allows for a convenient estimation and prediction algorithm. An extensive empirical analysis is conducted using the proposed framework with a merged mortality database containing a large number of countries and regions with credible old-age mortality data. The authors find that the proposed exponential model leads to superior goodness-of-fit to historical data, and better out-of-sample forecasting performance. Moreover, the exponential model predicts more balanced mortality improvements across ages, and thus leads to higher projected remaining life expectancy for the old ages than existing Gompertz-based mortality models. Finally, the modeling capacity of the proposed exponential model is further demonstrated by a multi-population extension, and an illustrative example of estimation and forecast is provided.

Finally, in ‘Mortality Data Correction in the Absence of Monthly Fertility Records’, Alexandre Boumezoued and Amal Elfassihi argue that since the conjecture of Richards (2008), the work by Cairns et al. (2016) and subsequent developments by Boumezoued (2020), Boumezoued et al. (2020) and Boumezoued et al. (2019), it has been acknowledged that observations from censuses have led to major problems of reliability in estimates of general population mortality rates as implemented in practice. These issues led to misinterpretation of some key mortality characteristics in the past decades, including ‘false cohort effects’. To overcome these issues, the exposure estimates for a given country can be corrected by using monthly fertility records. However, in the absence of birth-by-month data, the recent developments are not applicable. Therefore, this paper explores new solutions regarding the construction of mortality tables in this context, based on machine learning techniques. As a main result, it is demonstrated that the new exposure models proposed in this paper allow to provide correction with high quality and to improve the fitting of stochastic mortality models without a cohort component, as it is the case for the existing correction method based on monthly fertility data.

Longevity 16 will take place in Helsingør in Denmark on 13-14 August 2021, subject to the agreement of a ‘little critter’[292] called SARS-CoV-2. The *Journal of Demographic Economics* will publish a Special Issue of selected papers presented at this conference. *Longevity 17* is planned for Toronto in 2022 and *Longevity 18* is planned for Singapore in 2023.

References

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.

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. (2014) ‘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. (2014a) ‘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., (2014b) ‘Rethinking Age-Period-Cohort Mortality Trend Models’, *Scandinavian Actuarial Journal*, 2014(3): 208-227.

Alho, J. M. (1990) ‘Stochastic Methods in Population Forecasting’, *International Journal of Forecasting*, 6(4): 521–530.

[292] So named by the immunologist and geneticist Sir John Bell, Regius Professor of Medicine at Oxford University.

Aleksic, M.-C., and M. Börger (2012) 'Coherent Projections of Age, Period, and Cohort Dependent Mortality Improvements', Discussion Paper, University of Ulm.

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.

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.

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, Springer, New York.

Bahl, R. K., and Sabanis, S. (2021) 'Model-Independent Price Bounds for Catastrophic Mortality Bonds', *Insurance: Mathematics and Economics*, 96(C), 276-291.

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., 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.

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.

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., 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 Ruβ, 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.
Bernhardt, T., and Donnelly, C. (2019) ‘Modern Tontine with Bequest: Innovation in Pooled Annuity Products’, Insurance: Mathematics and Economics, 86(C): 168-188.
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.
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.
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.
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., 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., 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.
Bravo, J. M. (2011) 'Pricing Longevity Bonds Using Affine-Jump Diffusion Models', CEFAGE-UE Working Papers 2011_29, University of Evora.
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.

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.

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.

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.

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. 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.

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.

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.

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, 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., 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.

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.

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.

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.

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., 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.
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. (2018) 'De-Risking Strategy: Longevity Spread Buy-In', *Insurance: Mathematics and Economics*, 79: 124-136.
D'Amato, V., Di Lorenzo, E., Sibillo, M. (2018) '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.

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., M. Denuit, and P. Eilers (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.

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.

Ediev, D. M. (2011) 'Robust Backward Population Projections Made Possible', *International Journal of Forecasting*, 27(4): 1241–1247.

Enchev, V., Kleinow, T., and Cairns, A. (2017) 'Multi-Population Mortality Models: Fitting, Forecasting and Comparisons', *Scandinavian Actuarial Journal*, 2017(4): 319-342.

Feldstein, M., and Horioka, C. (1980) 'Domestic Saving and International Capital Flows', *Economic Journal*, 90 (358): 314–329.

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, 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.

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*, Palgrave Macmillan, London.

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.

Guibert, Q., Lopez, O., Piette, P. (2019) 'Forecasting Mortality Rate Improvements with a High-dimensional VAR', *Insurance: Mathematics and Economics*, 88: 255-272

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., 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.

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 Waegenaere, 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.

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.

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.-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, H., Milevsky, M., and Salisbury, T. S. (2012) 'Optimal Retirement Consumption with a Stochastic Force of Mortality', Papers 1205.2295, arXiv.org.

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.

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.

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.

Jen, S. (2007) Demographic Trends and the Financial Markets, Morgan Stanley Fixed Income Research, 20 September.

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.

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.

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.

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.

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.

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, 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.

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.

Li, H. (2018) ‘Dynamic Hedging of Longevity Risk: The Effect of Trading Frequency’, *ASTIN Bulletin*, 48(1): 197-232.

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., 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., and Lu, Y. (2017) 'Coherent Forecasting of Mortality Rates: A Sparse Vector-autoregression Approach, *ASTIN Bulletin*, 47, 563-600.
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. (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 Tang, Q. (2019) 'Analyzing Mortality Bond Indexes via Hierarchical Forecast Reconciliation', *ASTIN Bulletin*, 49 (3): 823-846.
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. (2017) '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., 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*, 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, Z., Shao, A. W., and Sherris, M. (2017) '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 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, 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., 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, 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, 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.

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.
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 Waegenaere, 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.
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., 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.
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.
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., 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. (2021) ‘An Analysis of Period and Cohort Mortality Shocks in International Data’, *North American Actuarial Journal,* 25(S1): S385-S409.

McNown, R., and Rogers, A. (1992) ‘Forecasting Cause-Specific Mortality using Time Series Methods’, *International Journal of Forecasting*, 8(3): 413–432.

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. (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.

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.

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., Sherris, M. (2020) 'Modeling Mortality with a Bayesian Vector Autoregression', *Insurance: Mathematics and Economics,* 94(C): 40-57.

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.

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.

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.

Pedroza, C. (2006) 'A Bayesian Forecasting Model: Predicting US Male Mortality', *Biostatistics,* 7: 530–550.

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.

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.

Raftery, A. E., Lalic, N., and Gerland, P. (2014) 'Joint Probabilistic Projection of Female and Male Life Expectancy'. *Demographic Research*, 30: 795–822.

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. (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. 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.

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.

Rogalla, R. (2021) 'Optimal Portfolio Choice in Retirement with Participating Life Annuities', *North American Actuarial Journal*, 25(S1): S182-S195.

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.

Sanzenbacher, G. T., Webb, A., Cosgrove, C. M., and 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.

Shang, H. (2019) 'Dynamic Principal Component Regression: Application to Age-Specific Mortality Forecasting', *ASTIN Bulletin*, 49 (3): 619-645.

Shang, H., 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.

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.

Stevens, R., De Waegenaere, 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.

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.

Thatcher, A. R., Kannisto, V., and Vaupel, J. W. (1998) *The Force of Mortality at Ages 80 to 120*, Odense University Press, Odense, Denmark.

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 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.

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.

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.

Venter, G., and Şahın, S. (2018) 'Parsimonious Parameterization of Age-Period-Cohort Models by Bayesian Shrinkage', *ASTIN Bulletin*, 48(1):1-22.

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.
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, 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., and Chong, C.-T. (2018) 'Mortality Models and Longevity Risk for Small Populations', *Insurance: Mathematics and Economics*, 78: 351-359.
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. (2021) '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, 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.
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, 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.

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.

Yang, B., Li, J., Balasooriya, U. (2015) 'Using Bootstrapping to Incorporate Model Error for Risk-Neutral Pricing of Longevity Risk', *Insurance: Mathematics and Economics,* 62, 16–27.

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. (2020) 'Mean Reversion in Stochastic Mortality: Why and How?', *European Actuarial Journal*, 10(2): 499–525.

Zelenko, I. (2014) 'Longevity Risk and the Stability of Retirement Systems: The Chilean Longevity Bond Case', *Journal of Alternative Investments,* 17 (1): 35–54.

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, R. (2019) 'Modelling Mortality Dependence with Regime-Switching Copulas', *ASTIN Bulletin*, 49 (2): 373-407.

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, 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.

Appendix 1: Mortality-linked bonds, 2003-2020

Sixteen mortality-linked bonds were issued between December 2003 and December 2020

Issuer	*Cedent*	*Risks covered*	*Size*	*Date*
Vita Capital Ltd.	Swiss Re	Extreme mortality	$400m	Dec 2003
Vita Capital II Ltd.	Swiss Re	Extreme mortality	$362m	Apr 2005
Vita Capital III Ltd.	Swiss Re	Extreme mortality	$705m	Jan 2007
Nathan Ltd.	Munich Re	Extreme mortality	$100m	Feb 2008
Vita Capital IV Ltd.	Swiss Re	Extreme mortality	$300m	Oct 2010
Vita Capital IV Ltd. (Series V and VI)	Swiss Re	Extreme mortality	$180m	Jul 2011
Vecta I Ltd.	Aurigen Reinsurance	Embedded value securitization of life insurance mortality and lapse risk	$111m	Dec 2011
Vita Capital V Ltd.	Swiss Re	Extreme mortality	$275m	Jul 2012
Mythen Re Ltd. (Series 2012-2)	Swiss Re	U.S. hurricane, UK extreme mortality	$200m	Nov 2012
Atlas IX Capital Limited (Series 2013-1)	SCOR Global Life SE	Extreme mortality	$180m	Sep 2013
Chesterfield Financial Holdings LLC (Series 2014-1)	Reinsurance Group of America	Embedded value securitization of life insurance mortality and lapse risk	$300m	Dec 2014
Valins I Limited	Aurigen Reinsurance	Embedded value securitization of life	$175m	Jan 2015

		insurance mortality and lapse risk		
Benu Capital Limited	AXA Global Life	Excess mortality (France, Japan, U.S.)	$305m	Apr 2015
Vita Capital VI Limited (Series 2015-1)	Swiss Re	Extreme mortality	$100m	Dec 2015
Matterhorn Re Ltd. (Series 2020-2)	Swiss Re	U.S. named storm, extreme mortality in Australia, Canada, UK	$255m	Feb 2020
La Vie Re Limited (Series 2020-1)	Minnesota Life Insurance Company	Extreme mortality	$100m	Oct 2020
Source: https://www.artemis.bm/deal-directory/				

Appendix 2: UK longevity swaps 2009-2020

Sixty-one longevity swaps covering liabilities worth £104.8bn have been completed between 30 June 2009 and December 2020

Pension scheme	*Date*	*No. of pension schemes*	*Bank or insurer*	*Value*
Babcock	Q3 2009	3	Credit Suisse	£1.2bn
RSA Insurance	Q3 2009	2	Rothesay Life	£1.9bn
Berkshire	Q4 2009	1	Swiss Re	£1bn
BMW	Q1 2010	1	Abbey Life	£3bn
British Airways*	Q3 2010	1	Rothesay Life	£1.3bn
Pall	Q1 2011	1	JP Morgan	£0.1bn
ITV	Q3 2011	1	Credit Suisse	£1.7bn
Rolls Royce*	Q4 2011	1	Deutsche Bank	£3bn
Pilkington	Q4 2011	1	Legal & General	£1bn

Akzo Nobel	Q2 2012	1	Swiss Re	£1.4bn
LV=*	Q4 2012	1	Swiss Re	£0.8bn
BAE Systems	Q1 2013	1	Legal & General	£3.2bn
Bentley	Q2 2013	1	Abbey Life	£0.4bn
Carillion	Q4 2013	5	Deutsche Bank	£1bn
AstraZeneca	Q4 2013	1	Deutsche Bank	£2.5bn
BAE Systems	Q4 2013	2	Legal & General	£1.7bn
Aviva	Q1 2014	1	Own insurer conduit- Munich Re SCOR SE & Swiss Re	£5bn
BT	Q2 2014	1	Own insurer conduit - PICA	£16bn
PGL*	Q3 2014	1	Own insurer conduit – Phoenix Life	£0.9bn
MNOPF*	Q4 2014	1	Own Insurer conduit – Pac Life Re	£1.5bn
Scottish Power	Q4 2014	1	Abbey Life	£2bn
AXA UK	Q3 2015	1	Own insurer conduit - RGA	£2.8bn
Heineken	Q3 2015	1	Aviva	£2.4bn
RAC (2003) Pension Scheme	Q4 2015	1	Owner insurer conduit – Scor Se	£0.6bn
Unnamed	Q4 2015	1	Zurich	£0.09bn
Serco*	Q4 2015	1	Undisclosed	£0.7bn
Pirelli Tyres Limited	Q3 2016	2	Zurich	£0.6bn
Manweb Group	Q3 2016	1	Abbey Life	£1bn
Unnamed	Q4 2016	1	Zurich	£0.05bn
Unnamed	Q4 2016	1	Legal & General	£0.9bn
Unnamed	Q1 2017	1	Zurich	£0.3bn
Skansa	Q2 2017	1	Zurich	£0.3bn

SSE*	Q2 2017	1	Legal & General	£0.8bn
Marsh & McLennan Companies	Q3 2017	1	Own insurer conduit – Canada Life Re & PICA	£3.4bn
BA	Q3 2017	1	Own insurer conduit – Canada Life Re & Partner Re	£1.6bn
National Grid	Q2 2018	1	Zurich	£2.0bn
Lafarge	Q3 2018	2	Own insurer conduit – Munich Re	£2.4bn
Unnamed	Q3 2018	1	Legal & General	£0.3bn
HSBC	Q3 2019	1	Own insurer conduit - PICA	£7.0bn
Unnamed	Q4 2019	1	Zurich, Hannover Re	£0.8bn
Lloyds Banking Group	Q1 2020	3	Scottish Widows – Pacific Life Re	£10.0bn
Willis Towers Watson	Q1 2020	1	Own insurer conduit – Munich Re	£1.0bn
UBS	Q2 2020	1	Zurich – Canada Life Re	£1.4bn
PIC	Q3 2020	1	MetLife	£0.3bn
Rothesay		1	MetLife	£0.24bn
Prudential Staff Pension Scheme	Q4 2020	1	Own insurer conduit – Pacific Life Re	£3.7bn
Barclays Bank UK Retirement Fund	Q4 2020	1	Reinsurance Group of America	£5.0bn
BBC Pension Scheme	Q4 2020	1	Zurich – Canada Life Re	£3.0bn
Legal & General	Q4 2020	1	MetLife	£1.5bn
Total to date		61		£104.8bn
* Since the original swap transaction date, these deals have been converted to buy-ins				
Source: https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/				

Thirty-three longevity swaps over £1bn have been completed between 30 June 2009 and December 2020:

Pension scheme	*Value*	*Insurer*	*Year*
BT Pension Scheme	£16.0bn	PICA	2014

Lloyds Banking Group pension schemes	£10.0bn	Pacific Life Re	2020
HSBC Bank (UK) Pension Scheme	£7.0bn	PICA	2019
Aviva Staff Pension Scheme	£5.0bn	Munich Re; SCOR, Swiss Re	2014
Barclays Bank	£5.0bn	Reinsurance Group of America	2020
Prudential Staff Pension Scheme	£3.7bn	Pacific Life Re	2020
MMC UK Pension Fund	£3.4bn	PICA; Canada Life Reinsurance	2017
BAE Systems 2000 Pension Plan	£3.2bn	L&G; Hannover Re	2013
Rolls-Royce UK Pension Fund	£3.0bn	Deutsche Bank	2011
BMW (UK) Operations Pension Scheme	£3.0bn	Deutsche Bank; Abbey Life	2010
BBC	£3.0bn	Zurich – Canada Life Re	2020
AXA UK Group Pension Scheme	£2.8bn	RGA Re	2015
AstraZeneca Pension Fund	£2.5bn	Deutsche Bank; Abbey Life	2013
Scottish and Newcastle Pension Plan (Heineken)	£2.4bn	Friends Life; Swiss Re	2015
National Grid	£2.0bn	Zurich	2018
Manweb Group of the Electricity Supply Pension Scheme	£2.0bn	Abbey Life	2015
Two schemes sponsored by RSA	£1.9bn	Goldman Sachs; Rothesay Life	2009
Two schemes sponsored by BAE Systems	£1.7bn	L&G	2013
ITV Pension Scheme	£1.7bn	Credit Suisse	2011
Airways Pension Scheme	£1.6bn	Partner Re; Canada Life Re	2017
MNOPF	£1.5bn	Pacific Life Re	2014
Legal & General	£1.5bn	MetLife	2021
UBS	£1.4bn	Canada Life	2020
Akzo Nobel (CPS) Pension Scheme	£1.4bn	L&G; Prudential	2012
Airways Pension Scheme	£1.3bn	Goldman Sachs; Rothesay Life	2011
Airways Pension Scheme	£1.3bn	Goldman Sachs; Rothesay Life	2010
Three schemes sponsored by Babcock	£1.2bn	Credit Suisse	2009
Willis Pension Scheme	£1.0bn	Munich Re	2020
ScottishPower Pension Scheme	£1.0bn	Abbey Life	2016
Five schemes sponsored by Carillion	£1.0bn	Deutsche Bank; Abbey Life	2013
LV=	£1.0bn	Swiss Re	2012

Pilkingtons	£1.0bn	L&G; Hannover Re	2011
Royal County of Berkshire	£1.0bn	Swiss Re	2009
Source: Willis Towers Watson; PP Research; https://www.professionalpensions.com/news/3080084/list-biggest-uk-longevity-swaps, 11 November 2020 (updated to end December 2020, https://www.artemis.bm/longevity-swaps-and-longevity-risk-transfers/)			