Longevity Risk and Capital Markets: The 2017-18 Update

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This Special Issue of the *North American Actuarial Journal* contains 13 contributions to the academic literature all dealing with longevity risk and capital markets. Draft versions of the papers were presented at *Longevity 13: The Thirteenth International Longevity Risk and Capital Markets Solutions Conference* that was held in Taipei on 21-22 September 2017. It was hosted by the Department of Risk Management and Insurance, NCCU (RMI), the Risk and Insurance Research Center, NCCU (RIRC), and the Pensions Institute at Cass Business School. It was co-hosted by CARDIF Bancassurance Research Development Center, NCCU (CBRC), the Research Center on the Sustainable Development of Insurance Industries, NCCU (SDII), the Taiwan Risk and Insurance Association (TRIA), and the Pension Fund Association, R.O.C.

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 and mortality (or *q*-) forward contracts. 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.

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 mortality catastrophe bond in December 2003 and the European Investment Bank/BNP Paribas/PartnerRe longevity bond in November 2004.

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[1] Blake et al. (2013).

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 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.

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 ageing 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 in life settlements and meet the needs of consumers by ensuring permanent anonymity of the

[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 ageing 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.

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.

The fourth conference (*L4*) was held in Amsterdam on 25-26 September 2008. It was hosted by Netspar and the Pensions Institute.[11] 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.

The fifth conference (*L5*) was held in New York on 25-26 September 2009.[12] On 1 February 2010, the Life and Longevity Markets Association (LLMA)[13] was established in London. Its current members are Aviva, AXA, Deutsche Bank, J.P. Morgan, Morgan Stanley, Prudential (UK) PLC, and Swiss Re. LLMA was formed to promote the development of a liquid market in longevity- and mortality-related risks. This market is related to the ILS market and is also similar to other markets with trend risks, e.g., the market in inflation-linked securities and derivatives. LLMA aims to support the development of consistent standards, methodologies and benchmarks to help build a liquid trading market needed to support the future demand for longevity protection by insurers and pension funds. In April 2011, the LifeMetrics indices were transferred to LLMA with the aim of establishing a global benchmark for trading longevity and mortality risk.

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

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

[13] www.llma.org

The sixth conference (*L6*) was held in Sydney on 9-10 September 2010.[14] 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.[15] 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)[16] formed a life settlement and derivatives committee and announced that it was developing a life 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 (i.e., bulk annuity purchase to hedge the longevity risk of pensions in payment) 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

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

[15] 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.

[16] www.islsp.org

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 organisational 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 Global Financial Crisis took place in June 2011 between Atlanticlux and institutional investors and was valued at €60m.

The seventh conference (*L7*) was held at the House of Finance, Goethe University, Frankfurt, Germany on 8-9 September 2011.[17]

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 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 achieved. 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.[18] The deal was classified as a partial buy-out rather than a buy-in because it involved the settlement of the obligation. In other words, the portion of the liabilities associated with the annuity contract will no longer be GM's obligation. Moreover, in contrast to a buy-in, the annuity contract will not be an asset of the pension plan, but instead an asset of the retirees. In October 2012, GM did a $3.6 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.

The eighth conference (*L8*) was held at the University of Waterloo, Ontario, Canada on 7-8 September 2012.[19]

In February 2013, the first medically underwritten bulk annuity (MUBA) transaction was executed in the UK by the UK insurer Partnership.[20] This involved each member filling in a

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

[18] In fact, the lump sum is only being offered to limited cohorts of plan members.

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

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.[21] 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 as part of a deal that moved $800m in pension obligations off SPX's balance sheet.

The ninth conference (*L9*) was held in Beijing, China on 6-7 September 2013.[22]

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[23] 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

[20] Harrison and Blake (2013).
[21] Hunt and Blake (2016).
[22] The conference proceedings for *L9* were published in *Insurance: Mathematics and Economics* (Volume 63 (July), 2015).
[23] https://www.isda.org/

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 defined benefit 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.[24] 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.

The tenth conference (*L10*) was held at Universidad Diego Portales in Santiago, Chile on 3-4 September 2014.[25]

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 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.

[24] Towers Watson (2015) *Corporate Briefing*, April.
[25] The conference proceedings for L10 were published in the *Journal of Risk and Insurance*, Volume 84, Number S1, April 2017, 273-532.

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.[26] 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).

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 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%.[27]

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

[26] Reported in *Financial News*, 14 July 2014.
[27] *Financial News*, 28 March–3 April 2016

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,[28] 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.[29] 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.[30] 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'.

The eleventh conference (*L11*) was hosted by Université Lyon 1, Lyon, France on 7-8 September 2015.[31]

In April 2016, 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.

[28] Sun Life Financial uses the RMS Longevity Risk Model, which RMS describes as a 'structural meta-model of geroscience advancement'.
[29] Eckler Consultants (2017) *Pension Risk Transfer Report*, November.
[30] http://www.artemis.bm/blog/2015/06/26/delta-lloyd-rga-in-second-e12-billion-longevity-swap-deal/
[31] The conference proceedings for *L11* were published in *Insurance: Mathematics and Economics*, 78 (2018), 157–380.

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)[32] 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.[33]

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[34] 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.[35] Similarly, in September, Deutsche Bank sold its Abbey Life subsidiary to Phoenix Life – a consolidator of closed insurance books – for £935mn, 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 inadequate return on capital and to transfer that capital to its growing businesses in Asia.[36] 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 Willis Towers Watson'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.

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

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

[34] 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

[35] Solvency II has 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% (*Financial News*, 28 March–3 April 2016).

[36] https://www.ftadviser.com/pensions/2016/12/05/prudential-seeks-buyers-for-45bn-annuity-business/

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.[37] Yet this equates to just 5% of the £1.5trn of UK defined benefit (DB) pension assets and 3% of the £2.7trn of DB pension liabilities on a buy-out basis. 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).[38] Figure 1 shows the growth of the global market in longevity risk transfer between 2007 and 2017. A total of $366bn in transactions have been completed during this period.

The twelfth conference (*L12*) was held in Chicago on 29-30 September 2016 and hosted by the Society of Actuaries and the Pensions Institute.[39]

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 predicts that £15bn will take 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'.[40]

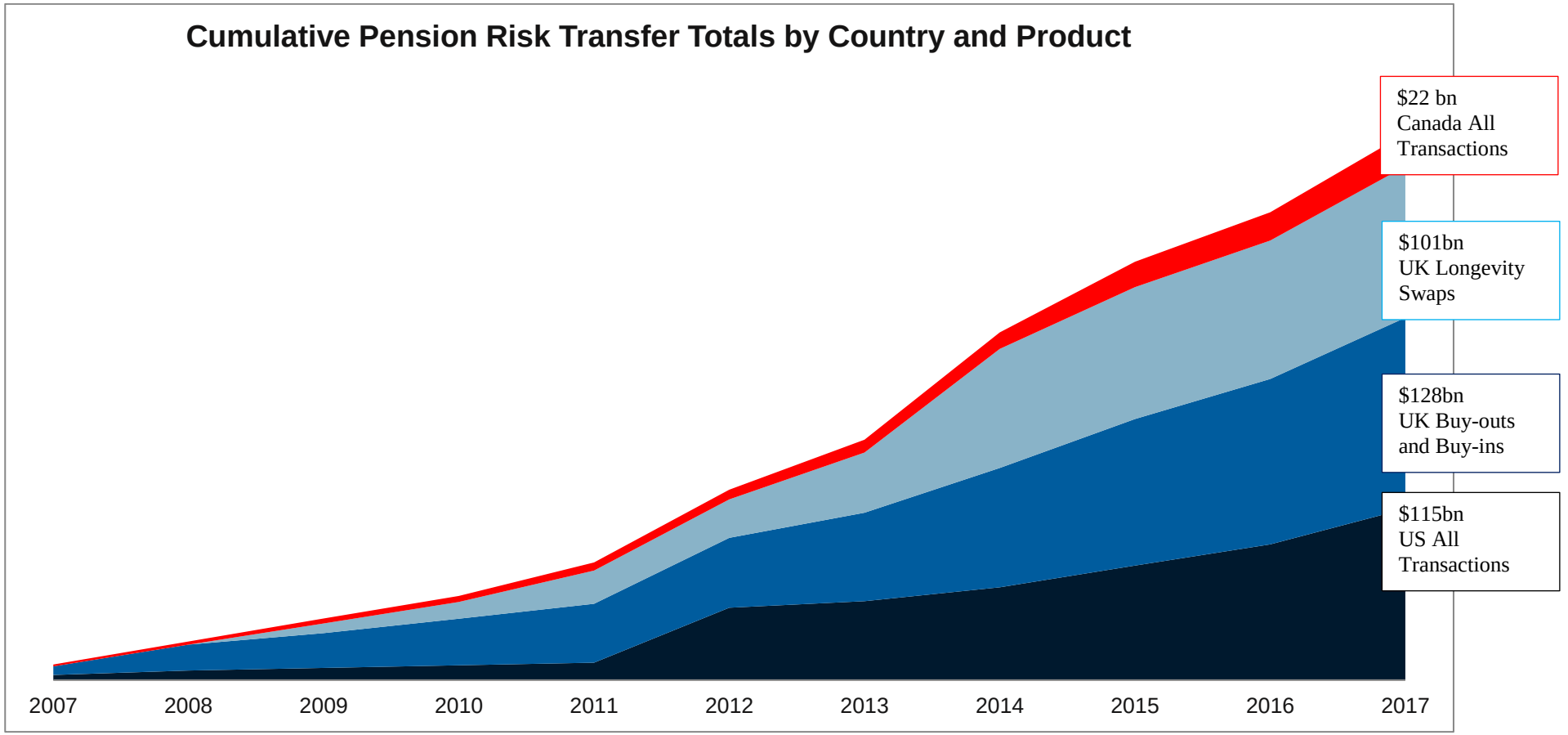
[37] LCP, *Professional Pensions* (15 December 2016 and 26 January 2017). Since 2007, some 92 buy-ins have been completed – see Table A1.

[38] www.artemis.bm/library/longevity_swaps_risk_transfers.html; see Table A2 for a full list of UK publicly announced longevity swaps between 2007 and 2016.

[39] The conference proceedings for *L12* were published in the *North American Actuarial Journal*.

[40] 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, 2007-17



Sources: LIMRA, Hymans Robertson, LCP and PICA analysis as of December 31, 2017

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.[41] 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.[42] In November 2017, PIC executed a £900m longevity swap with PICA, while in December 2017, L&G executed a £600m longevity swap with PICA.[43]

In December 2017, NN Life, part of the Nationale-Nederlanden Group, 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[44] 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.[45, 46]

In order to reduce the costs of de-risking, pension plans are encouraged to perform some liability reduction exercises, the key ones being:[47]

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[41] 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.

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

[43] 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.

[44] 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'.

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

[46] https://www.nn-group.com/Investors/Capital-Markets-Day-2017.htm

[47] *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.[48]
- 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):

- 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.[49]
- 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, 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 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.[50]

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

[49] 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.

[50] 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'.

- Automated bulk plan transfers – to reduce risks (introduced in November 2017 by Scottish Widows and Standard Life).[51]
- 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.[52]
- 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.[53]
- 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.
- 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

[51] Michael Klimes (2017) How the first automated bulk scheme transfers happened, *Professional Pensions*, 10 November.
[52] James Phillips (2017) DB schemes insuring wrong tranche of members in buy-ins, *Professional Pensions*, 14 August.
[53] Stephanie Baxter (2017) Converting longevity swaps into bulk annuities: The next de-risking innovation?, *Professional Pensions*, 13 April.

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.[54]
- 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 defined benefit plans in the UK.[55] 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.[56] Third, their longevity risk is greater, because the longevity improvement assumption used for pricing has greater reliance on the assumed long-run trend.[57] 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.[58]

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,

[54] 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.

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

[56] 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.

[57] 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.

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

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'.[59]

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 pension pots.[60] In particular, there was no longer a requirement to purchase an annuity.[61] 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 GFC. 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.[62] 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 leaves just six providers left in what was once the world's largest annuity market: Aviva (offering standard and enhanced annuities), Canada Life (standard and enhanced), Hodge Lifetime (standard only), Just Group (enhanced only), L&G (standard and enhanced) and Scottish Widows (standard only).[63]

In place of annuities, individuals took their pension pot either as a lump sum or they purchased an income drawdown product. In both cases, they bear their own longevity risk. Evidence shows that people systematically underestimate their life expectancy which implies that there is a significant probability that many people will spend their pension pot before they die. A 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.[64]

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

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[59] 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.

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

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

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

[63] *Source: Hargreaves Lansdown, August 2017.*

[64] 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.

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) 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 rent 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 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,[65] 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.[66]

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

[65] Athene is majority owned by private equity company Apollo Global Management, LLC.
[66] Navigating you through your de-risking journey: Overseas, *Aon Risk Settlement Market Review 2018*.

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'.

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 capital provided by Disruptive Capital and Warburg Pincus. It promises employers a cheaper way to offload their pension obligations than a traditional insurance buy-out. 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 would be initially targeting schemes with assets between £200m-£1bn with a strong sponsor covenant. Another example is Clara. Insurers have expressed concerns that since such pension consolidation vehicles come under the Pensions Regulator (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 PRA.[67]

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

2018 longevity risk transfer highlights for the UK included:

- 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.[68] 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.

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

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

- 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.
- In March, Marks & Spencer Pension Scheme executed two buy-ins totalling £1.4bn with Aviva and Phoenix covering 15% of its pension liabilities. It was Aviva's largest buy-in to date (at £925m) and Phoenix's first external buy-in (at £475m).
- In March, PIC and PICA introduced a 'flow reinsurance' system which automates the longevity reinsurance element of buy-outs and buy-ins for schemes with liabilities below £200m. The system allows PIC to secure a commitment from PICA to assume the longevity risk early on in a transaction.
- In March, employee benefits consultant, JLT, launched a 'buy-out comparison service' and monitoring tool which allows schemes to upload their own data and receive regular bulk annuity quotations from eight insurers currently active in the market.
- In April, JLT became the first consultant to implement Club Vita's longevity analytics capabilities which have been incorporated into RiskFirst's PFaroe modelling system for defined benefit plans. This will allow JLT clients to set best-estimate longevity assumptions.[69] 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.[70]
- 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[71] 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

[69] 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.

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

[71] 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.

point they can enter into buy-in or buy-out, but want to manage their longevity risk'.

- In September, the British Airways Pension Scheme entered into the UK's largest buy-in agreement to date (at £4.4bn) with Legal & General, 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 Legal & General, covering 15,000 pensioners and 7,200 deferred members, thereby avoiding entering the Pension Protection Fund which takes on the assets and liabilities of failed companies.
- In December, PIC executes another longevity swap, this time with SCOR, covering 8,000 pensioners and valued at £1.2bn.[72]

There are number of reasons explaining the strength of the UK longevity risk transfer market in 2018. First, funding levels have improved as a result of a) deficit reduction contributions and strong equity returns, which have increased asset values, and b) lower liability values due to a combination of higher interest rates and lower mortality improvements since 2011.[73] Second, there has been an increase in competition from insurers which have recruited heavily and so have more staff to provide price quotations and implement transactions. Third, insurers have been increasing their investment in high yielding illiquid matching assets, such as infrastructure and equity release, and have passed on the additional yield (including illiquidity premium) to schemes in the form of lower prices. Fourth, 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.[74]

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 2008 and US Dodd Frank Act which followed led to the majority of investment banks withdrawing from the market. A few banks with insurance subsidiaries – such as Goldman Sachs, owner of Rothesay Life, and Deutsche Bank, owner of Abbey Life – remained for a while before they too sold their life businesses. So for the

[72] This brought the total value of the deals between the two companies to £2.2bn.
[73] This is discussed later.
[74] Attractive pricing opportunities for buy-in/buy-out, XPS Pensions, Briefing Note No, 2, June 2018.

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. (forthcoming)).

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,[75] 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, 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

[75] 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.[76]

In January, 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.[77]

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.[78]

In July, the island of Guernsey announced it would develop a simplified structure for the ILS market via an all-in-one legal entity that would combine insurance/reinsurance and investment activity in one vehicle – described as a 'Fund of One'. This would create a more transparent vehicle for investors which would promote 'true convergence' in ILS. Investors would establish both an unregulated investment fund and a reinsurance transformer cell. This would remove the need for multiple vehicles and allow a sidecar to have both the risks and the assets held in a single vehicle. This would help to reduce the challenges often associated with multiple vehicles, such as doing business in various jurisdictions, regulation, time zones, account rules, audit, and multiple layers of administration expenses.[79]

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

[76] 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/

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

[78] 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/

[79] 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/

(2010), Bravo (2011), Dowd et al. (2011a), Mayhew and Smith (2011), Zhou et al. (2011, 2013), Chen et al. (2013), Shen and Siu (2013), Denuit et al. (2015), Hunt and Blake (2015), Milevsky and Salisbury (2015), Yang et al. (2015), Chen et al. (2017), Lin et al. (2017), Leung et al. (2018), MacMinn and Richter (2018), Mayhew et al. (forthcoming)).

- 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)) 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. (2010)), *q*-forwards (e.g., Deng et. al. (2012), Barrieu and Veraart (2016)), mortality options (e.g., Milevsky and Promislow (2001), Zhou and Li (forthcoming)), and guaranteed annuity options (e.g., Gao et al. (2015))
- 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 Huang (2013), Michaelson and Mulholland (2014), MacMinn and Brockett (2017), Bugler et al. (forthcoming))
- 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), Zelenko (2014), Zhu and Bauer (2014), Li et al. (2017a), Zhou and Li (2017), D'Amato et al. (2018), Liu and Li (2016, 2018), Kessler (forthcoming), Cairns and El Boukfaoui (forthcoming), Hsieh et al. (forthcoming))
- Mortality modeling, mortality term structure [80] 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),

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

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), 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, forthcoming a,b), Mayhew and Smith (2014), Villegas and Haberman (2014), Danesi at al. (2015), Tomas and Planchet (2015), Berkum et al. (2016), Currie (2016), Li and Lu (2017), Li and O'Hare (2017), Milidonis and Efthymiou (2017), Neves et al. (2017), Tsai and Lin (2017), Börger and Schupp (2018), Debonneuil et al. (2018), Hainaut (2018), McCarthy (2018), Salhi, and Thérond (2018), Boumezoued (forthcoming), Guo and Bauer (forthcoming))

- 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), Börger and Ruß (2012), Torri and Vaupel (2012), D'Amato et al. (2014), Raftery et al. (2014), Zhou et al. (2014), Chen et al.(2015), Kleinow (2015), Biffis et al. (2017), Li et al. (2015c), Zhu et al. (2017), Hunt and Blake (2018), Pascariu et al. (2018), Wang et al. (2018), Yang et al. (forthcoming))
- Cause-of-death mortality modelling (e.g., Beard (1971), McNown and Rogers (1992), Christensen and Vaupel (1996), Hanewald (2011), Alai et al. (2014), Gourieroux and Lu (2015), Boumezoued et al. (2018), Yue et al. (2018))
- 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))
- 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))
- 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), Rogalla (forthcoming))
- Longevity risk in pension plans, pension systems and annuities (e.g., Aro (2014), Bisetti and Favero (2014), Donnelly (2014), Lin et al. (2014, 2015), Ai et al. (2015), Wan and Bertschi (2015), Ai et al. (2017), Lin et al. (2017), Bravo and El Mekkaoui de Freitas (2018), Bruszas and Siegelin (2018), Cox et al. (2018), Hsieh et al. (2018), Kurtbegu (2018), Mayhew et al. (2018), Cox et al. (forthcoming), Dowd et al. (forthcoming)).

As mentioned before, not all paths to progress are smooth. In recent years, this has been particularly true currently in the largest market dealing with micro-longevity risk, namely

life settlements.[81] 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 US Dodd-Frank (Restoring American Financial Stability) Act 2010 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, i.e., 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 £1.4 billion 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 £3 billion, was sold to Rothesay Life for an undisclosed sum, bringing its total assets to £10 billion.

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.

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 2008-09 Global Financial Crisis; and longer term reasons, such as 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, and there was no longer scope for further

[81] 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.

improvements.[82] 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.[83]

This prompted a debate in the UK about the reliability of life expectancy projections. Mortality improvements in UK males averaged 0.6% p.a. over the preceding four years, compared with 3.2% p.a. in the decade before and 1.5-2% between 1995 and 2000. The most recent view of the UK actuarial profession is that the change in trend is permanent. The Mortality Projections Model of the Institute and Faculty of Actuaries' Continuous Mortality Investigation (CMI) – which covers England & Wales – published in March 2018 showed that the average cohort life expectancy of a 65-year old man in 2018 was 22.1 years, down from 22.2 in 2017; the corresponding figures for a 65-year old woman were 24 and 24.1 years.[84] 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 indeed a permanent change in trend or if the trend will again reverse in response to advances in applied biotechnology and in molecular and regenerative medicine. The most recent evidence from CMI published in December 2018 comes from their SAPS (Self-Administered Pension Scheme) data set. This covers UK members of defined benefit pension schemes. The S3 series mortality tables for the period 2009-16 showed that life expectancy in this select group was still increasing.[85]

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 ageing and its implications. One aspect of population ageing 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. But 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 pants; oestrogen in the water supply from the female

[82] 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. See also www.bbc.com/news/health-4060825.

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

[84] Victoria Ticha (2018) Latest CMI model reveals clear trend in life expectancy, *Professional Pensions*, 1 March.

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

contraceptive pill; and electromagnetic radiation from wi-fi routers.[86] Another aspect of population ageing is the differential impact on the rich and poor. 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.[87] This 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. Some of these issues do not immediately affect the longevity risk transfer market, but they might do in due course, so it is important to flag them now.

As with the previous conferences, *Longevity 13* consisted of both academic papers and more practical and policy-oriented presentations. There were five plenary sessions: Demography, Population Ageing, and Medical Advances; Longevity Risk in Asia: A Roadmap for Retirement Security; Mortality Modelling and Hedging Longevity Risks for Pension Funds and Insurers; Longevity Risk and Market Solutions; and Longevity Risk and FinTech Developments. The following keynote speakers and panellists contributed to these sessions:

- Shripad Tuljapurkar (Professor of Biology and the Dean & Virginia Morrison Professor of Population Studies at Stanford University) gave a presentation on 'Global Trends in Population Ageing and Longevity Risk'.
- Richard Jackson (President of Global Ageing Institute) discussed 'How Global Ageing Will Transform the Economy, Society, and Geopolitical Order of the 21st Century'. He pointed out that the world stands on the threshold of a stunning demographic transformation called global ageing, the inevitable result of rising longevity and falling fertility. As a consequence, the developed world faces a future of rising fiscal burdens and paying more for pensions, health care, and long-term care for the elderly. Few countries will be able to raise taxes enough to cover more than a fraction of the age wave's total cost. Most countries will have to cut old-age benefits, but the required reductions are large and are likely to meet with resistance from ageing electorates. The only alternatives are to let old-age benefits crowd out other government spending and/or run widening budget deficits. A second consequence is a future of slower economic growth. Slowly growing or contracting working-age populations will translate into slower GDP growth. Japan and some European countries may face a future of 'secular stagnation'. Productivity and living standard growth may also slow as rates of saving and investment decline. Ageing workforces may be less flexible, less mobile, and less entrepreneurial, putting a further drag on growth. As domestic markets stagnate, the danger of 'beggar-thy-neighbor' protectionism will grow. By contrast, the developing world will experience a 'demographic transition': the slowdown in population growth and upward shift in age structure may push it toward greater peace and prosperity. Fading youth bulges and rising median ages will foster stability, while declining dependency burdens and growing working-age populations create a 'demographic dividend' and open up a window of opportunity for rapid development. But

[86] India Sturgis (2018) Prepare for Spermageddon, *Daily Telegraph Magazine*, 27 January.
[87] Life expectancy gap between rich and poor widens, *BBC News*, 15 February 2018.

journeys can be more dangerous than destinations. Societies undergo tremendous stresses as they move from the traditional to the modern. These stresses include: contact with the global marketplace and culture, urbanization, environmental degradation, growing income inequality, and religious extremism.

- Guy Coughlan (Chief Risk Officer, USS) gave a presentation on 'Longevity Black Swans: Looking Beyond Past Trends to What Potential Disruptive Developments in Medicine, Healthcare, Technology and Lifestyle May Mean for Life Expectancy'. He began by identifying the key drivers of longevity extension: lifestyle, heath environment, medicine and the facilitating role of new technologies which might transform medicine and allow us to treat and even cure many intractable illnesses. He then considered realistic disruptive scenarios that could lead to a longevity black swan – a low probability event, beyond experience and expectation, that has an extreme impact – such as artificial intelligence (AI) to aid the early detection of problems, quantum computing in medical diagnosis and decision making, the use of gene therapy to reprogram a patient's own cells to attack a deadly cancer, and the 3D printing of organs.
- Dylan Tyson (Executive Vice President and Former Chief Strategy Officer, Prudential Life of Korea) discussed 'Defining Retirement Security – The Needs of Real People in Asia'. He pointed out that 60% of the world's senior citizens live in the Asia- Pacific region and that the support ratio is projected to fall from 8 to 4 by 2050. Decisive action is needed to deal with this. But too few people in Asia are financially prepared for their retirement. They used to rely on their children for support in old age, but 60% of households in Korea, for example, are without children. He proposed a number of solutions for dealing with this problem: increase awareness among individuals, help citizens solve their financial challenges, and lead a societal conversion that enables better outcomes.
- Ronald Klein (Director of Ageing at The Geneva Association) chaired a panel session on 'Changing the Environment to Encourage Solutions' with contributions from Wonshik Kim (Professor, Economics, College of International Business, Konkuk University), Donghyun Park (Principal Economist, Asian Development Bank) and Jennifer Wang (Vice President of National Chengchi University, Former Chairman of Financial Supervisory Commission, R.O.C).
- Amy Kessler (Senior Vice President and Head of Longevity Risk Transfer, Prudential Retirement) gave a presentation on 'Providing Retirement Security – Balancing Value and Risk in Lifetime Income Solutions'. She discussed the assets that insurers hold (such as corporate bonds, mortgages, loans and other spread-oriented fixed income assets) to provide life-long security for their clients.
- Dale Hall (Managing Director of Research, Society of Actuaries) talked about 'The Society of Actuaries Mortality Research: Implications for Insurers and Pensions'.
- Douglas Anderson (Hymans Robertson and Founder of Club Vita) discussed 'One Size Does Not Fit All: The Importance of Granular Mortality Data in Pricing Longevity De-risking Solutions'. His analysis of the Club Vita data reveals that a smaller part of longevity differences are explained by the genes that we are born with than originally thought. Over 80% of differences are now believed to be due to lifestyle and environmental effects. Lifestyles follow tribal patterns within our societies.

- Chao-Ting Lin (Managing Senior Executive Vice President of Cathay Life) gave a presentation on 'Mortality Modelling and Longevity Challenges for Taiwan Insurers' in light of the fact that Taiwan is super-ageing very quickly and also has one of the lowest fertility rates in the world.
- Cheng-Wei Chang (Manager, Product Pricing Department, Fubon Life Insurance) spoke about 'Insurance Product Design, Natural Hedging and Longevity Risk'.
- Ricky Chau (Vice President, Portfolio Manager, Franklin Templeton Solutions) discussed the 'Evolution of Multi-Asset Strategies and Longevity Risk'. Beginning in the 1930s with strategies based on a single asset class from the home market, he explained the transition to the outcome-oriented multi-asset solutions of today, but warned of the challenges ahead in terms of low yield, high volatility and ageing populations, pointing out that the sales of adult diapers in Japan outsold those for infants in 2014.
- Vanessa Wang (Managing Director, North Asia Amundi Hong Kong Ltd.) spoke about 'Market Solutions for Longevity Risk', and, in particular, those retirement income and longevity solutions that responded to the needs of ageing, while promoting capital market and infrastructure development, including renewable energy assets.
- James Liu (Chairman of Phew Inc.) discussed four reasons explaining 'InsurTech Innovations' that exploit AI, Big Data, blockchain and the internet of things (IoT), the network of physical devices that are able to connect and exchange data: open systems/platforms lower the costs/hurdles of entering the insurance industry, customer demand for more diversified and customized insurance products, the emergence of new types of risk, and customer dissatisfaction with current underwriting and claims processes
- Tetsushi Yamaguchi (General Manager of Reinsurance Dept. of The Gibraltar Life Insurance Company Co., Ltd) talked about 'Longevity Risk and Fintech Long-term Care Experiences in Japan', involving mobility, toileting and bathing aids and LTC robots.
- Finally, Jennifer Wang (Vice President of National Chengchi University, Former Chairman of Financial Supervisory Commission, R.O.C.) gave a presentation on 'Insurance Technology and Longevity Risk' which showed how a robo-adviser could help with retirement planning and pension investment and how AI, Big Data and the IoT could improve health care management.

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 *North American Actuarial Journal*. They cover the following themes: longevity hedging, mortality modelling, mortality forecasting and inequalities in life expectancy. We briefly discuss each of the 13 papers selected.

In 'An Efficient Method for Mitigating Longevity Value-at-Risk', Yanxin Liu and Johnny Siu-Hang Li point out that many existing index-based longevity hedging strategies focus on the reduction in variance. However, solvency capital requirements are typically based on τ-year-ahead Value-at-Risk, with $\tau = 1$ under Solvency II. Optimizing a longevity hedge using variance minimization is inadequate when the cost of hedging is non-zero

and mortality improvements are driven by a skewed and/or heavy-tailed distribution. In this paper, the authors contribute a method to formulate a value hedge that aims to minimize the Value-at-Risk of the hedged position over a horizon of τ years. The proposed method works with all stochastic mortality models that can be formulated in a state-space form, even when a non-normal distributional assumption is made. The authors also develop a technique to expedite the evaluation of a value longevity hedge. By utilizing the generic assumption that the innovations in the stochastic processes for the period and cohort effects are not serially correlated, the proposed technique avoids the need for nested simulations that are generally required when evaluating a value hedge.

In 'Constructing Out-of-the-Money Longevity Hedges Using Parametric Mortality Indexes', Johnny Siu-Hang Li, Jackie Li, Uditha Balasooriya, and Kenneth Q. Zhou argue that parametric mortality indexes (i.e., indexes created using the time-varying parameters in a suitable stochastic mortality model) can be used to develop tradable mortality-linked derivatives such as K-forwards. Compared to existing indexes such as the LLMA's LifeMetrics, parametric mortality indexes are richer in information content, allowing the market to better concentrate liquidity. This paper contributes to the literature in a number of ways. First, it considers options written on parametric mortality indexes. Such options enable hedgers to create out-of-the-money longevity hedges, which, compared to at-the-money-hedges created with q-/K-forwards, may better meet hedgers' need for protection against downside risk. Second, using the properties of the time-series processes for the parametric mortality indexes, the authors derive analytical risk-neutral pricing formulas for K-forwards and options. In addition to convenience, the analytical pricing formulas remove the need for computationally intensive nested simulations that are entailed in, for example, the calculation of the hedging instruments' values when a dynamic hedge is adjusted. Finally, the authors construct static and dynamic Greek hedging strategies using K-forwards and options, and demonstrate empirically the conditions under which an out-of-the-money hedge is more economically justifiable than an at-the-money one.

In 'Hedging Longevity Risk: Does the Structure of the Financial Instrument Matter?', Richard D MacMinn and Nan Zhu point out that longevity-linked securities can be constructed either as cash-flow hedging instruments or as value hedging instruments. This article studies the interaction between the structure of longevity-linked securities and shareholder value. Relying on a strand of literature that investigates corporate risk management decisions made in the interests of shareholders, the authors present a framework that compares cash-flow hedges with value hedges. Both the theoretical model and the numerical experiments show that value hedging dominates cash-flow hedging in the context of management decisions being made to maximize shareholder value. This finding provides an explanation for the failure of some attempted issues of longevity risk transfer instruments and suggests efficient alternate structures.

In 'An Analysis of Period and Cohort Mortality Shocks in International Data', David McCarthy and Po-Lin Wang use Bayesian maximum *a posteriori* (BMAP) estimation to fit a cohort-based mortality model that applies the Gompertz (1825) mortality law to fixed cohorts across different periods (rather than the more usual application to fixed

periods across different cohorts). Period effects are then estimated as residuals. In this approach, cohort effects can be viewed as a proxy for causes of death with long latency, which have become relatively more important in recent decades in richer countries. The authors estimate the model independently using male and female mortality data in 31 countries. They are able to associate historical events with many of the observed period and cohort shocks, most notably the 1918 flu epidemic, and find striking geographical and cultural correlations in the results. They find that after 1960, the variance of period mortality shocks has declined by an average factor of 5 in most of the countries examined. Over the same period, cohort shocks appear to have become a more important factor causing changes in mortality than period shocks. They also find that period and cohort shocks appear to be driven by different underlying factors. Their results have important implications for stochastic mortality modeling and may explain why stochastic mortality models that rely largely on period mortality shocks struggle to generate sufficient variation in mortality rates. Their results will also be useful to those who construct reinsurance portfolios, those who issue or trade longevity-linked securities and for those who study the origins of human mortality.

In 'Using Graduation to Modify the Estimation of Lee-Carter Model for Small Populations', Jack C. Yue, Tzu-Yu Wang and Hsin-Chung Wang point out that many mortality models, such as the Lee-Carter model (1992), have unsatisfactory estimation properties in the case of small populations. Increasing population size is a natural choice to stabilize the estimation, if we can find a larger reference population which has a similar mortality profile as the small population. Aggregating historical data of the small populations is a potential candidate as the reference population. However, it is often not feasible in practice and we need to rely on other reference populations. In this study, the authors want to explore whether graduation methods can be used if the mortality profile of small population differ from that of reference population. In order to explore when it is appropriate to use graduation methods, the authors create several mortality scenarios and similarity types between small and reference populations. They propose combining the graduation methods and mortality models, either graduating mortality rates first or applying mortality model first, and verify if they can improve the model fit. They use computer simulation to check if the proposed approach has better mortality estimation properties than the Lee-Carter model and the Li-Lee model (2005). They found that the Li-Lee model always has smaller estimation errors than the Lee-Carter model, and the proposed new approach has smaller estimation errors than the Li-Lee model in most cases.

In 'A Multi-Population Approach to Forecasting All-Cause Mortality Using Causes-of-Death Mortality Data', Pintao Lyu, Anja De Waegenaere and Bertrand Melenberg argue that all-cause mortality is driven by various types of cause-specific mortality. Projecting all-cause mortality based on cause-of-death mortality allows one to understand the drivers of the recent changes in all-cause mortality. However, the existing literature has argued that all-cause mortality projections based on cause-specific mortality experience have a number of serious drawbacks, including the inferior cause of death mortality data and the complex dependence structure between causes of death. In this paper, the authors use the recent WHO causes of death data to address this issue in a

multi-population context. They construct a new model in the spirit of Li and Lee (2005) but in terms of cause-specific mortality. A new two-step beta convergence test is used to capture the cause-specific mortality dynamics between different countries and between different causes. They show that the all-cause mortality projections produced by the new model perform similarly in-sample as the projections by the Lee-Carter and the Li-Lee all-cause mortality models. However, in contrast to results from earlier studies, they find that the all-cause mortality projections of the new model have a better out-of-sample performance in a long forecast horizon. Moreover, for the case of the Netherlands, about one year higher remaining life expectancy projections of a 67-year-old Dutch male in a 30-year forecast horizon is obtained by this new model, compared to the all-cause Li-Lee mortality model.

In 'A Synthesis Mortality Model for the Elderly', Karen C. Su and Jack C. Yue agree that mortality improvement has been a common phenomenon since the 20th century and the human longevity continues to prolong. Post-retirement lifetimes receive a lot of attention and the need for modelling mortality rates of the elderly (ages 65 and beyond) is essential because life expectancy has reached the highest level in history. Mortality models can be divided into two groups: relational and stochastic models, but there is no consensus which model is better in modelling the elderly's mortality rates. In this study, instead of choosing either relational or stochastic models, the authors propose a synthesis model, selecting and modifying appropriate models from both groups, which not only has satisfactory estimation properties but also can be used for mortality projection. They use the data from the U.S., U.K., Japan and Taiwan to evaluate the proposed approach. They found that the proposed model performs well and is a possible choice for modelling the elderly's mortality rates.

In 'Forward Mortality Rates in Discrete Time I: Calibration and Securities Pricing', Andrew Hunt and David Blake point out that many users of mortality models are interested in using them to place values on longevity-linked liabilities and securities. Modern regulatory regimes require that the values of liabilities and reserves are consistent with market prices (if available), whilst the gradual emergence of a traded market in longevity risk needs methods for pricing new types of longevity-linked securities quickly and efficiently. In this paper, the authors develop a new forward mortality framework to enable the efficient pricing of longevity-linked liabilities and securities in a market-consistent fashion. This approach starts from the historical data of the observed mortality rates. Building on the dynamics of age/period/cohort models of the force of mortality, the authors develop models of forward mortality rates and then use a change of measure to incorporate whatever market information is available. The resulting forward mortality rates are then used to value a number of different longevity-linked securities, such as q-forwards, s-forwards and longevity swaps.

In 'Forward Mortality Rates in Discrete Time II: Longevity Risk and Hedging Strategies', Andrew Hunt and David Blake argue that longevity risk has emerged as an important risk in the early 21st century for the providers of pension benefits and annuities. Any changes in the assumptions for future mortality rates can have a major financial impact on the valuation of these liabilities and motivates many of the longevity-linked securities that

have been proposed to hedge this risk. Using the framework developed in 'Forward Mortality Rates in Discrete Time I: Calibration and Securities Pricing' (the previous paper in this special issue), the authors investigate how these assumptions can change over a one-year period and the potential for hedging longevity risk in an illustrative annuity portfolio, and find that relatively simple hedging strategies can significantly mitigate longevity risk over a one-year period.

In 'Mortality Forecasts for Long-Term Care Subpopulations with Longevity Risk: A Bayesian Approach', Atsuyuki Kogure, Takahiro Fushimi and Shinichi Kamiya propose a new Bayesian methodology to forecast mortality rates of the long-term care (LTC) subpopulations with longevity risk. A major obstacle to developing such a method is lack of data on the number of deaths in LTC subpopulations, which would prevent us from using the conventional mortality models such as the Lee-Carter model. To overcome this difficulty, the authors propose an extended Lee-Carter model for mortality differentials by LTC status which does not require the data on the number of deaths in LTC subpopulations. They apply the proposed model to mortality forecasts for the subpopulations under the public long-term care system in Japan. The results show that the proposed method captures the heterogeneity in the mortality rates between the LTC statuses properly and provides reasonable forecasts.

In 'An Investigation into Inequalities in Adult Lifespan', Les Mayhew and David Smith point out that people in the UK are living longer than ever but the gap between the shortest and longest lived appears to be increasing. Based on data from the Human Mortality Database, the authors measure the differences in age between the first 10% of adult deaths and the top 5% of survivors. They find that in the period from 1879 to 1939, this gap steadily closed. They cite evidence that the reduction in inequalities in age at death was due to significant improvements in the health and condition of the population through better housing, sanitation, mass vaccination, occupational health, clearer air and other public health improvements which disproportionately improved the lives of the poorest in society relative to the wealthiest. Although life expectancy continued to rise after 1950, the inequality gap remained roughly constant and in recent years has started to widen again – more so for men than for women. A key difference between pre-1939 and now is that deaths are much more likely to be from chronic rather than infectious diseases or environmental causes. Since chronic disease is often attributable to life choices such as smoking and diet, the authors maintain that the blame for the widening must be laid increasingly at the door of individual lifestyles rather than ambient risks and hazards.

In 'Rising Inequality in Life Expectancy by Socioeconomic Status', Geoffrey T. Sanzenbacher, Anthony Webb, Candace M. Cosgrove and Natalia Orlova show that inequality in life expectancy is growing in the United States, but evidence is mixed regarding how much it has grown. Some studies have found that life expectancies have decreased for those with the lowest socioeconomic status (SES). Other studies have found that while inequality is rising, there have been life expectancy gains across the board. A primary difference in these studies is how SES is measured. Some studies use an absolute measure, such as years of school completed, while others use relative measures, such as a person's ranking of years of school completed compared to others

born at the same time. This study uses regression analysis to assign people a relative education ranking and, in doing so, attempts to isolate the changing relationship between SES and mortality from the fact that certain education-based groups, especially high school dropouts, actually have a lower SES level today than in the past. The study finds that when SES is defined in this way – relatively – inequality in mortality by SES is increasing but life expectancies have also increased across SES groups. The study also finds that white women in the bottom of the education distribution have experienced the least improvement of any group and that rectangularization of the mortality distribution has occurred much more in the top of the income distribution than the bottom.

In 'Mortality Differential & Social Insurance: A Case Study in Taiwan', Chih-Kai Chang, Jack C. Yue, Chian-Jing Chen, and Yen-Wen Chen point out that the mortality differential is important information for planning the social insurance programs, such as health insurance and public pensions. It can also be used to evaluate if certain areas need additional medical facilities or traffic infrastructure. The ignorance of mortality differentials can result in adverse selection and problems of pricing and liability quantification. In this study, the authors use mortality models to estimate the mortality differentials of two social pension plans in Taiwan, National Pension Insurance (NPI) and Farmer Health Insurance (FHI), which account for over one third population of Taiwan (about 9 million). They compare the mortality profiles of two pension groups, in terms of economic status, and geographic region. The empirical study leads to several policy implications such as the feasibility of unifying the FHI and NPI systems, reallocating more premium subside according to mortality differences and corresponding annuity costs, as well as the anti-selection effect in suburban areas with lower annuity costs and a lower willingness to pay the premium.

Longevity 14 took place in Amsterdam on September 20–21, 2018. *Annals of Actuarial Science* will publish a Special Issue of selected papers presented at this conference. *Longevity 15* will take place in Washington DC on September 12-13, 2019. *Insurance: Mathematics and Economics* will publish a Special Issue of selected papers presented at this conference.

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 (-Gaille), 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.

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', Organisation for Economic Cooperation and Development Working Papers on Insurance and Private Pensions, No. 4, OECD Publishing, Paris.

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.

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.

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 Ruβ, 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., 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.

Berkum, F. V., Antonio, K., and Vellekoop, M. H. (2016) 'The Impact of Multiple Structural Changes on Mortality Predictions', *Scandinavian Actuarial Journal*, 2016(7): 581-603.

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.

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 Ruß, J. (2012) 'It Takes Two: Why Mortality Trend Modeling is More than Modeling one Mortality Trend', Discussion Paper, University of Ulm.

Börger, M., and Schupp, J. (2018) 'Modeling Trend Processes in Parametric Mortality Models', *Insurance: Mathematics and Economics,* 78: 369-380.

Boumezoued, A. (forthcoming) 'Improving HMD Mortality Estimates with HFD Fertility Data', *North American Actuarial Journal*.

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.

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.

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.

Bugler, N., Maclean, K., Nicenko, V., and Tedesco, P. (forthcoming) 'Reinsurance Side-cars: The Next Stage in the Development of the Longevity Risk Transfer Market', *North American Actuarial Journal*.

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., 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. (forthcoming) 'Basis Risk in Index Based Longevity Hedges: A Guide for Longevity Hedgers', *North American Actuarial Journal*.

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.

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.

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. (forthcoming) 'Optimal Longevity Risk Transfer and Investment Strategies', *North American Actuarial Journal*.

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.

Currie, I. D. (2016) 'On Fitting Generalized Linear and Non-linear Models of Mortality', *Scandinavian Actuarial Journal,* 2016: 356-383.

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., 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 Co-integration 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.

Debonneuil, E. (2010) 'Simple Model of Mortality Trends aiming at Universality: Lee Carter + Cohort', *Quantitative Finance Papers* 1003:1802, arXiv.org.

Debonneuil, E., Loisel, S., and Planchet, F. (2018) '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.

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.

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., Cairns, A. J. G., and Blake, D. (forthcoming) 'Hedging Annuity Risks with the Age-Period-Cohort Two-Population Gravity Model', *North American Actuarial Journal*.

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.

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

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.

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.

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.

Guo, G., and Bauer, D. (forthcoming) 'Different Shades of Risk: Mortality Trends Implied by Term Insurance Prices', *North American Actuarial Journal*.

Hainaut, D. (2012) 'Multidimensional Lee-Carter Model with Switching Mortality Processes', *Insurance: Mathematics and Economics,* 50: 236-246.

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. (2018) 'A neural-network analyzer for mortality forecast', *ASTIN Bulletin,* 48: 481-508.

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.

Hobcraft, J., Menken, J., and Preston, S. H. (1982) 'Age, Period and Cohort Effects in Demography: A Review', Population Index, 48 (1): 4–43.

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. (forthcoming) 'Mortality Risk Management Under The Factor Copula Framework - With Applications To Insurance Policy Pools', *North American Actuarial Journal*.

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. (2018) Identifiability, Cointegration and the Gravity Model', *Insurance: Mathematics and Economics*, 78: 360-368.

Hunt, A., and Blake, D. (forthcoming a) 'On the Structure and Classification of Mortality Models', *North American Actuarial Journal*.

Hunt, A., and Blake, D. (forthcoming b) 'A Bayesian Approach to Modelling and Projecting Cohort Effects', *North American Actuarial Journal*.

Hyndman, R., Booth, H., and Yasmeen, F. (2013) 'Coherent Mortality Forecasting the Product-Ratio Method with Functional Time Series Models', *Demography,* 50: 261-283.

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.

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.

Kessler, A. (forthcoming) 'New Solutions to an Age-Old Problem: Innovative Strategies for Managing Pension and Longevity Risk', *North American Actuarial Journal*.

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.

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.

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., De Waegenaere, A., and Melenberg, B. (2015a) 'The Choice of Sample Size for Mortality Forecasting: A Bayesian Learning Approach', *Insurance: Mathematics and Economics*, 63, 153–168.

Li, H., De Waegenaere, A., and Melenberg, B. (2017a) 'Robust Mean–Variance Hedging of Longevity Risk', *Journal of Risk and Insurance*, 84(S1): 459-475.

Li, H., and Lu, Y. (2017) 'Coherent Forecasting of Mortality Rates: A Sparse Vector-autoregression Approach, *ASTIN Bulletin*, 47, 563-600.

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 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, 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., 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., and Luo, A. (2012) 'Key q-duration: A Framework for Hedging Longevity Risk', *ASTIN Bulletin*, 42: 413–452.

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.

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. (2017) '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. (2017) '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. (2018) 'A Strategy for Hedging Risks Associated with Period and Cohort Effects using q-Forwards', *Insurance: Mathematics and Economics*, 78: 267-285.

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.).

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.

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.**,** Rickayzen, B., and Smith, D. (forthcoming) 'Flexible and Affordable Methods of Paying for Long-Term Care Insurance', *North American Actuarial Journal*.

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., 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.

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

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., 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.

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.

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.

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.

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.

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.
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.
Rogalla, R. (forthcoming) 'Optimal Portfolio Choice in Retirement with Participating Life Annuities', *North American Actuarial Journal*.
Russolillo, M., Giordano, G., Haberman, S. (2011) 'Extending the Lee-Carter model: A Three-way Decomposition', Scandinavian Actuarial Journal, 2011 (2): 96–117.
Richter, A., and Weber, F. (2011) 'Mortality-Indexed Annuities: Managing Longevity Risk via Product Design', *North American Actuarial Journal,* 15: 212-236
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.
Salhi, Y., and Thérond, P. E. (2018) 'Age-specific adjustment of graduated mortality', *ASTIN Bulletin*, 48, 543-569.
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.
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.
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 Lin, T. (2017) '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.

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.

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., Valdez, E., and Piggott, J. (2008) 'Securitization of Longevity Risk in Reverse Mortgages', *North American Actuarial Journal*, 12: 345-371.

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.

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., and Huang, H.-C. (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. (forthcoming) 'Understanding Patterns of Mortality Homogeneity and Heterogeneity across Countries and Their Role in Modelling Mortality Dynamics and Hedging Longevity Risk', *North American Actuarial Journal*.

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.

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. (forthcoming) 'Longevity Greeks: What do Insurers and Capital Market Investors Need to Know?', *North American Actuarial Journal*.

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., 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.