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INTRODUCTION

Longevity risk and capital markets: the 2021–22 update[1]

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Abstract

This special issue of the *Journal of Demographic Economics* contains 10 contributions to the academic literature all dealing with longevity risk and capital markets. Draft versions of the papers were presented at *Longevity 16: The Sixteenth International Longevity Risk and Capital Markets Solutions Conference* that was held in Helsingør near Copenhagen on 13–14 August 2021. It was hosted by PerCent at Copenhagen Business School and the Pensions Institute at City, University of London.

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

[1]An extended version of the editorial introduction (entitled "Longevity Risk and Capital Markets: The 2021–22 Update") appears as an online appendix to this special issue of the *Journal of Demographic Economics* here: https://doi.org/10.1017/dem.2023.2

David Blake and Richard MacMinn are co-founders of the *Longevity Risk and Capital Markets Solutions Conferences*.

sidecars (also called strategic reinsurance vehicles). The aim of the *International Longevity Risk and Capital Markets Solutions Conferences* is to bring together academics and practitioners from all over the world to discuss and analyze these exciting new developments.

As with the previous conferences, *Longevity 16 (L16)* consisted of both academic papers and more practical and policy-oriented presentations. There were four plenary sessions and the following keynote speakers and panelists contributed to these sessions:

- Plenary session 1
  - Stephen Kramer (Swiss Re Institute) opened the conference with a presentation entitled "Modelling the Covid-19 pandemic." He explained that the standard infectious disease model is the SIR model.[2] There are three aspects to the model:
    - timing, duration, and severity of illness (asymptomatic, mild, hospital, intensive care unit (ICU), dead)—determines the burden on the health system
    - timing, duration, and level of infectiousness—determines the next generation of infections
    - rate of lethality (death-per-infection)/IFR (infection fatality rate)—this was age-specific (the vast majority of fatalities were elderly) and country-specific.

    The model can give a sense of possible attack rates and mortality under various scenarios, but, more importantly, is useful in developing strategies for determining whether containment is possible and which interventions would be most effective, such as rapid self-identification, isolation, and contact tracing versus social distancing and closures of schools and workplaces.
  - Nicola Oliver (Medical Intelligence) discussed "The Covid-19 vaccine landscape: Progress, challenges, and the road ahead." She pointed out that most vaccines take years to develop, but scientists—such as Drs. Ugur Sahin and Ozlem Tureci, co-founders of BioNTech—developed multiple vaccines for Covid-19 (SARS-CoV-2) within one year. This included the first three phases of clinical trials—phase I: trials to test the safety of a new treatment; phase II: trials to test the efficacy of the new treatment on a small sample of patients; phase III: trials to test the efficacy of the new treatment on a large sample of patients.[3] The vaccine works by creating an immune response in the form of antigen-presenting cells which ingest the virus and display proportions of it to activate T helper cells. These enable other immune responses: B cells make antibodies that can block the virus from infecting cells, as well as mark the virus for destruction. Cytotoxic T cells identify and destroy virus-infected cells. Long-lived "memory" T and B cells that recognize the virus can patrol the body for months and years, providing immunity. The vaccines have an efficacy of 90% which means that 90% fewer people contract the disease when they come into contact with the virus, significantly reducing hospitalization and death. The optimal efficacy was reached after the second dose. Challenges ahead relate the supply chain (in particular manufacturing

[2]Where S is the number of susceptible individuals, I is the number of infected individuals, and R is the number of recovered individuals; https://www.maa.org/press/periodicals/loci/joma/the-sir-model-for-spread-of-disease-the-differential-equation-model

[3]Phase IV trials—which find out more about efficacy, side effects, and safety—are ongoing.

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and storage), variants (e.g., the omicron variant was more transmissible but had lower severity of illness, compared with earlier variants), equity (economic recovery depends on securing equal access to vaccines in all countries), and misinformation (spread by social media). Finally, it looks as though the virus will transition from being pandemic to being epidemic, like flu.

- Josephine Robertson (Health & Care/Risk Actuary) discussed "Long Covid."

- Plenary session 2
  - Hamish Galloway (RGA Re) gave a presentation on "Counterparty risk and the effects of regulation in structuring transactions." He pointed out that the longevity risk transfer market is now a very large market—individual transactions of £3–10 bn are not uncommon—with potential counterparty risk. The primary market transfers longevity risk from pension funds to insurers. The insurance market is backed by capital, but capital is expensive. The secondary markets are the reinsurance and retrocession[4] markets. For insurers based in Europe, longevity risk is migrating offshore to the most capital efficient location and reinsurance is the conduit. This is because of the size of the risk margin in Solvency II. In the US, there is no offset to capital requirements and risk stays onshore with little or no secondary market activity to date. Reinsurance swaps longevity risk for counterparty risk which is low since counterparties are generally well-rated and the required capital generated is small; also counterparty risk diversifies. Nevertheless, insurers must consider the failure of their largest counterparty at an inconvenient moment: the risk will fall back onto their own balance sheet, there will be current losses plus the need to re-establish their capital position in a distressed environment, and a recovery and resolution plan will need to be established. Various tools exist to minimize the impact of reinsurer failure, such as collateral, diversification of reinsurance, external guarantees (e.g., credit default swaps), cut-through clauses which allow reinsurers to modify the original reinsurance agreement in certain conditions, and recouponing (if a swap gets out of line, collateral is paid down and terms are reset to something closer to what is now expected). Counterparty calculation is now a common negotiating point in reinsurance treaties.
  - Amy Kessler (Head of International Reinsurance Strategic Initiatives, Prudential Financial) gave a presentation entitled "Resilient in a crisis: How pandemic insights supported a rock solid longevity risk transfer market in 2020." She explained the following related markets turned out to be very resilient during the Covid-19 pandemic: pension/longevity risk transfer, funded reinsurance, and life reinsurance capital raising and sidecars. In the pension/longevity risk transfer market, the volatility of funded status and the unpredictability of mortality rates during the pandemic increased the incentive for well-funded plans to exit the risk—and in 2020, the UK and US buy-in and buy-out market volumes were the second- and third-highest on record. The arrival of funded reinsurance supported the continued growth in the UK pension de-risking market, since insurers were able to bring in reinsurance partners with capital and asset management expertise. In these transactions, insurers

[4]Retrocession is reinsurance for reinsurers.

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transfer asset and longevity risk and receive indirect access to the reinsurer's asset management capabilities and illiquid asset origination. Finally, life reinsurers are raising new third-party capital through sidecars where the risk is co-shared. Private equity companies, such as KKR, Blackstone, and Apollo Global, are acquiring insurance platforms or investing in insurance blocks through sidecars and thereby facilitating a traded longevity market. Since 2018, there has been over $20 bn in investor capital leveraged for the life and annuity markets, supporting nearly $400 bn in liabilities.

- This session ended with a panel discussion called "The challenges of valuing future pension liabilities post Covid-19." The panel members were Amy Kessler, Douglas Anderson (ClubVita), and Tim Gordon (Aon). It was chaired by Guy Coughlan (Universities Superannuation Scheme).

- Plenary session 3
  - Cord-Roland Rinke (Hannover Re) spoke about "Creating opportunities beyond longevity risk transfer." He accepted that standard longevity reinsurance was a comprehensive, intuitive, and field-proven solution. But he then discussed some examples of new tailor-made structures:
    - Bespoke Regular Premium Annuity Treaty (RPAT) with cash flow optimization. This is a proportional reassurance agreement—typically a quota share. The reinsurer pays the actual annuity benefits for the reassured business and receives regular reinsurance premiums equal to the expected annuity payments plus a fee, fixed at inception, based on best estimate mortality and mortality improvements. There is a net settlement of cash flows.
    - Home reversion RPAT. This is a reinsurance agreement involving a quota share swap of actual and expected annuity payments. The aim is the stabilization of cash flows and longevity cover.Limited term cover for longevity in pension and annuity payments. This provides reinsurance cover only for the initial years, together with (a) a structured fee, (b) forced termination/recapture, and (c) a fee after year x depending on experience.
    - Corridor solution for longevity in pension and annuity payments. This provides carve out cover with symmetric up- and down-sides. Three corridors for the payments are specified. If the actual payments (floating rate) lie in the central corridor, the reinsurer receives a reinsurance fee only; mortality deviations from the fixed rate of $\pm x\%$ are retained by the insurer. If the actual payments lie in the upper corridor, the insurer receives the difference (within the corridor), but this is restricted to the upper bound. If the actual payments lie in the lower corridor, the reinsurer receives the difference (within the corridor), but this is restricted to the lower bound.
    - Longevity index cover provides longevity trend protection and capital relief. The positives are: no experience data required, no data cleansing, and limited duration at a level acceptable for the capital markets. The negatives are: the challenge of the termination assumptions, gaining regulatory approval, and the recognition that there is no perfect portfolio hedging. There are three steps: step 1—rebuild the actual portfolio via a simplified

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artificial portfolio; step 2—use an officially published population mortality index instead of the portfolio mortality, so that the present value of the liabilities "equals" past and future annuity exposure for the artificial portfolio based on the realized past and projected future official mortality index; step 3—the final payment has an excess of loss (equivalent to a bull call spread) structure, with a claim payment if the present value of liabilities exceeds the attachment point (of the official index value at the transaction end) capped at the detachment point.

- Avery Michaelson (Longitude Solutions and Longitude Exchange) gave a presentation called "Constructing a longevity market that works for all stakeholders: Exploring market inefficiencies in managing longevity risk on a global basis, and suggestions for regulatory and market-based way to correct them." He began by accepting that insurers and reinsurers have so far been very successful in transferring longevity risk from pension plans, but there were some key issues emerging, such as capacity constraints, concentration and counterparty risks, the size of the risk margin, and uncertainty surrounding the capital benefit from index hedges. The solution is to bring in new investors via the capital markets. The attractions are that longevity risk is uncorrelated with other asset classes, index longevity risk can be modelled by financial quants, and taking trend risk with a fixed downside and maturity is like an alternative fixed income asset with which the financial markets are familiar. However, there is currently insufficient deal flow to dedicate resources and there needs to be options for secondary liquidity to develop. To overcome this, Michaelson helped to set up the Longitude Exchange as a marketplace for longevity risk. It brings hedgers and investors together on a digital platform designed for transacting longevity risk. By providing a marketplace, Longitude Exchange will drive down frictional costs and timelines, leading to more transaction volume and presenting an option for secondary liquidity. LE's tools streamline the process of hedging and investing in longevity risk:
    - For hedgers: hedge reporting—receive reporting, payment, and collateral instructions; hedge placement—conduct auctions, negotiate terms, and execute deals; hedge construction—construct trades optimized for risk and capital objectives; hedge analysis—measure hedges impact on risk and capital positions; hedge management—increase or decrease hedges through secondary trading.
    - For investors: longevity modeling—models and datasets to generate longevity scenarios; secondary trading—list positions, request bids, and buy listed transactions; on-going valuations—live quotes and historical trades to mark positions; investment analysis—price transactions using longevity scenarios; investment execution—place bids and negotiate terms with counterparties.
- Luca Tres (Head of EMEA Strategic Risk and Capital Life Solutions at Guy Carpenter) gave a talk called "Capital market investors and longevity risk: the past—and more importantly—the future." He began by considering some old myths about capital markets and longevity:
    - "The duration cannot be longer than 10 years." This is only partially true. Most of the recent structures have long final maturities and a much shorter

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expected one, i.e., the focus has partially shifted to the expected maturity. Still most capital market investors cannot take transactions with a final maturity of 20+ years.

- "It needs to be remote risk." This is only partially true. The out-of-the-money structuring has been mostly driven by Solvency II on the cedant's side. Still, it is true that capital markets investors tend to have a preference for remote risk hedges.
- "It needs to be population index based." This is not true. Most of the recent transactions have been indemnity based. Sophisticated investors do not have a strong preference and index transactions are suboptimal for cedants (due to basis risk). Population index transactions might make sense for new entrants and can be relevant to expand the potential investor universe.

He then considered some capital market structures that he thought would be successful:

- "Hedge Fund Re" model. The insurer enters into a standard longevity reinsurance contract with a reinsurance vehicle. The vehicle is typically owned by private equity, a hedge fund or more generally capital market investors. The only difference compared to the traditional structure is the mindset of the reinsurer. Unlike most traditional reinsurers, the reinsurer will strongly focus on the asset return as its key source of return on equity. Since this type of reinsurer is mostly focused on the asset management component, it often wants to hedge out longevity. Pros: simple reinsurance structure; flexible structuring. Cons: complexity in finding the asset mix that complies with local regulation plus gives the insurer comfort on counterparty risk and gives the reinsurer the intended expected return (will require switching into less liquid assets); counterparty risk and collateral considerations; high regulatory complexity in Europe. A number of players active in the space operate from a balance sheet outside Solvency II (often in Bermuda). While it depends on the specific structure and asset mix, generally moving long dated risks outside Europe might often find pushback from the EU regulators. A number of players in these areas have weaker rating levels compared to most of the "traditional" reinsurers—although this is not necessarily linked to their financial strength but simply to the shorter track record. A longer (and strong) track record helping on the regulatory front, the hedge fund re model is expected to play a major role in the future longevity.
- Capital market investors longevity swap (typically life ILS (insurance-linked securities) funds). The insurer enters into a longevity reinsurance contract with a reinsurance cell. This is typically done with an attachment and detachment point to cap the maximum counterparty exposure. The reinsurance cell passes all the risk to a capital market investor with a longevity swap. If the insurer does not require a reinsurance treaty from a legal standpoint, the same result can be achieved with capital market investors transacting a longevity swap directly with the insurer. Pros: flexible structuring; quick(er) execution. Cons: counterparty risk/collateral structuring required; likely to attract higher regulatory scrutiny as it is more innovative than traditional

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solutions; it requires an attachment and detachment point to set a maximum counterparty risk limit (bringing additional regulatory checks). Counterparty risk is a key factor, since almost all capital market investors are unrated, hence additional structuring is required to tackle this challenge. Investment banks used to intermediate these transactions, providing a rated counterparty to insurers. However, the changing regulatory landscape (e.g., the Dodd-Frank Act) has made this intermediation expensive. Instead, reinsurers are sometimes acting as fronter: their more sophisticated internal credit system can apply an internal rating to the counterparty risk. There are possible alternative structuring solutions. For example, large asset managers could pledge available assets; however, because of investors' right to redeem, this might be an option only for a minority of the funds. More and more capital market investors are looking at rated solutions, either directly or through a fronter. This format is expected to play a key role in longevity derisking in the future.

- Future new investors include sovereign wealth funds and very large asset managers. Tres concluded that we are close to making longevity a sustainable risk for our financial industry and our society. If not now, when?

- Plenary session 4

Douglas Anderson, Chief Visionary Officer of Club Vita, and Steven Baxter, Club Vita's Chief Data Scientist, gave a joint talk entitled "Necessary remaining steps to encourage more transactions." They began by summarizing today's insurance market: bespoke private contracts, typically between two parties; a small group of risk takers with deep specialism; long duration commitments (with penalties on early exit); tracks a named group of lives—the market is illiquid and physical. They then offered a vision of tomorrow's capital market: standardized contracts; a larger pool of investors (e.g., thematic hedge funds); penalty-free early exit (at the prevailing market price); tracks published proxy index—the market is liquid and synthetic. The aim is to give ILS mass appeal for longevity cedants. The current perceptions of the ILS market is that it is short time horizon (c.10 years) and more expensive (since an illiquidity premium is included in the price). The keys to unlocking the market are to make secondary trading easier and to help market sentiment to develop—and the common criterion for achieving both is better data.

Secondary trading can be made easier through the use of timely, reliable, and relevant proxy indices. The liquidity "battle" needs to recognize that the capital markets need timeliness, while risk cedants need relevance and reliability. Relevance means dealing with "basis risk", the socio-economic differences (including mortality trend differences) between a particular pension plan and the national population. This can be estimated using member postcodes and pension amounts. Reliability relates to the accuracy of national statistics—national population indices tend to rely on estimated populations and actual deaths. Population estimates can involve significant biases.[5] Timely, relevant,

[5]See the article in *The Economist* dated 17 December 2016 entitled "The curious case of Britain's missing nonagenarians" which begins: "Anyone who comes across 50,000 missing nonagenarians should notify the

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and reliant data can be achieved using life existence checking (LEC) service providers. This involves non-invasive identification of deaths in advance of formal confirmation with pension plan updates, and reduces the lead time for robust insights from c.18 months to c.3 months.

Developing market sentiment requires an understanding of the key factors that could lead to either higher or lower future life expectancy. First, the Covid legacy could lead to both longer lives for some survivors (due to improved hygiene, reduced infectious disease deaths, immunity of survivors) and shorter lives for other survivors (due to the impaired health of some survivors and delayed treatments, e.g., for cancer). Second, there is an acceleration in technology innovations. The mRNA vaccine revolution is just beginning. mRNA brought us a Covid-19 vaccine in record speed. Next it could tackle flu, malaria, or HIV. Third, investor pressure for health improvements. For example, Business for Health is a business-led coalition supporting long-term sustainable innovation and investment in preventative health and care. Its aim is to enhance the health and economic resilience of the UK, catalyzing and facilitating business contributions to achieve Mission 7 of the UK's Levelling Up ambition: to reduce health inequalities and add five years to healthy life expectancy ("HLE+5").[6]

Different investors will take different views on how these key factors will pan out in future—and this diversity of investor opinion is essential for a market to develop. There will be both longevity bears (equivalent to mortality bulls) and longevity bulls (equivalent to mortality bears) and the balance between the two will drive market prices up or down. Diversity of view is essential for a liquid market to develop. By equipping a new breed of traders with the tools to express their longevity/mortality sentiment, longevity swaps can evolve into liquid and tradeable capital market instruments, providing a new investment opportunity. One such tool is a dashboard of leading longevity indicators. It will have three phases: observed mortality (short duration phase), observed morbidity (medium duration phase), future interventions (long duration phase). The innovations required for success in the three phases are respectively, "quicker" (i.e., faster insights), "translation," and "visibility." By making it easier for a larger pool of professional investors to take different thematic health views, we can increase the appetite for longer durations and enable better pricing.

- Roshan Tajapra (SCOR Life) gave a talk called "Why smooth the past? How to deal with abnormal years of mortality experience." The exceptional Covid-19 mortality experience in 2020–21 posed a problem for setting base mortality rates. Many actuaries ignored or applied limited credibility to 2020–21 data for future experience analyses. However, Tajapra offered a framework to allow the inclusion of such outliers. It involved adjusting the improvement rate in the

Office for National Statistics (ONS) at once. "There is no definitive count of the population aged 90 and over in England and Wales," the statisticians acknowledged in a little-noticed report on December 12th. The ONS compared three estimates, which varied by more than 46,000, or nearly a tenth of the official total. Why is it so hard to measure the number of oldies? The official count of the population is the census, taken every ten years. On an annual basis, estimates are produced by rolling forward the census figures and allowing for deaths and migration. By this measure, in 2015 there were 504,030 people aged 90 or over"; https://www.economist.com/britain/2016/12/17/the-curious-case-of-britains-missing-nonagenarians

[6]https://www.businessforhealth.org/

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first year of projection to get back to trend (denoted a "bounce back" adjustment) and then adjusting the base mortality table to avoid double-counting.

- Razvan Ionescu (SCOR Life) gave a presentation called "The end of life tables? Mortality modelling history and outlook." Life tables were originally developed by people such as Johan de Witt, Edmond Halley, and Pierre-Joseph Cambon to improve the pricing of life annuities—which originally was not based on age. Over time, the pricing became more sophisticated by including factors such as gender and social class. Recently, with the advent of machine learning and big data, computational power has significantly increased, allowing much wider information sets to be analyzed. An example is the random survival forests algorithm which generalizes the survival tree algorithm. The survival tree algorithm segments the population based on mortality. For each final segment, mortality is estimated. This is equivalent to dividing a population in several groups and constructing a life table for each group. It is close to current actuarial practice. By contrast, the random survival forests algorithm performs data sampling, and then for each sample, a survival tree is constructed. The final prediction is obtained by averaging the prediction of each constructed tree. It is equivalent to constructing thousands of life tables and averaging them. Ionescu ended by asking whether this means the end of standard life tables.

- Guy Coughlan (Universities Superannuation Scheme, USS) considered "The implications of Covid-19 for pension scheme longevity." He first asked how the impact of Covid-19 at a national level is reflected in pension plan mortality. The answer depended on two key observations. First, pension plans have very different member profiles which vary by gender, age, socio-economic group, location, etc., so the impact of Covid-19 on a particular pension plan's mortality will reflect its particular member profile which in general will not be the same as the impact on the national population. Second, following the research of Cairns et al. (2020), Covid-19 mortality in adults appears to be proportional to all-cause mortality (at higher ages), i.e., Covid-19 mortality rate=[All-cause mortality rate]×[infection rate]×[relative frailty].[7] Hence, Covid-19 mortality for a particular pension plan can be estimated from the all-cause mortality appropriate for its profile of members. Using USS to illustrate, the member profile suggests Covid-19 mortality should be lower than for the national population, since most members (>60%) live in the higher socio-economic areas in South and Central England which have the lowest mortality rates. In fact, USS all-cause mortality is much lower than even the least deprived decile (IMD-10)[8] of the English population. A closer look at IMD centiles shows USS male life expectancy in the top 1% of the national population. Because Covid-19 mortality is proportional to all-cause mortality, the impact of Covid-19 on USS was expected to be very low. This is what happened: excess deaths for USS over 2020–21 followed a similar cumulative profile to the total for England, but at a lower level, with cumulative percentage excess deaths for USS

[7]Relative frailty is measured as the ratio of the death rate at age x from Covid-19 (conditional on being infected) to the death rate at age x from all causes in the absence of Covid-19. It recognizes, for example, that older males are more frail than females, and that more deprived people are more frail than less deprived people at a given age.

[8]Index of Multiple Deprivations; https://www.gov.uk/government/collections/english-indices-of-deprivation

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about half that of the national population during the first Covid-19 peak (during April–May 2020) about 40% lower during the second peak (January–February 2021). Coughlan concluded: "While not impossible, it seems unlikely that Covid-19 will have a significant long-term impact on pension plans."

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 *Journal of Demographic Economics*. They cover the following themes: the implications of Covid-19 for the longevity risk transfer market; longevity-linked transactions, such as buy-ins, buy-outs, longevity bonds, and equity release mortgages; the impact on life expectancy on marriage, economic disadvantage, and disabilities and diseases such as cancer; the financial burden of cancer insurance; and mortality models that take account of Covid-19 shocks, Covid-19 frailty heterogeneity, and mortality differentials between different populations using long memory processes. We briefly discuss each of the 10 papers selected.

In "Resilience in a Time of Crisis: How Covid-19 Pandemic Insights are Supporting a Vibrant Longevity Risk Transfer Market," Amy Kessler explains that pension risk transfer and longevity risk transfer are now growing secular trends. From North America to Europe, companies are de-risking pension plans in near-record volumes and have continued to do so throughout the pandemic—at or near the most favorable pricing experienced in years. The arrival of funded reinsurance on both sides of the Atlantic is bringing reinsurer capital and private assets to support the steady growth in the pension risk transfer market. Additionally, the enduring low interest-rate environment and quest for uncorrelated risk has seen the world's largest investors directing billions into life reinsurance sidecars. Kessler investigates how these markets thrived during the worst global pandemic in a century. The answer is that key research on the pandemic's impact on pensioner life expectancy allowed prices to be set and transactions to proceed through a time of significant uncertainty.

In "Buy-ins, Buy-outs, Longevity Bonds, and the Creation of Value," Richard MacMinn, Yijia Lin, and Tianxiang Shi argue that unanticipated increases in life expectancy expose corporations and pension funds to the risk of insufficient funds to pay a more extended stream of annuity benefits. Buy-ins, buy-outs, and longevity bonds provide pension funds with insurance and financial market instruments designed to hedge longevity risk. The most straightforward instruments and the most robust markets are currently for buy-ins and buy-outs. A model developed by the authors shows that these instruments transfer value to pension holders and, other things being equal, would not be used by firms since shareholder value is reduced. The analysis, however, also shows that these instruments can be used to solve the under-investment problem created by underfunded pension plans and so increase not only the pension fund value but also the corporate stock value.

Dean Buckner and Kevin Dowd contributed a paper entitled "A Market Consistent Approach to the Valuation of No Negative Equity Guarantees and Equity Release Mortgages." In addition to providing a new market consistent approach to the valuation of "no negative equity guarantees" and "equity release mortgages," the paper also provides a new approach to the estimation of the volatility inputs. The proposed approach to volatility produces a volatility term structure that is dependent on the age and gender of the borrower. Illustrative valuations are provided based on the Black '76 put option pricing formula and mortality projections based on the M5

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Cairns-Blake-Dowd (CBD) mortality model. Results have interesting ramifications for industry practice and prudential regulation.

In "The Effect of Marital Status on Life Expectancy: Is Cohabitation as Protective as Marriage?," Anne G. Balter, Dorethe S. Bjerre, and Malene Kallestrup-Lamb argue that marital status is an important predictor for life expectancy. However, non-married individuals are often misclassified as singles which ignores the heterogeneity within the group. The paper shows the importance of distinguishing between types of singles, and in particular whether they are cohabiting, when predicting life expectancies. The authors use unique and detailed longitudinal register data to track marital status throughout the individual's lifetime. They find that all types of singles consistently benefit from living with a partner, i.e., after divorce, becoming widowed, or never being married. This result holds for both men and women. For certain types of cohabiting singles, the authors reject significant differences in life expectancy compared to married individuals. Finally, they use a case study to show that, like married individuals, all types of singles that cohabit also serve as informal caregivers and have the potential to limit end-of-life long-term care expenditure levels.

In "Counting the Cost of Inequality," Les Mayhew argues that an aging population increases pressure on health and social care, on welfare payments and on pensions—and hence on taxes, especially in public funded systems. There is no simple measure linking health, on the one hand, to economic disadvantage, on the other—and hence the tax burden that would be needed to pay for health and welfare services. The author imagines a situation in which each local area is responsible for financing its own public services out of earnings. He classifies all local authorities in England according to their health, life, and work span. He hypothesizes that a local tax is levied to cover health care costs, welfare benefits for those sick and unable to work, and state pension payments. He uses a model to partition life time costs to the public purse based on years spent in ill health, disability, and pensionable years over the life course using the average costs per person per year for each district. He argues that differences in these hypothetical tax rates between districts provide a summary measure of inequality since a higher tax burden would fall on those who can least afford it. He shows that a one-year improvement in healthy life expectancy would add around 4.5 months to life expectancy and 3.4 months to working lives in England whilst reducing the tax burden by around 0.5%. He casts doubt on current UK government targets to increase health expectancy by five years by 2035; however, were it to be achieved it would add an estimated 23 months to life expectancy and 17 months to work expectancy and reduce taxes by 2.4%.

Marjan Qazvini contributed a paper entitled "Survival Analysis of Longitudinal Data: The Case of the English Population Aged 50 and Over." The paper analyzes data from 5 waves of the English Longitudinal Study of Aging (ELSA). The aim is to study the impact of demographic and self-rated health variables, including disability and diseases, on the survival of the population aged 50+. The disability variables considered are mobility impairment, difficulties in performing activities of daily living, and instrumental activities of daily living (IADL). One of the problems with the survey is missing observations. This may happen for different reasons, such as errors, nonresponses, and temporary withdrawals. The author addresses this problem by applying single and multiple imputation methods and then fitting a generalized linear model (GLM) and a generalized linear mixed model (GLMM) to the data. The results indicate that a GLMM performs better than a GLM in terms of information

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criteria. The paper also looks at the predictability of the model in terms of the receiver operating characteristic (ROC) and the area of ROC. The author concludes that among the disability factors, IADL, and among the diseases, cancer significantly affect the survival of the English population aged 50 and older.

Hsin-Chung Wang, Jack C. Yue, Ting-Chung Chang, and Ting-Chen Chang contributed a paper entitled "Morbidity Compression and Cancer Insurance." Cancer is among the leading causes of death in the world, with about 10 million deaths, one in every six deaths, related to cancer in 2020. Asian countries suffer even more from cancer. For example, in the Four Asian Tigers (Hong Kong, Japan, South Korea, and Taiwan), cancer is the leading cause of death. In Taiwan, cancer insurance is the most popular commercial health product. However, the loss ratio of cancer products increases with policy year and exceeds 100% in many insurance companies. In addition, almost all cancer benefits are significantly limited in order to avoid financial insolvency. In this study, the authors evaluate the risk to the provider from offering cancer insurance from the perspective of morbidity compression. They obtain age-specific survival rates and medical expenditures for those diagnosed with cancer, as well as mortality rates and cancer incidence rates, using the data from Taiwan's National Health Insurance Research Database. Also, they apply the standardized mortality ratio and the Lee–Carter model to estimate the trend of cancer-related values. They find that cancer incidence rates gradually increase with time, which indicates that the assumption of morbidity compression is violated. On the other hand, the mortality rates and survival rates of cancer patients decrease significantly annually. Thus, length of life with cancer increases, and so does the cancer insurance premium. The authors recommend that cancer insurance covers only the first five years of medical expenditure after the insured is diagnosed with cancer. This can greatly reduce the burden on insurers and provide a possibility to deal with the cancer longevity risk.

In "Accounting for Covid-19-Type Shocks in Mortality Modeling: A Comparative Study," Simon Schnürch, Torsten Kleinow, and Andreas Wagner point out that mortality shocks such as the one induced by the Covid-19 pandemic have a substantial impact on mortality models. They describe how to deal with this in the period effect of the Lee–Carter model. The main idea is to not rely on the usual normal distribution assumption as it is not always justified. Instead, the authors consider a mixture distribution model based on the peaks-over-threshold method, a jump model and a regime switching model and introduce a modified calibration procedure to account for the fact that varying amounts of data are necessary for calibrating different parts of these models. They perform an extensive empirical study for nine European countries, comparing the models with respect to their parameters, quality of fit, and forecasting performance. They define five exemplary scenarios regarding the future development of pandemic-related mortality. As a result of their evaluations, the authors recommend the peaks-over-threshold approach for applications with a possibility of extreme mortality events.

In "Effect of the Covid-19 Frailty Heterogeneity on the Future Evolution of Mortality by Stratified Weighting," Maria Carannante, Valeria D'Amato, and Steven Haberman start by pointing out the inadequacy of assuming, in the construction of a model of mortality, that frailty is constant for the individuals comprising a demographic population. This assumption is implicitly made by standard life table techniques. The substantial differences in the individual susceptibility to specific causes of death lead to heterogeneity in frailty, and this can have a material effect on mortality models

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and projections—specifically a bias due to the underestimation of longevity improvements. Given these considerations, the authors develop a stochastic model based on a stratification weighting mechanism, which takes into account heterogeneity in frailty. Furthermore, the stratified stochastic model has been adapted also to capture Covid-19 frailty heterogeneity, that is a frailty worsening due to the Covid-19 virus. Based on different frailty levels characterizing a population, which affect mortality differentials, the analysis allows for forecasting the temporary excess of deaths by the stratification schemes in a stochastic environment.

Finally, in "The Impact of Long Memory in Mortality Differentials on Index-based Longevity Hedges," Kenneth Q. Zhou and Johnny Siu-Hang Li point out that in multi-population mortality modeling, autoregressive moving average (ARMA) processes are typically used to model the evolution of mortality differentials between different populations over time. While such processes capture only short-term serial dependence, it is found in their empirical work that mortality differentials often exhibit statistically significant long-term serial dependence, suggesting the necessity for using long memory processes instead. In this paper, the authors model mortality differentials between different populations with long memory processes, while preserving coherence in the resulting mortality forecasts. The results indicate that if the dynamics of mortality differentials are modeled by long memory processes, mean reversion would be much slower, and forecast uncertainty over the long run would be higher. These results imply that the true level of population basis risk in index-based longevity hedges may be larger than what we would expect when ARMA processes are assumed. The authors also study how index-based longevity hedges should be calibrated if mortality differentials follow long memory processes. It is found that delta hedges are more robust than variance-minimizing hedges, in the sense that the former remain effective even if the true processes for mortality differentials are long memory ones.

Longevity 17 took place on 12–13 September 2022. The plan was to hold a physical conference in Toronto in Canada. Unfortunately, during the early planning stage in December 2021, the Canadian government decided, in response to a surge in Covid-19 cases, to impose an international travel ban and, following discussions with our conference sponsors, we decided to hold L17 online. We also decided to call the conference the Waterloo conference to acknowledge all the ground work Johnny Li had expended in trying to get a physical conference for 2022. We did not want to call it the Toronto conference because we are determined to hold a physical conference in Toronto at a future date and will not be put off by a "little critter"[9] called SARS-CoV-2. *Geneva Papers on Risk and Insurance* will publish a special issue. *Longevity 18* will take place on 7–8 September 2023 at Bayes Business School in London. The *European Actuarial Journal* will publish a special issue.

Finally, we would like to express our deep sadness on hearing of the tragically early death of Professor Ken Seng Tan in 2022. He was a long-time supporter of our conference series and organized *Longevity 9* in Beijing in September 2013. We offer our sincere condolences to his family and friends.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/dem.2023.2

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

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