LIVING to 100
SOCIETY OF ACTUARIES
INTERNATIONAL SYMPOSIUM

2020 Symposium
Jan. 13–15
Lake Buena Vista, FL

1A - Management of Longevity Risk

SOA 2020 Living to 100 Symposium

Quantification and Management of Longevity Risk in China

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January 13, 2020

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Chinese mortality on the move

- General population:
  - Life expectancy at birth for males increased from **57** years in 1970 to **74** years in 2017.
  - Life expectancy at birth for females increased from **61** years in 1970 to **79** years in 2017.
- Pension insurers:
  - Life expectancy at birth for males increased by **8.2** years over the period of 1990-1993 to 2010-2013.
  - Life expectancy at birth for females increased by **9.2** years over the period of 1990-1993 to 2010-2013.

The urban pension system in China

Pillar 1

- Mandatory
- Publicly-managed by the government
- Defined-benefit
- PAYGO portion funded by employer contributions
- Funded portion supported by employee contributions
- Protection against longevity risk?

Moderate

Pillar 2

- Mandatory
- Privately-managed by the employer
- Defined-contribution
- Known as “Enterprise Annuity”
- Funded by both employer and employee contributions
- Protection against longevity risk?

No

Pillar 3

- Voluntary
- Life annuities from insurance companies
- Known as “Commercial Annuity”
- Individual savings
- Protection against longevity risk?

Yes

A rising demand for life annuities

- The demand for life annuities in China grows rapidly over the last decade.
- The total amount of life annuities purchased with individual savings has increased from **62.6** billion yuan in 2006 (Source: Chen and Zhu, 2009) to **150.0** billion yuan in 2016 (Source: China Insurance Regulatory Commission).
- The total annuity benefit payout has risen from **14.0** billion yuan in 2010 to **85.3** billion yuan in 2017 (Source: China Insurance Regulatory Commission).
- The total amount of funds accumulated in Enterprise Annuity accounts in 2018 was **1.477** trillion yuan, which is almost 8 times that in 2008 (Source: Ministry of Human Resources and Social Security).

Challenges to Chinese insurers

- A large part of the longevity risk is ‘trend risk’.
- The risk affects all annuitants in the Chinese insurance industry systematically.
- The effect of natural hedging (with the life insurance book) may be limited.
- The newly introduced China Risk Oriented Solvency System (C-ROSS) specifically requires insurers operating in China to hold longevity risk solvency capital.

Who else can bear the risk?

The government?

- By issuing longevity bonds or bailing out insurance companies.
- It is already assuming huge longevity trend risk due to its public pension plan (with asset amounts to 2826.9 billion yuan at 2013 year-end).

Capital markets?

- Capital market investors may be interested in taking longevity trend risk exposures.
- In 2014, the total market capitalization of the equity markets in China is 8.3 trillion USD.
- In 2014, the total notional amount of derivatives traded in Chinese exchanges is 271 trillion USD.

The importance of standardization

- Standardization could resolve the misalignment of incentives between annuity providers and capital market investors.
- There is a need to create standardized mortality indexes, upon which derivative securities can be written.
- Existing indexes such as the LLMA's LifeMetrics index are based on the mortality experience in the Western world.
- With a population of over 1.35 billion, China deserves its own standardized mortality index.

Our goals

Primary objective: To study the possibility of developing a market for standardized mortality-linked securities in China.

- Goal 1: To quantify the longevity risk facing insurers in China using a stochastic mortality model that is specifically designed for China.
- Goal 2: To develop a dynamic longevity hedging strategy that is compatible with the demographic situation in China.
- Goal 3: To examine how much C-ROSS solvency capital that a standardized longevity hedge can release.

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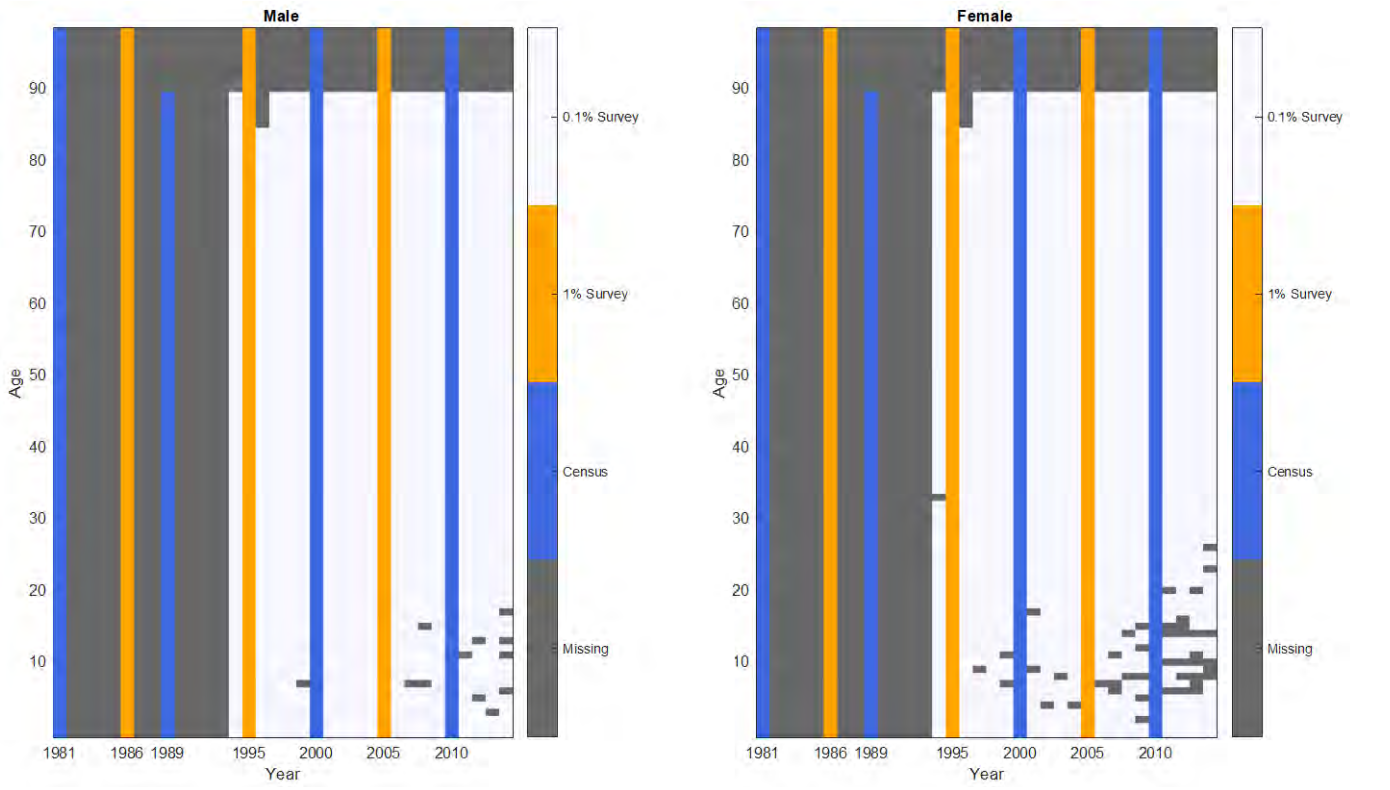
A Stochastic Mortality Model for China

The problems of Chinese mortality data



The Bayesian mortality model for China

- An adapted version of the classical Lee-Carter model (Lee and Carter, 1992):

$$\ln\big(m(x,t)\big) = a(x) + b(x)k(t) + \epsilon(x,t),$$

  where

  - $\epsilon(x,t)$ follows a normal distribution with a zero mean and a time-specific variance.

- The time-varying trend $k(t)$ is modeled by a random walk with drift.

$$k(t) = c + k(t-1) + \xi(t),$$

  where

  - c is a constant drift term, and
  - $\xi(t)$ follows a normal distribution with a zero mean and a constant variance of σ_ξ^2.

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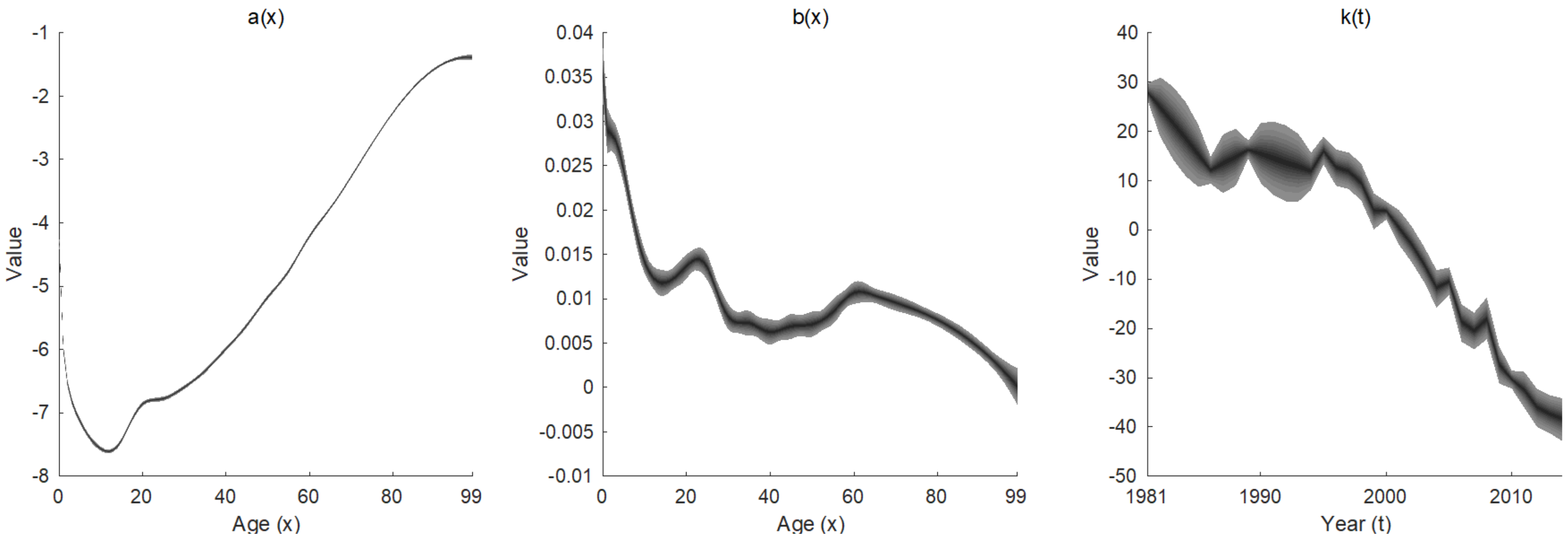
Estimating the model

- The model is formulated as a Gaussian state-space model, with $k(t)$ being treated as hidden states.
- The estimation procedure:
  - Gibbs sampling: Draw samples of the model parameters from the conditional posterior distributions.
  - Sequential Kalman filtering: Retrieve the hidden states over the calibration window by sequential Kalman filtering and smoothing algorithm.
  - Imputation of missing data: Given the sample of parameters drawn and the hidden states retrieved, simulate the values of some missing data.
  - Cubic B-splines smoothing: smooth the age-specific parameters $a(x)$ and $b(x)$ using cubic B-splines functions.

Estimation results



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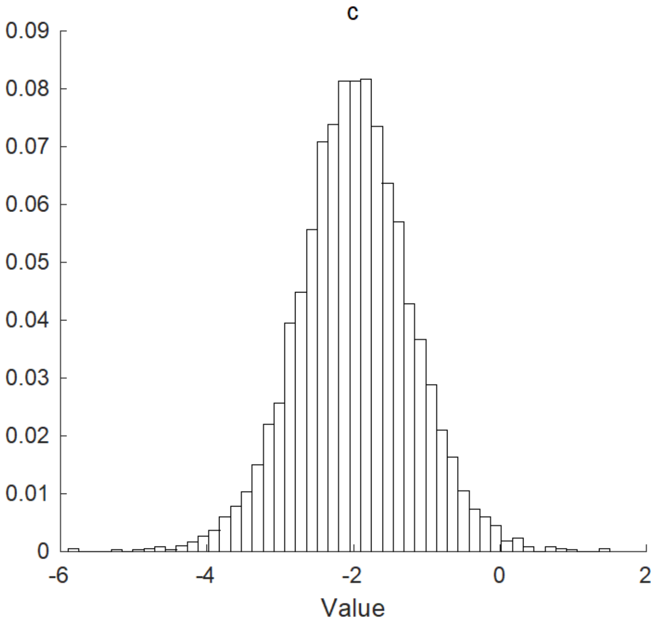
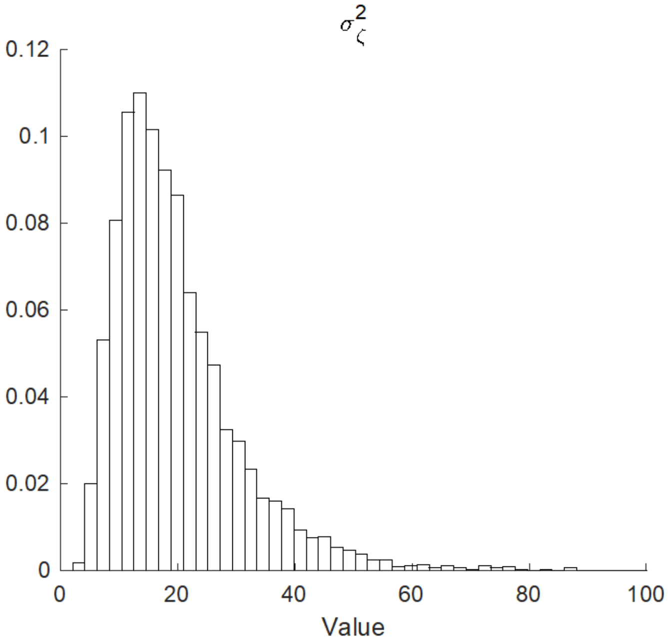
Estimation results





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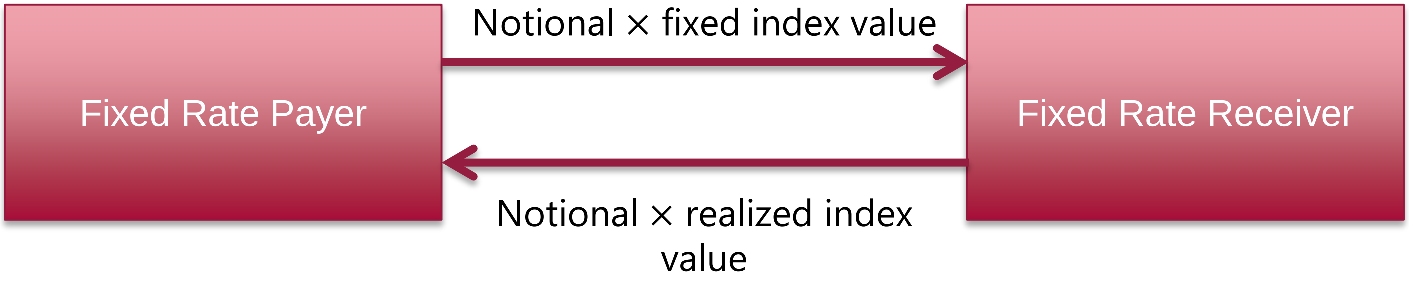
A Standardized Longevity Hedge for China

Derivatives written on Chinese mortality indexes



- A zero-coupon swap that exchanges a fixed mortality index for a realized (random) index at maturity.
- q-forward:
  - The index is an age-specific mortality rate for the general Chinese population.
- S-forward:
  - The index is an age-specific survival probability for the general Chinese population.

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Calculating the appropriate notional amount

- Define
  - FL_t: the hedger's future liabilities (per policyholder) at time t.
  - Q_t: the value of a q-forward (per \$1 notional) at time t.
  - h_t: the required notional amount of the hedging instrument at time t.
- For a q-forward hedge, we have $\frac{\partial FL_t}{\partial k(t)} = h_t \frac{\partial Q_t}{\partial k(t)}$.
- The partial derivatives can be computed semi-analytically.
- An approximation method is used to avoid the need for nested simulations.

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Measuring the hedge effectiveness

- Define
  - t_h: the time when the longevity hedge is established.
  - PL_t: the time-t_h value of all liability payments (discounted to time t_h), given the information up to and including time $t \geq t_h$.
  - PA_t: the time-t_h value of the assets backing the liabilities at time $t \geq t_h$.
- The potential deviation between PA_t and PL_t is the residual risk that is not eliminated by the longevity hedge.
- A metric for measuring hedge effectiveness:

$$HE_u = 1 - \frac{\mathrm{Var}\left(PA_{t_h+u} - PL_{t_h+u} | \mathcal{F}_{t_h}\right)}{\mathrm{Var}\left(PL_{t_h+u} | \mathcal{F}_{t_h}\right)}, u = 1,2,\ldots$$

An illustration: Key assumptions

- The liability being hedged is a portfolio of life annuities that are sold to males who are aged 60 at the end of 2014. Each annuity pays $1 at the end of each year until the annuitant dies or reaches age 90, whichever is the earliest.
- The mortality experience of the annuitants is the same as that of the males in the Chinese national population.
- The hedging horizon is 30 years and the hedge portfolio is adjusted annually.
- The hedging instruments used are q-forwards that are linked to the national population of China. They all have a time-to-maturity of 10 years and a reference age of 75.
- The market for q-forwards is liquid and no transaction cost is required.

An illustration: Numerical results

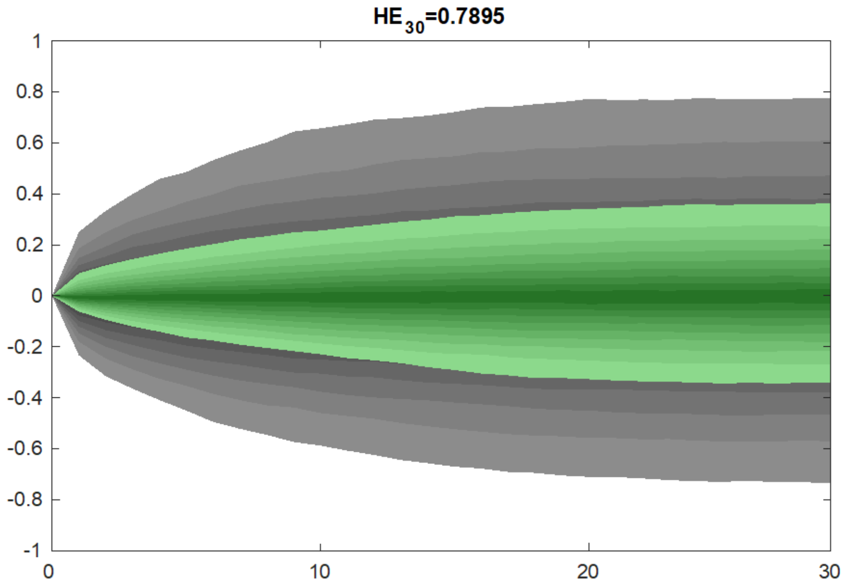

Figure: Simulated distributions of $PL_{t_h+u}|\mathcal{F}_{t_h}$(the grey fan chart) and $PA_{t_h+u} - PL_{t_h+u}|\mathcal{F}_{t_h}$ (the green fan chart), $u = 1,2, \dots, 30$, for the annuity liabilities that are associated with males in China.

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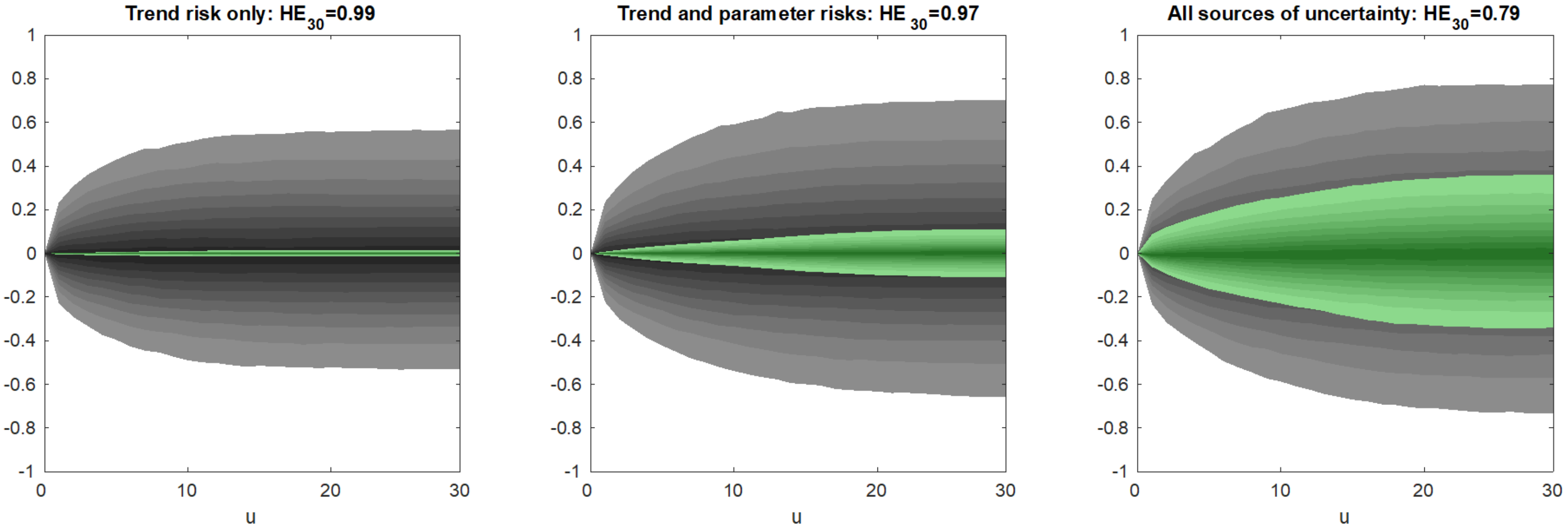
An illustration: Numerical results



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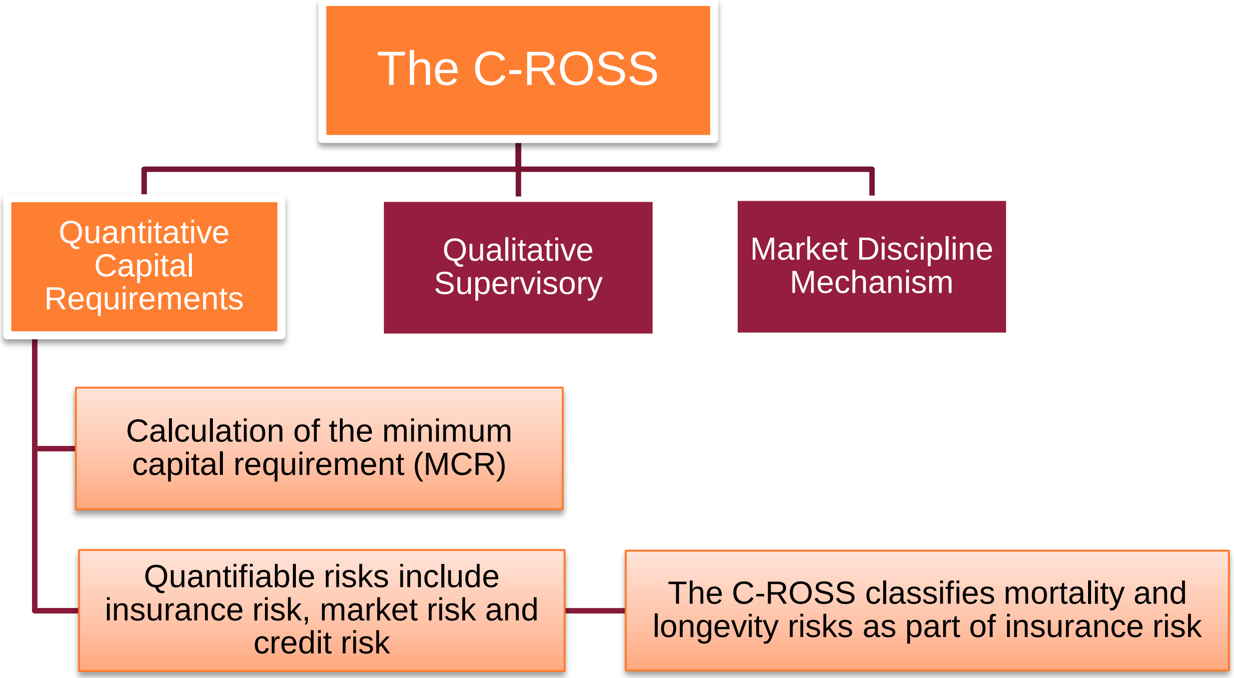
Longevity Risk Solvency Capital under C-ROSS

The China Risk Oriented Solvency System (C-ROSS)

- Introduced by the China Insurance Regulatory Commission (CIRC) in 2012 to supersede the former Insurance Company Solvency Regulations (ICSR).
- Can be regarded as the Chinese version of Europe's Solvency II.
- Officially released by the CIRC in February 2015.
- Regulations and capital requirements are emphasized on a risk-oriented system rather than on a factor-based system.
- The C-ROSS is a three-pillar system.

A three-pillar regulatory framework



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The C-ROSS MCR for mortality risk

$$MCR^{(M)} = \max\left[V\left(\left(1 + SF^{(M)}\right)\boldsymbol{m}\right) - V(\boldsymbol{m}), 0\right]$$

- $V(\cdot)$ is the present value of all cash flows from the insurance/annuity liabilities.
- $\boldsymbol{m}$ is the best-estimated mortality curve.
- $SF^{(M)}$ is the adverse scenario factor for mortality risk:

$$SF^{(M)} = \begin{cases} 10\% & N > 200 \\ 15\% & 100 < N \leq 200 \\ 20\% & N \leq 100 \end{cases}.$$

- N is the number of contracts.

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The C-ROSS MCR for longevity risk

$$MCR^{(L)} = \max\left[V\left(\left(1 + SF^{(L)}\right)\boldsymbol{m}\right) - V(\boldsymbol{m}), 0\right]$$

- $V(\cdot)$ is the present value of all cash flows from the insurance/annuity liabilities.
- $\boldsymbol{m}$ is the best-estimated mortality curve.
- $SF^{(L)}$ is the adverse scenario factor for longevity risk:

$$SF^{(L)} = \begin{cases} (1-3\%)^{t}-1 & 0 < t < 5 \\ (1-3\%)^5(1-2\%)^{t-5}-1 & 5 < t \leq 10 \\ (1-3\%)^5(1-2\%)^5(1-1\%)^{t-10}-1 & 10 < t \leq 20 \\ (1-3\%)^5(1-2\%)^5(1-1\%)^{-10}-1 & t > 20 \end{cases}.$$

The C-ROSS MCR for mortality and longevity risks

- Once $MCR^{(M)}$ and $MCR^{(L)}$ are both determined, the C-ROSS MCR for mortality and longevity risks is calculated as

$$MCR = \sqrt{\boldsymbol{M}\boldsymbol{\Sigma}\boldsymbol{M}'},$$

where

$$\boldsymbol{M} = \left(MCR^{(M)}, MCR^{(L)}\right),$$

$$\boldsymbol{\Sigma} = \begin{pmatrix} 1 & -0.25 \\ -0.25 & 1 \end{pmatrix}.$$

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The impact of a longevity hedge on the C-ROSS MCR

Minimum Capital Requirement (MCR)		
Unhedged Liability	q-Forward Portfolio	Hedged Liability
0.7037	0.6370	0.0679

Conclusion

Concluding remarks

Three contributions on the quantification and management of longevity risk in China:

1. A stochastic mortality model that is specifically designed for China and quantifies the longevity risk faced by insurers in China.
2. A dynamic hedging strategy that can remove a meaningful portion of longevity risk with trend, parameter and error risks taken into account.
3. A significant reduction in the C-ROSS MCR, making a strong case for introducing a standardized longevity risk transfer market in China.

Thank you!

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A Value-Based Longevity Index for Hedging Retirement Income Portfolios

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Living to 100 Symposium
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January 2020

Outline

- **Research Motivation and Background**
- **Value-Based Longevity Index**
- **Liability Profile**
- **The Hedging Framework**
- **Basis Risk Metrics**

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Background and Context

- Retirement income providers are heavily exposed to longevity risk.
- The traditional approach to managing longevity risk has involved insurance or reinsurance-based solutions (Coughlan et al., 2011).
- Reinsurers have a limited appetite and capacity to absorb longevity risk (Wadsworth, 2005).
- Global longevity risk exposure is approaching the limit of the global reinsurance capacity (Cairns and El Boukfaoui, 2018).
- The development of a longevity risk transfer market offers a potential solution (Coughlan, 2009; Xu et al., 2019).
- Investors have the potential to earn a risk premium by diversifying into securities with near zero correlation with traditional asset classes (Anderson and Baxter, 2017).

The Case for Index-Based Longevity Hedging

- There are two broad categories of hedging longevity risk: customised (indemnity-based) hedges and standardised (index-based) hedges.
- To date, customised transactions have dominated the longevity market (Anderson and Baxter, 2017).
- Indemnity-based hedges have drawbacks (Coughlan, 2009):
  - Disclosure of pension fund/annuity book data,
  - Complex for capital markets to analyse transactions and manage risks,
  - Lack of transparency,
  - Discourages investment and market liquidity, and
  - High cost of hedging for retirement income providers.
- Standardised hedges overcome these shortcomings (Villegas et al., 2017).
- However, they are subject to basis risk (Coughlan et al., 2007).

Barriers to Index-Based Longevity Hedging

1. Availability of a **longevity index** that closely tracks the value of longevity-linked liabilities (Sweeting, 2010).
   - Retirement income providers are exposed to longevity risk, interest rate risk and inflation risk (Towers Watson, 2013)
   - Value-based longevity indices offer a potential solution (Sherris 2009; Chang and Sherris, 2018).
2. **Basis risk**. (Li et al., 2017)
   - Materiality of the residual risk exposure.
   - Robust basis risk quantification framework for the proposed longevity index that can be applied to individual retirement income portfolios.

- Research motivation: a framework to facilitate the transition towards index-based longevity hedging by addressing these two issues.

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Value-Based Longevity Index

- We consider a value-based index, $I_{x,t}$, which quantifies the expected present value of a unit of longevity and inflation indexed income paid annually in arrears to a cohort aged, x, at initial time, t.
- The value of the index is represented as

$$I_{x,t} = \sum_{i=1}^{\omega - x} S^R(x, t, t+i) \times P_R(t, t+i),$$

  where
  - ω is the maximum attainable age,
  - $S^R(x, t, t+i)$ denotes the i year survival probability of the population underlying the index, forecast using mortality modelling frameworks, and
  - $P_R(t, t+i)$ denotes the time t price of an inflation-indexed zero coupon bond making a single unit payment at time $t+i$, forecast using interest rate modelling frameworks.

Joint Affine Mortality Model

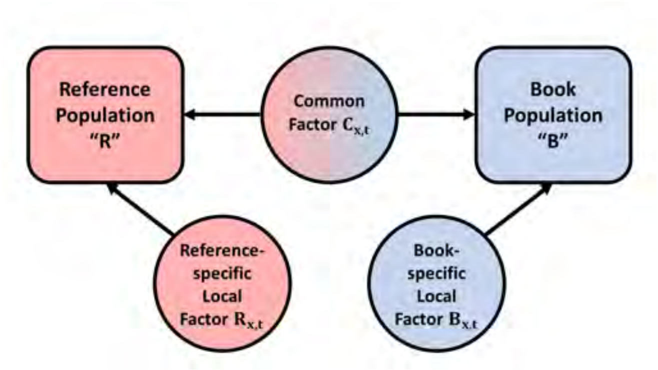


Figure 1: Structure of the joint affine term structure model for mortality.

Joint Affine Mortality Model cont...

- Common factor captures all the dependence in mortality experience across the two populations arising from their mutual exposure to certain common influences (for example, a strong winter).
- The two local factors facilitate discrepancies in mortality dynamics over time between the two populations owing to differences in their demographic composition.
- The average mortality intensities $\bar{\mu}^R_{x,t}$ and $\bar{\mu}^B_{x,t}$ of the book and reference populations are modelled as

$$\bar{\mu}^R_{x,t} = \delta_{R,0} + \delta_{R,1} C_{x,t} + \delta_{R,2} R_{x,t},$$
$$\bar{\mu}^B_{x,t} = \delta_{B,0} + \delta_{B,1} C_{x,t} + \delta_{B,2} B_{x,t}.$$

Joint Affine Term Structure Model cont...

- The factors are assumed to evolve independently, implying that the common factor does not depend on the local factors.
- This allows the joint ATSM to be decomposed into two single-population term structure mortality models.
- Due to the incompleteness of the longevity market, Xu et al. (2019) define a best-estimate measure $\bar{Q}$, fixed to observed mortality rates. Factor dynamics under $\bar{Q}$ can be represented as

$$\begin{bmatrix} dC_{x,t} \\ dR_{x,t} \\ dB_{x,t} \end{bmatrix} = -\begin{bmatrix} \phi_1 & 0 & 0 \\ 0 & \phi_2 & 0 \\ 0 & 0 & \phi_3 \end{bmatrix} \begin{bmatrix} C_{x,t} \\ R_{x,t} \\ B_{x,t} \end{bmatrix} dt + \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix} \begin{bmatrix} dW_t^{\bar{Q},C} \\ dW_t^{\bar{Q},R} \\ dW_t^{\bar{Q},B} \end{bmatrix},$$

where ϕ_1, ϕ_2, ϕ_3, σ_1, σ_2 and σ_3 are constant parameters with $W_t^{\bar{Q},C}$, $W_t^{\bar{Q},R}$ and $W_t^{\bar{Q},B}$ being Wiener processes under the best-estimate measure.

Joint Affine Mortality Model cont...

- The survival probabilities for the reference and book populations are respectively given by

$$S^R(x,t,T) = e^{B_1(t,T)C_{x,t}+B_2(t,T)R_{x,t}+A^R(t,T)},$$
$$S^B(x,t,T) = e^{B_1(t,T)C_{x,t}+B_3(t,T)B_{x,t}+A^B(t,T)},$$

where

$$B_j(t,T) = -\frac{1-e^{-\phi_j(T-t)}}{\phi_j} \qquad \text{for} \quad j=1,2,3,$$

$$A^R(t,T) = \frac{1}{2}\sum_{j=1,2}\frac{\sigma_j^2}{\phi_j^3}[\frac{1}{2}(1-e^{-2\phi_j(T-t)})-2(1-e^{-\phi_j(T-t)})+\phi_j(T-t)],$$

$$A^B(t,T) = \frac{1}{2}\sum_{j=1,3}\frac{\sigma_j^2}{\phi_j^3}[\frac{1}{2}(1-e^{-2\phi_j(T-t)})-2(1-e^{-\phi_j(T-t)})+\phi_j(T-t)].$$

Dynamic Nelson Siegel Model

- We use the Dynamic Nelson Siegel (DNS) interest rate model developed in Diebold and Li (2006).
- The yield function of the model is:

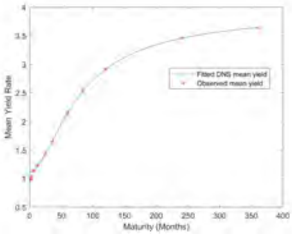
$$y_t(\tau) = L_t + S_t\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + C_t\left(\frac{1-e^{-\lambda\tau}}{\lambda t} - e^{-\lambda\tau}\right),$$

where λ is the Nelsen Siegel parameter and

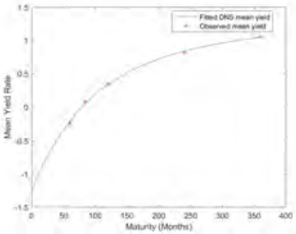
$$\begin{bmatrix} dL_t^N \\ dS_t^N \\ dC_t^N \end{bmatrix} = -\begin{bmatrix} 0 & 0 & 0 \\ 0 & \lambda^N & -\lambda^N \\ 0 & 0 & \lambda^N \end{bmatrix} \begin{bmatrix} L_t^N \\ S_t^N \\ C_t^N \end{bmatrix} dt + \begin{bmatrix} \sigma_1^N & 0 & 0 \\ 0 & \sigma_2^N & 0 \\ 0 & 0 & \sigma_3^N \end{bmatrix} \begin{bmatrix} dW_t^{Q,L^N} \\ dW_t^{Q,S^N} \\ dW_t^{Q,C^N} \end{bmatrix},$$

Dynamic Nelson Siegel Model cont...

- The nominal (N) interest rate model is calibrated using US Treasury security yields with maturities ranging from 1 month to 30 years.
- The real (R) interest rate model is calibrated using US Treasury Inflation Protected Security (TIPS) yields with maturities of ranging from 5 years to 30 years.



(a) Nominal



(b) Real

Figure 2: Nominal & Real US bond yields from Oct 2006 to May 2018

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Liability Profile

- We consider a closed annuity pool comprising of individuals from a single cohort initially aged x in year t who are promised \$1 of inflation-indexed income per year upon survival from ages $x+1$ to the maximum attainable age, ω.
- The present value of the retirement income portfolio liability is

$$PV(\text{Unhedged Portfolio}) = \sum_{i=1}^{\omega-x} l_{x+i,t+i}^{B} \times P_R(t, t+i),$$

  where $l_{x+i,t+i}^{B}$ is the number of surviving annuitants (aged $x+i$ at time $t+i$) and this is dependent on the simulated book population mortality dynamics generated by the mortality model.
- Binomial sampling of deaths used to reflect the sampling variability in a finite book size: $D_{x,t}^{B} \sim \text{Bin}(E_{x,t}^{B}, q_{x,t}^{B})$ where $q_{x,t}^{B}$ is simulated for each path.

Liability Profile cont...

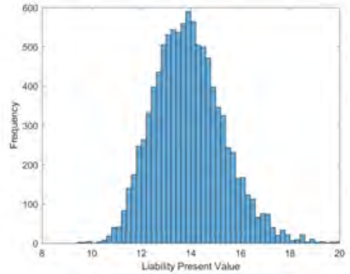

Figure 3: Liability present value histogram for the book population cohort initially aged 65 (joint ATSM, 10,000 simulations, 100,000 lives).

- A degree of positive skewness is apparent, with the simulated distribution exhibiting a heavier right tail.
- This highlights the importance of effectively hedging against more extreme outcomes in pension liabilities resulting from unexpected mortality or financial market experience.

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Index Swap Instrument

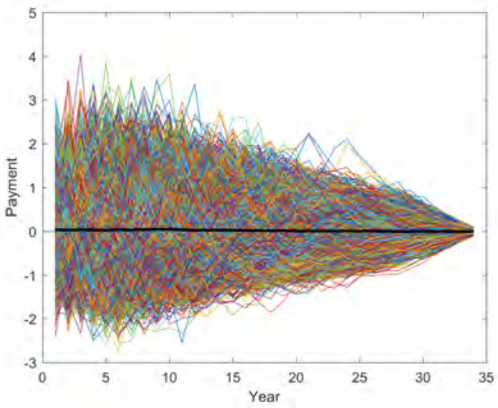
- An annually-settled index swap trades in the longevity risk transfer market where at time $t + i$, the fixed leg pays the i year forward index value $I^f_{x+i,t+i}$ while the floating leg pays the realised index value $I_{x+i,t+i}$.
- The random present value of the swap for the payer of the fixed leg (e.g., a pension fund looking to hedge) is:

$$PV(\text{Index Swap}) = \sum_{i=1}^{\omega-x-1} (I_{x+i,t+i} - I^f_{x+i,t+i}) \times P_N(t, t+i),$$

where the forward values $I^f_{x+i,t+i}$ are computed from central forecasts, while the realised index values $I_{x+i,t+i}$ are simulated.

Simulated Swap Payments

Figure 4: Simulated swap payments for the reference population cohort initially aged 65 (joint ATSM, 10,000 simulations)



Hedge Construction

- The random present value of the annuity provider's aggregate portfolio can therefore be expressed as:

$$PV(\text{Hedged Portfolio}) = PV(\text{Unhedged Portfolio}) + PV(\text{Swap}),$$

$$= \sum_{i=1}^{\omega-x} l^{B}_{x+i,t+i} P_R(t, t+i) + w_0 \sum_{i=1}^{\omega-x} (l_{x+i,t+i} - l^{f}_{x+i,t+i}) P_N(t, t+i),$$

where w_0 refers to the notional amount of the longevity swap which is estimated using numerical optimisation with an objective to minimise the variance of the hedged portfolio's present value as in Li et al. (2017).

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Assessing Risk Reduction

- The survival index value is represented as

$$I^0_{x,t} = \sum_{i=1}^{\omega - x} S^R(x, t, t+i).$$

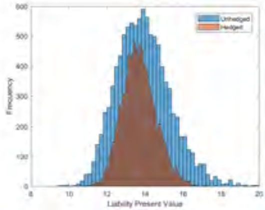
- Nominal-linked index value is represented as

$$I^1_{x,t} = \sum_{i=1}^{\omega - x} S^R(x, t, t+i) \times P_N(t, t+i).$$

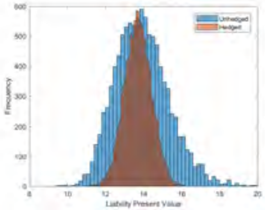
- Risk reduction achieved by hedging the retirement income portfolio using $I^0_{x,t}$ represents the impact of longevity risk.
- Additional risk reduction achieved by hedging using $I^1_{x,t}$ represents the impact of interest rate risk.
- Additional risk reduction achieved by hedging the retirement income portfolio using $I_{x,t}$ a represents the impact of inflation risk.

Liability present value distributions by hedging index

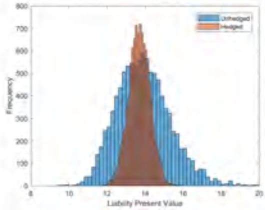
(a) Survival index



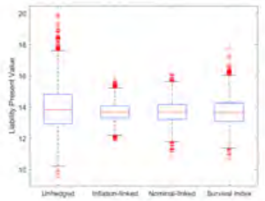
(b) Nominal-linked index



(c) Inflation-linked index



(d) Box and whisker plot



Longevity Risk Reduction

- We define our Longevity Risk Reduction metric as

$$\left(1 - \frac{\rho(\text{Hedged Portfolio})}{\rho(\text{Unhedged Portfolio})}\right) \times 100\%,$$

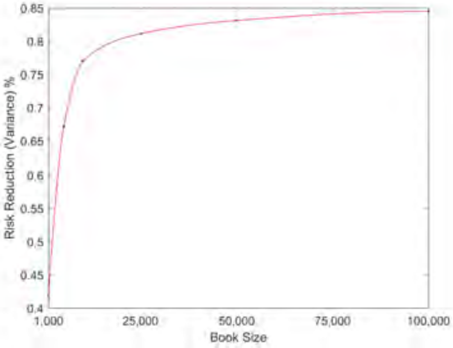
where the risk measures ρ is set to the portfolio variance as in Cairns et al., (2014).

Table 1: Longevity risk reduction: percentage reduction in variance showing the greater effectiveness of the inflation-linked value-based longevity index relative to alternate indices (joint ATSM)

Hedging Index	Book Size		
	1,000	10,000	100,000
Survival index $I^0_{x,t}$	31.52	54.07	58.71
Nominal-linked value index $I^1_{x,t}$	37.82	67.24	74.07
Inflation-linked value index $I_{x,t}$	42.67	77.43	84.58

Book Size

Figure 6: Hedge efficiency by book size indicating the diminishing marginal benefit of increasing book size (joint ATSM)



Limitations and Scope for Future Research

- Book population data: older ages and real annuitant mortality
- Application to realistic retirement income portfolios consisting of open-ended pension funds with multiple cohorts
- Dynamic hedging

Acknowledgements

Financial Support from:

- The Society of Actuaries Center of Actuarial Excellence Research Grant 2017-2020: Longevity Risk: Actuarial and Predictive Models, Retirement Product Innovation, and Risk Management Strategies;
- The Australian Research Council Discovery Project DP170102275 on Retirement Income Product Innovation.

Questions and Comments?

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