A Cautious Note on Natural Hedging of Longevity Risk

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Introduction

Mortality Forecasting Models

Economic Capital for a Stylized Insurer

Natural Hedging of Longevity Risk

Robustness of the Results

Conclusion
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Background & Literature Review

Longevity risk
\[ \downarrow \]
Policyholders’ future realized mortality rates
\[ \downarrow \]
Life insurers’ liabilities

Approaches to protecting against longevity risk:

- **Stochastic** mortality forecasting models
- Externally $\rightarrow$ Mortality-linked securities
- Internally $\rightarrow$ natural hedging
  - life insurances $\leftrightarrow$ annuities

Literature:

- Cox and Lin (2007): Companies selling both life and annuity products charge cheaper prices $\Rightarrow$ evidence of natural hedging
- Wetzel and Zwiesler (2008): Portfolio composition significantly impacts longevity exposure
- Tsai et al. (2010): Optimal product mix to minimize $CVaR$
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Underlying mortality forecasting models:

- **Existing literature:**
  - (Low-dimensional) factor models: Lee-Carter model (Lee and Carter (1992)), CBD model (Cairns et al. (2006))
  - Error term $\sigma_t$ affects time-$t$ mortality rates at different ages simultaneously
  - Cannot capture disparate shifts in mortality rates at different ages
  - Life insurances (working class) $\Leftrightarrow$ annuities (retirees)
  - Positive conclusions of natural hedging

- **This paper:**
  - Parametric factor model & non-parametric mortality model
  - Natural way to test natural hedging

**Main findings:**

- Using factor models helps to create a perfect hedge for mortality risk by utilizing natural hedging
- **BUT:** Different result from non-parametric mortality model
  - Natural hedging might not be as effective as we think
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4 Natural Hedging of Longevity Risk

5 Robustness of the Results

6 Conclusion
Non-Parametric Model

Forward survival probabilities:

\[ \tau p_X(t) 1\{\gamma_{x-t} > t\} = \mathbb{E}_P^P \left[ 1\{\gamma_{x-t} > t + \tau\} \middle| \mathcal{F}_t \vee \{\gamma_{x-t} > t\} \right], \quad 0 \leq T \leq t \leq T + \tau \]

Generational survival data \( \tau p_X(t_j) \): \( j = 1, \ldots, N \)

\[ F(t_j, t_{j+1}, (\tau, x)) = -\log \left\{ \frac{\tau + 1 p_X(t_{j+1})}{\tau p_X(t_{j+1})} \right\} \frac{\tau + 1 + t_{j+1} - t_j p_X(t_{j+1}) + t_j(t_j)}{\tau + t_{j+1} - t_j p_X(t_{j+1}) + t_j(t_j)} \]

- \( \bar{F}(t_j, t_{j+1}) = (F(t_j, t_{j+1}, (\tau, x)))_{(\tau, x) \in \bar{C}, j = 1, 2, \ldots, N - 1} \)

\( \Rightarrow \) \( \bar{F}(t_j, t_{j+1}) \) are i.i.d. Gaussian distributed (Prop. 2.1, Zhu and Bauer (2013))

\( \Rightarrow \) Simulate \( \bar{F}(t_N, t_{N+1}) \) based on sample mean and covariance matrix from \( F(t_j, t_{j+1}, (\tau, x)), j = 1, \ldots, N - 1 \)

\( \Rightarrow \tau p_X(t_{N+1}) \)
Mortality Forecasting Models

Parametric Factor Model

Forward force of mortality (easier to model/work with than $\tau p_x(t)$):

$$\mu_t(\tau, x) = -\frac{\partial}{\partial \tau} \log \{\tau p_x(t)\}$$

Consider **time-homogenous diffusion-driven** models (cf. Bauer et al. (2012))

$$d\mu_t = (A\mu_t + \alpha) \, dt + \sigma \, dW_t$$

- **Drift condition** (Cairns et al. (2006, ASTIN)): With $W_t$ Brownian motion under $\mathbb{P}$,

  $$\alpha(\tau, x) = \sigma(\tau, x) \times \int_0^\tau \sigma'(s, x) \, ds$$

- **Bauer et al. (2012)**: $\mu_t$ allows for a Gaussian finite-dimensional realization (FDR) iff

  $$\sigma(\tau, x) = C(x + \tau) \times \exp\{M\tau\} \times N$$

- **Zhu and Bauer (2013)**:

  $$\sigma(\tau, x) = (k + c \, e^{d(x+\tau)}) \, (a + \tau) \, e^{-b\tau}$$
Economic Capital for a Stylized Insurer

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Economic Capital Calculation

- Newly founded life insurer selling traditional products (term-life, endowment, annuity); Equivalence Principle; risk-neutral w.r.t. mortality risk
- Available Capital at time zero: \( AC_0 = E \)
- Available Capital at time one: \( AC_1 = \mathbb{E}^Q[Assets|\mathcal{F}_1] - \mathbb{E}^Q[Liabilities|\mathcal{F}_1] \)
- One-year mark-to-market approach for calculating Economic Capital:

\[
EC = \rho \left( \frac{AC_0 - AC_1 \rho(0,1)}{} \right)
\]

- \( \rho \): monetary risk measure \((L^2(\Omega, \mathcal{F}, \mathbb{P}) \rightarrow \mathbb{R})\)
  - Solvency Capital Requirement (Solvency II):
    \[
    EC = SCR = \text{VaR}_\alpha(L) = \arg\min_x \{\mathbb{P}(L > x) \leq 1 - \alpha\}
    \]
  - Conditional Tail Expectation (used within SST):
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    EC = CTE_\alpha = \mathbb{E}[L|L \geq \text{VaR}_\alpha(L)]
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Mortality estimation:

- U.S. female data (Human Mortality Database), year 1933-2007
- 46 generational life tables: 1963-2008, age: 0-100 $\Rightarrow \tau p_x(t_j)$, $j = 1, \ldots, 46$
- Calibrate and forecast under:
  0. Deterministic mortality (Lee-Carter)
  1. Non-parametric model
  2. Parametric factor model

Financial market estimation:

- Financial portfolio: stock, 5-year, 10-year, and 20-year gov. bond
- Financial market model: Extended Black-Scholes model with stochastic interest rates (Vasicek model)
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Economic Capital for a Stylized Insurer

Base Case

Duration match with financial portfolio; \( E = \$20,000,000 \)

<table>
<thead>
<tr>
<th>Term Life</th>
<th>( x )</th>
<th>( i )</th>
<th>( n_{x,i}^{\text{term/end/ann}} )</th>
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</tr>
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<tbody>
<tr>
<td>30</td>
<td>20</td>
<td>2,500</td>
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<tr>
<td>35</td>
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6. Conclusion
Optimal static hedge:
- Exposure in annuity/endowment $\Rightarrow$ fixed
- Adjust exposure in term-life insurance $n^{term}$:
  - Minimize capital with optimizing financial risk
- Three cases: deterministic mortality vs. factor mortality model vs. non-parametric model
Natural Hedging of Longevity Risk

Observations

- Without systematic mortality, EC increases in $n_{term}$
- With factor mortality model, EC convex of $n_{term}$ ($n_{term}^* = 60,000$)
- BUT With non-parametric forecasting model, only very mild effect of natural hedging

Economic capital: ($n_{term} = 60,000$)

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- Using the factor mortality model, adding mortality risk increases the optimal economic capital slightly
  - ? (Almost) perfect hedge of mortality risk with natural hedging
- Using the non-parametric mortality model, adding mortality risk increases the optimal economic capital considerably
  - $\Rightarrow$ Natural hedging does not work as well as we expect
  - $\Rightarrow$ Factor models too simplified
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Robustness of the Results

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Robustness of the Results

Alternative Mortality Models

• Repeat the calculations for alternative mortality models
  ▶ Stochastic Lee-Carter model (one-factor model)
  ▶ Non-parametric bootstrapping model from Li and Ng (2010, JRI)

• U-shape EC curve for the Lee-Carter model $\rightarrow$ highly effective natural hedging ($n^{term\star} = 60,000$)

• Mild effect of natural hedging from the Li&Ng model

(a) Lee-Carter model

(b) Li&Ng model
Conclusion
Conclusion

Natural hedging proposed to handle longevity risk

- Positive results from existing literature
  - Use factor mortality models
  - Neglect disparate mortality evolutions under different ages
  - Entail potential biases

- We compare results derived from both parametric factor and non-parametric stochastic mortality model
  - Concur the existing literature when the factor model used
  - With non-parametric model, natural hedging much less effective

How much should we trust model-based results?

- Advantages: simple, easy to use, etc.
- CAVEAT: important features might be stripped
Conclusion

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  - Use factor mortality models
  - Neglect disparate mortality evolutions under different ages
  - Entail potential biases

- **We compare results derived from both parametric factor and non-parametric stochastic mortality model**
  - Concur the existing literature when the factor model used
  - With non-parametric model, natural hedging much less effective

How much should we trust model-based results?

- **Advantages:** simple, easy to use, etc.
- **CAVEAT:** important features might be stripped