# Index Based Longevity Hedging as a Practical Risk Mitigation Tool for Deferred Pension Liabilities

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# Outline

- Why are deferred pensioners harder to hedge?
- Practical considerations
- Case study
- Conclusions

# Intro: Why are deferred pensions difficult to hedge?

- Pension plan deferred pensioners
  - perceived as more risky than pensions in payment
  - purchase of *individual annuities* potentially expensive or not possible (no active insurers)
  - potential conversion options before/at retirement
- Pension plan active members
  $\Rightarrow$ still accruing pension
- Potential solution:
  use index based longevity instruments to achieve a partial hedge
  Counterparty: e.g. reinsurer; capital markets
  Precedent: Hannover Re deal with NN Life

# Practical Issues to Consider When Assessing a Hedge

- Hedging objective and risk appetite
- Hedge instrument maturity date, $T$
- Hedge instrument design and structure

- Models:
  - Practice versus academic ideal (one model)

  - Valuation model at time 0: $ML(0)$
  - Simulation model at time 0: $MS(0)$

  - Hedge instrument payoff model at time $T$: $MH(T)$
  - Liability valuation model at time $T$: $ML(T)$

# Current UK Practice: models $ML(0)$ and $ML(T)$

- Valuations and buyouts etc. in the UK typically rely on Excel software for mortality improvements produced by the CMI (Continuous Mortality Investigation)
- Current version:
  *The CMI Mortality Projections Model CMI_2018*
- Data: historical *national* deaths and exposures (pop. 1)
- Model fitting: Fit the *Age Period Cohort Improvements* (APCI) model to historical data

$$\log m_{\text{APCI}}(t,x) = \alpha(x) + \beta(x)(t-\bar{t}) + \kappa(t) + \gamma(t-x)$$

- Minimise *Deviance* + *roughness penalty*
  $\Rightarrow$ smooth curves for $\alpha(x), \beta(x), \kappa(t), \gamma(t-x)$
- The APCI model is recalibrated every year: CMI_yyyy

# Current UK Practice: models $ML(0)$ and $ML(T)$ (cont.)

- Year 0: final year in data
  - $IP(0,x)$ = age-period *improvement rate* in final year
  - $IC(0,x)$ = cohort-linked *improvement rate* in final year
  - $m_B(0,x)$: base table (not $m_{\text{APCI}}(0,x)$)
- Projections ($t > 0$):
  - *Not the APCI model!*
  - Starts from $m_B(0,x)$, and $IP(0,x)$ & $IC(0,x)$
  - $IP(t,x)$ glides smoothly from $IP(0,x)$ to a *long term rate*
  - $IC(t,x+t)$ follows cohorts and glides smoothly to 0
  - Use $IP$, $IC$ to generate future $m(t,x)$
- Here:
  build continued use of the CMI_yyyy model into our model with automated recalibration

# Current UK Practice: Population 2

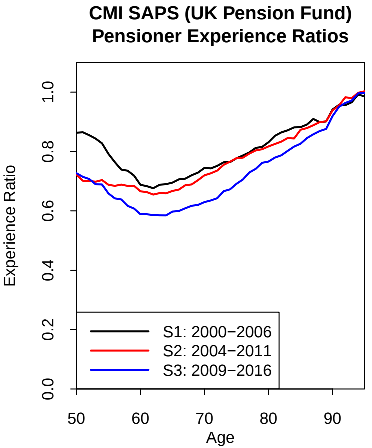
- Population 1: national population
- Population 2: sub-population (e.g. pension plan)
- Experience ratios:

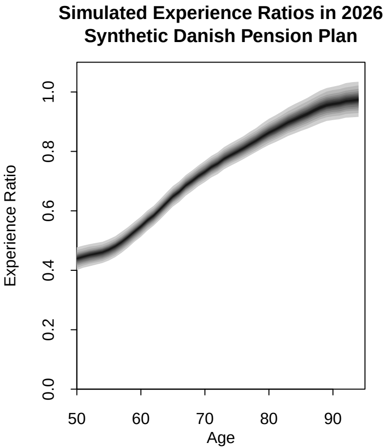
$$ER(T,x) = \frac{m_2(T,x)}{m_1(T,x)} \qquad (\text{or } q_2/q_1)$$

  or an average over the last $K$ years
- Valuation at $T$:
  - Project $m_1(t,x)$ for $t > T$ using recalibrated CMI_$T$
  - Recalibrate experience ratios: $ER(T,x)$
  - Project $m_2(t,x) = m_1(t,x)ER(T,x)$ for $t > T$

- In practice: experience ratios are stochastic
  $\Rightarrow$ build this into our model: population basis risk

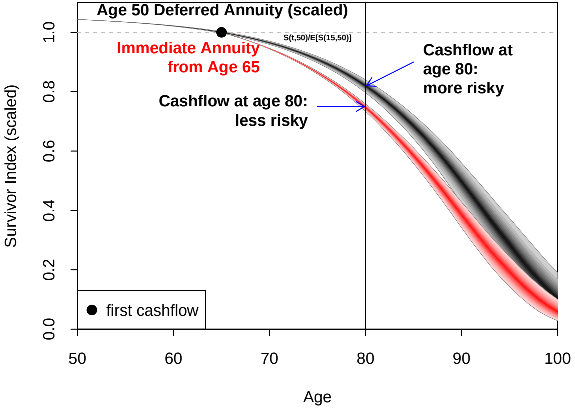
# $ER(T, x)$: CMI SAPS experience vs Danish model




- CMI SAPS: *pensioner* data (i.e. no pre-retirement or deferred members)
- Denmark: Cairns et al. (2019) simulations
- Some differences; some similarities

# Deferred pensions are perceived as more risky




- Deferred $\Rightarrow$ more risk: but this is complex
- Uncertainty in cashflow $\times$ discount factor
- Inclusion/exclusion of large, highly certain cashflows

# Reasons why a deferred pension is more difficult to hedge

Run-off risk: 95% Quantile versus Median

| (Real) Interest Rate | Deferred Annuity Age 50 | Immediate Annuity Age 50 | Immediate Annuity Age 65 | Immediate Annuity Age 80 |
|---|---|---|---|---|
| 0% | +6.6% | +4.0% | +5.4% | +4.9% |
| 2% | +5.1% | +2.6% | +3.9% | +4.1% |

- Deferred $\Rightarrow$ more risky than immediate
- Lower interest rates $\Rightarrow$ more risk
- Immediate annuity:
  Younger $\Rightarrow$ more risky in absolute terms
  In relative terms: more complex

# Non-hedgeable risks

- In deferment and at retirement
  - member might take cash transfer
  - conversion options at retirement
  - uncertainty over marital/cohabitation status at later date
  - uncertain accrual of further pension benefits
- Customised (member specific) transaction becomes more expensive or impossible
- Increased administration

- Index-based transaction *reduces* risk without the ongoing administrative hassle

# Case Study

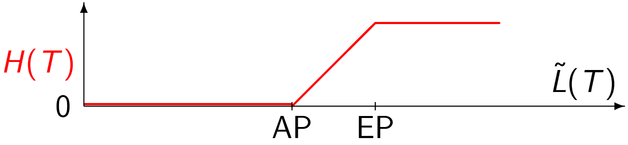
- Index: Danish males national mortality
- Pension plan: affluence deciles 7, 8, 9
- Cohort of males aged 50
- Pensions deferred to age 65
- Plan objective:
  to buy out the pensions when they vest in 15 years

# Hedging Instrument

Index-based hedge (derivative)

- Synthetic $\tilde{L}(T) \approx$ true $L(T)$
- Call spread derived from underlying $\tilde{L}(T)$

Payoff at $T$, *per unit*




$$H(T) = \begin{cases} 0 & \text{if } \tilde{L}(T) < AP \quad \text{(Attachment Point)} \\ \tilde{L}(T) - AP & \text{if } AP \le \tilde{L}(T) < EP \quad \text{(Exhaustion Point)} \\ EP - AP & \text{if } EP \le \tilde{L}(T) \end{cases}$$

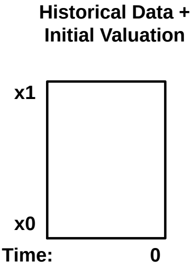
Call spread $\longleftarrow$ SPV $\longrightarrow$ Cat. bond

# The Synthetic $\tilde{L}(T)$

- $\tilde{L}$ = random PV at time 0 of a portfolio of synthetic liabilities
- Synthetic mortality experience
  - based on national population mortality
  - adjusted using experience ratios, $ER(0,x)$

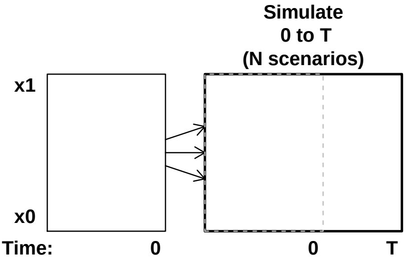
- $\tilde{L}(T)$ = point estimate of $\tilde{L}$ based on info at $T$
  = PV of actual *synthetic* cashflows up to $T$
  + PV of estimated *synthetic* cashflows after $T$
  using a model specified at time 0.

# Methodology



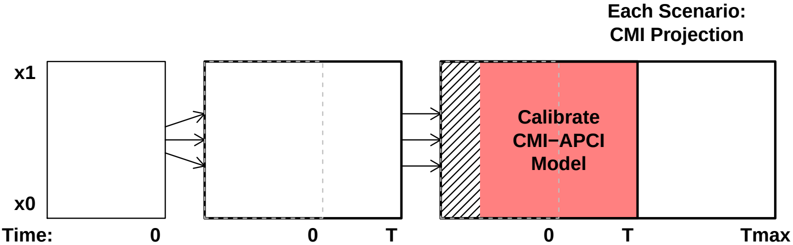

- Time 0 valuation model $ML(0)$

# Methodology



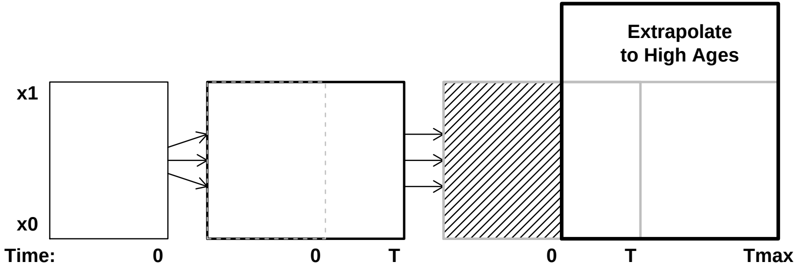

- Identify and fit a suitable two/multi-population stochastic mortality model: $MS(0)$
- Use this model to generate stochastic scenarios

# Methodology

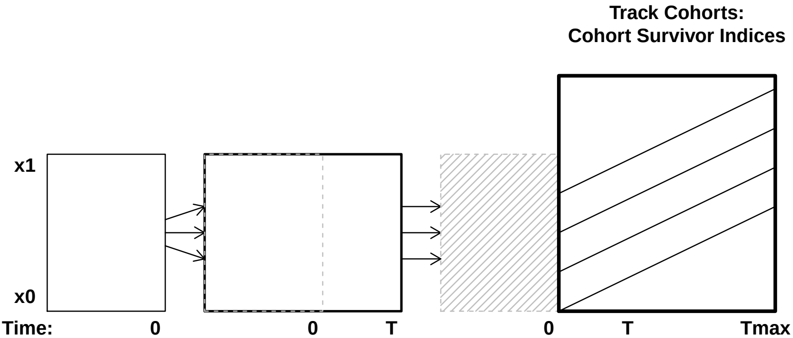



- $ML(T)$ and possibly $MH(T)$:
- Scenario $j$: recalibrate the APCI model using data up to $T$
- Use the CMI projections model to project scenario $j$ mortality beyond time $T$

# Methodology

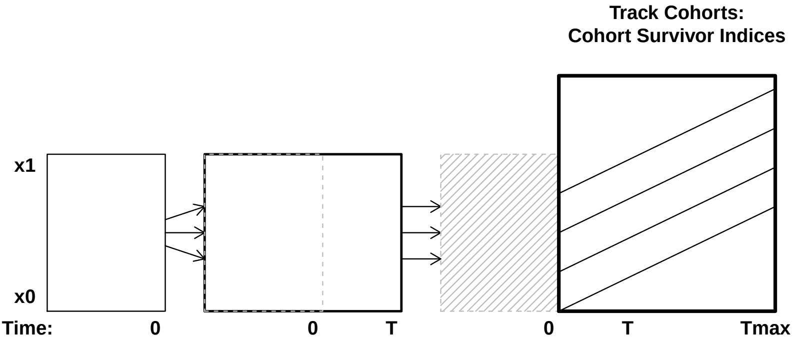


# Methodology




- Scenario $j \Rightarrow$ survivor indices $S(j, T, t, x)$ for cohorts aged $x$ at the start of year 1
- Simulation scenario $j$ to $T$
- Model recalibration and scenarion $j$ projection beyond $T$

# Methodology




- $S(j,T,t,x) \longrightarrow a(j,T,x) = \sum_{t=0}^{\infty} e^{-rt} B(t) S(j,T,t,x)$

$$B(t) = \begin{cases} 0 & \text{in deferment (e.g. before age 65)} \\ 1 & \text{in payment (e.g. 65 and older)} \end{cases}$$

# Case Study: Danish Males Mortality + Stochastic Model

- Cairns, Kallestrup et al. (2019) ASTIN Bulletin
- National population subdivided into *deciles* by *affluence*
- 1995-2016; ages 50-94 (updated data)
- Decile $i$:

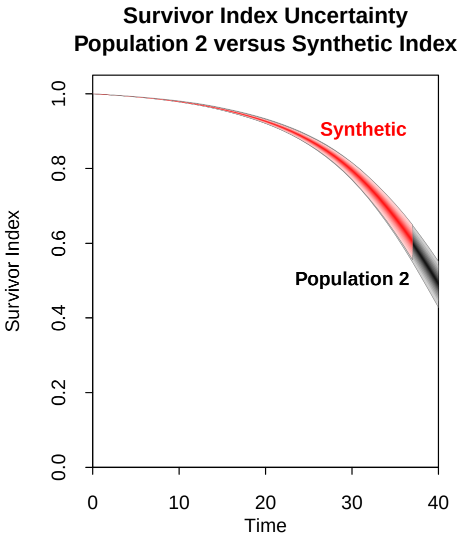
$$\log m(i,t,x) = \alpha(x) + \kappa_1(t) + \kappa_2(t)(x - \bar{x})$$

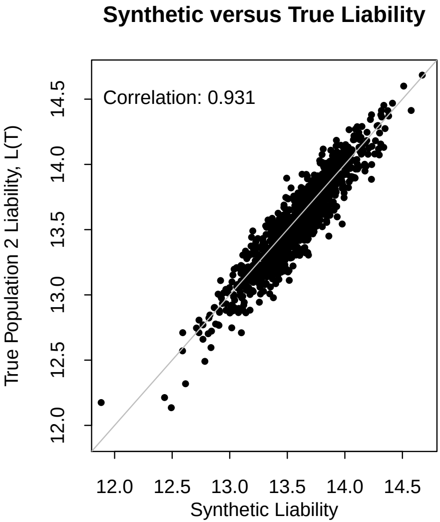
- For this study:
  - Simulate the 10 deciles
  - Aggregate into
    (a) national population
    (b) white collar pension plan = deciles 7, 8, 9
  - Simulation incorporates full *parameter uncertainty*
    e.g. drift; average spread between groups

# Results

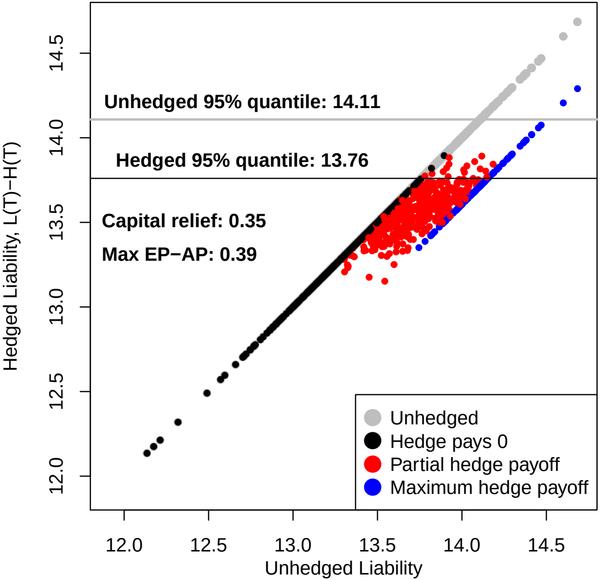
- Age 50; deferred pension from 65
- $T = 15$ hedge maturity
- Attachment point: $AP =$median of $\tilde{L}(T)$
- Exhaustion point: $EP =$90% quantile of $\tilde{L}(T)$
- Assess the overall impact of the hedge
  and at the 95% level

# True liability versus synthetic liability: 1000 scenarios



# Impact of hedge on time $T = 15$ liability



# Summary

All discounted to time 0:

| | | |
|---|---|---|
| Unhedged: | | |
| Mean liability, $E[L(T)]$: | 13.30 | |
| 95% quantile: | 14.11 | (+6.1%) |
| Hedged: | | |
| 95% quantile: | 13.76 | (+3.5%) |
| Capital relief: | 0.35 | |
| Max capital relief ($EP - AP$): | 0.39 | (e.g. no/lower pop. basis risk) |
| Hedge payoff | | |
| Mean, $E[H(T)]$: | 0.11 | |
| Hedge price: | ??? $> E[H(T)]$ | |

# Conclusions

- Deferred pensions are more difficult to hedge or buy out than pensions in payment
- Index based longevity hedges offer a possible solution
- Counterparties: reinsurers or capital markets
- Assessment requires careful specification of all models at time 0 and time $T$

# Thank You!

# Questions?

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# Bonus slides

# Model $MS(0)$ for simulating future mortality

- Model used for simulating mortality in populations 1 and 2 at times $0 < t \leq T$, or all times $t > 0$ for assessment of full run-off
- Calibrated at time 0
- Step 1: fit the model to historical mortality data
- Step 2: choose a time series model for forecasting
- Step 3: estimate time series parameters for forecasting
- Generate $N$ stochastic scenarios $m_S(i, j, t, x)$ for populations $i = 1, 2$, scenario $j$, year $t$, age $x$.

## Model $MS(0)$ for simulating future mortality (cont.)

- Alternatively, we might choose a time series model in advance and then calibrate the model to historical mortality rates and the forecasting parameters simultaneously (e.g. Bayesian).

# Model $MH(T)$ for the hedge instrument payoff

- Scenario $j$
- Simulation scenario $j$ gives $m_S(i, j, t, x)$ for populations $i = 1, 2$ for $t = 1, \ldots, T$
- Used to calculate the hedge instrument payoff at $T$
- Calibrated at $T$ including central forecasts of improvement rates after $T$
- Calibration uses reference population (population 1) mortality up to $T$ (population 2 mortality is not used)
- Method of calibration is specified at time 0

- Refer to this model and calibration as $MH(T)$.
- Median projection for $T+1, T+2, \ldots$ using time $T$ calibration
- Giving

$$m_H(1,j,t,x) = \begin{cases} m_S(1,j,t,x) & \text{for } t = 1,\ldots,T \\ \tilde{m}_H(T,1,j,t,x) & \text{for } t = T+1, T+2, \ldots \end{cases}$$

- Convert to
  $q_H(1,j,t,x) = 1 - \exp[-m_H(1,j,t,x)]$

## Model $MH(T)$ for the hedge instrument payoff (cont.)

- Calculate the synthetic mortality rates for the hedged population 2

$$q_H(2,j,t,x) = q_H(1,j,t,x)\epsilon_H(0,x)$$

  where the $\epsilon_H(0,x)$ are the experience ratios embedded in the hedge contract at time 0

- Define $p_H(2,j,t,x) = 1 - q_H(2,j,t,x)$
- Calculate the synthetic cohort survival rates

$$S_H(T,2,j,t,x) = p_H(2,j,1,x)\times\ldots\times p_H(2,j,t,x+t$$

- Calculate the synthetic liability $\tilde{L}(T)$ (discounted to time 0)
- Calculate the hedge instrument payoff, $H(T)$

# Model $ML(T)$ for liability valuation at time $T$

- Scenario $j$
- Simulation scenario $j$ gives $m_S(i, j, t, x)$ for populations $i = 1, 2$ for $t = 1, \ldots, T$
- Specify what the liability valuation model at time will be (ML).
  For example: a combination of the CMI APCI model and experience ratios. Hence
- Recalibrate ML at time $T$: $ML(T)$.
- Recalibrate the experience ratios $\epsilon_L(T, x)$
- Within $ML(T)$: calibrate the improvement rates for years $T + 1, T + 2, \ldots$

# Model $ML(T)$ for liability valuation at time $T$ (cont.)

- Calculate the median (or best estimate) mortality projection at the core ages
- Project mortality rates to higher ages
- For $t = 1, \ldots, T$:
  - $q_L(T, 1, j, t, x) = q_S(1, j, t, x)$
  - $q_L(T, 2, j, t, x) = q_S(2, j, t, x)$
- For $t = T + 1, T + 2, \ldots$
  - $q_L(T, 1, j, t, x) = q_L(T, 1, j, t, x)$ (i.e. $ML(T)$ population 1 projection)
  - $q_L(T, 2, j, t, x) = q_L(T, 1, j, t, x)\epsilon_L(T, x)$
- Calculate the cohort survival rates $S_L(T, i, j, t, x)$ using the $q_L(T, i, j, t, x)$
- Calculate the liability $L(j, T)$.

# DK historical experience ratios