Longevity 5: Fifth International Longevity Risk and Capital Markets Solutions Conference
New York City

POPULATION BASIS RISK AND HEDGE EFFECTIVENESS

Hedging Longevity Risk

Guy Coughlan, Managing Director
Pension Advisory Group

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"Buy an annuity cheap, and make your life interesting to yourself and everybody else that watches the speculation."

- Charles Dickens (1812 - 1870)
Overview

- **Hedging longevity risk with index-based hedges**
  - Can be beneficial because
    - The only practical alternative for deferred pensions/annuities
    - Some pension plans are too large to fully hedge any other way
    - Cost and liquidity
  - Basis risk must be measured

- **Framework for basis risk analysis**
  - Focus on Data and Context

- **Empirical analysis of UK and US case studies**
  - Widely available data
  - Evidence of stable relationships between them
  - Risk reduction using national population longevity index-based hedges can be significant if hedge optimally calibrated
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What is basis risk?

- **Basis risk** refers to the mismatch associated with a hedging relationship
  - Present in most financial hedges
  - Differences between underlying exposure and hedging instrument
  - Leads to residual risks because the hedge is imperfect

- **Longevity basis risk** refers to mismatch in demographics between the beneficiaries of a pension plan or annuity portfolio and the population associated with the longevity hedging instrument
  - Gender basis
  - Age basis
  - Socioeconomic basis
  - Geography basis
Framework for analyzing basis risk and hedge effectiveness

- Framework must be aligned to the objective of longevity hedging
  - Focus on the implications for hedge effectiveness

- Key elements:
  1. Data:
     - Metric
     - Time horizon
     - Analytical method
  2. Context

- Framework must recognize that data is likely to be insufficient
  - Most pension plans and annuity portfolios don’t have enough historical data to draw rigorous statistical conclusions
  - Careful analysis using available data but also taking account of demographic, social and economic context

Conclusions based on judgment not statistical proofs
Metrics for analyzing basis risk

1. Mortality rates  
2. Mortality improvements  
3. Survival rates  
4. Life expectancy  
5. Liability cash flows  
6. Liability values

- Simple comparison of mortality rates can be misleading
  - Mortality rates do not directly relate to hedge effectiveness
  - Annual mortality rates contain a lot of “noise”

Underlying observable data

Derived data
Time horizon for basis risk analysis should be long

- Longevity risk is a slowly-building cumulative trend risk that should be evaluated over long horizons
  - Metrics should be compared over multi-year horizons
  - This better reflects the nature of the risk
  - Helps reduce the impact of noise that can give misleading results

- But long horizons mean fewer independent observations available from historical data.

Selecting an appropriate time horizon involves a trade-off
Analytical methods

- Analytical approaches to explore relationship between populations:
  - **Correlation**
    - E.g. correlation in improvements in mortality rates
  - **Regression**
    - E.g., regression of life expectancies through time
  - **Graphical assessment**
    - E.g., stability of ratio of survival rates through time
  - **Risk reduction**
    - E.g., reduction in volatility of liability value after hedging

- Techniques to reduce noise:
  - Graduation of mortality rates
  - Age bucketing
  - Long-term horizon
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UK males who own life assurance: “CMI Assured Lives”

- Assured population is an affluent subset of the national population
- Data collected by the CMI (Continuous Mortality Investigation)
- Contributors are UK Life offices

- Characterized by:
  - Lower mortality rates
  - Higher mortality improvements
  - Higher life expectancy
  - Fewer lives at high ages
  - Number of lives variable
  - Contributors vary

At face value basis risk relative to national population is “high”
Setting the context

- CMI assured lives:
  - A subpopulation of the UK national population
    - Influenced by the same trends that impact national population
  - Affluent, high income
    - Lower mortality rates, higher life expectancy, faster improvements
  - Data very noisy
    - Changing contributors, changing numbers of lives and small numbers at high ages

- Implications
  - The socioeconomic fabric of the UK means that mortality rates and life expectancies should not diverge without bound over the long run
  - This doesn’t mean that they converge, rather they shouldn’t get too far apart over the long run
  - Noise may mask underlying relationships, particularly at high ages
Metric 1: Graduated mortality rates: Assured lives vs. national population

2005 mortality rates

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Assured</th>
<th>National</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>30</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>40</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>50</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>60</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>70</td>
<td>10%</td>
<td>12%</td>
</tr>
<tr>
<td>80</td>
<td>12%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Historical mortality rates age 65

<table>
<thead>
<tr>
<th>Year</th>
<th>Assured</th>
<th>National</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>1972</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>1983</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>1994</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>2005</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: J.P. Morgan, LifeMetrics Index and CMI publications

At face value experience has been very different
Comparing graduated mortality rates 1961-2005

Ratio of mortality rates [assured / national]

<table>
<thead>
<tr>
<th>Year</th>
<th>Younger: 40-64</th>
<th>Older: 65-89</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>62%</td>
<td>74%</td>
</tr>
<tr>
<td>2005</td>
<td>46%</td>
<td>68%</td>
</tr>
</tbody>
</table>

Annualized improvements 1961-2005

<table>
<thead>
<tr>
<th>Year</th>
<th>Assured</th>
<th>National</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>2.32%</td>
<td>1.75%</td>
<td>0.57%</td>
</tr>
<tr>
<td></td>
<td>1.67%</td>
<td>1.57%</td>
<td>0.10%</td>
</tr>
<tr>
<td></td>
<td>0.65%</td>
<td>0.18%</td>
<td></td>
</tr>
</tbody>
</table>

Assured population has lower mortality and higher improvements

Source: J.P. Morgan, LifeMetrics Index and CMI publications
Metric 2: Mortality improvements converge over the long run

**Ratio of cumulative mortality improvements*: [assured / national]

**Age group 50-59**

**Age group 60-69**

**Age group 70-79**

**Age group 80-89**

* Ratio of annualized improvements since 1961

Source: J.P. Morgan, LifeMetrics Index and CMI publications

* Ratio of annualized improvements since 1961
Aggregate correlations of changes in mortality rates

<table>
<thead>
<tr>
<th>Aggregate correlation for individual ages</th>
<th>Aggregate correlation for 10-yr age buckets</th>
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</thead>
<tbody>
<tr>
<td>1-year horizon</td>
<td>1-year horizon</td>
</tr>
<tr>
<td>5-year horizon</td>
<td>5-year horizon</td>
</tr>
<tr>
<td>10-year horizon</td>
<td>10-year horizon</td>
</tr>
<tr>
<td>20-year horizon</td>
<td>20-year horizon</td>
</tr>
<tr>
<td>36%</td>
<td>54%</td>
</tr>
<tr>
<td>69%</td>
<td>91%</td>
</tr>
<tr>
<td>80%</td>
<td>94%</td>
</tr>
<tr>
<td>97%</td>
<td>99%</td>
</tr>
</tbody>
</table>

Source: J.P. Morgan, LifeMetrics Index and CMI publications

- Aggregate correlations between assured lives and national population
- Calculated as one correlation across time and age
- Graduated mortality rates, non-overlapping time periods
- Correlations increase with the time horizon
- But long horizons have few data points
Metric 3: Survival rates historically have differed, but increased broadly in unison.

- **10-yr survival rates for age 65**
  - Assured vs. National survival rates over time.

- **Ratio of 10-yr survival rates**
  - Ratio of survival rates [assured / national]
  - Relatively constant through time
  - Increases with age
  - 1.03 (age 45); 1.19 (age 65); 1.36 (age 75); 1.55 (age 80)

Source: J.P. Morgan, LifeMetrics Index and CMI publications
Metric 4: Period life expectancy has increased broadly in step

### Period life expectancy for age 65

- **Assured**
- **National**

### Ratio of period life expectancy

- **Age 45**
- **Age 55**
- **Age 65**
- **Age 75**
- **Age 80**

#### Source:
J.P. Morgan, LifeMetrics Index and CMI publications

- **Ratio of life expectancy [assured / national]**
- Relatively constant through time
- Increases with age
- 1.14 (age 45); 1.22 (age 65); 1.24 (age 75); 1.24 (age 80)
45-year change in period life expectancy has been approximately the same for all ages

- Period life expectancy over 1961-2005
  - Similar percentage increases between the two populations
  - Greatest percentage increases for higher ages

Source: J.P. Morgan, LifeMetrics Index and CMI publications
Metric 5: Liability cash flows realized over 10-year historical periods

- Lifetime annuity paying GBP1 annually to survivors of a cohort
  - Calculate sum of cash flows over 10 years
  - Ratio relatively constant through time
  - Ratio increases with age

Source: J.P. Morgan, LifeMetrics Index and CMI publications
Metric 6: Theoretical liability value: Fixed age perspective

- **Liability value for age 65**
  - Assured
  - National

- **Ratio of liability values**
  - Age 60
  - Age 65
  - Age 70
  - Age 75
  - Age 80

Source: J.P. Morgan, LifeMetrics Index and CMI publications

- Lifetime annuity paying GBP1 annually to survivors of a cohort
- Calculate theoretical annuity price, using mortality projection model
- Ratio relatively constant through time
- Ratio increases with age

Note: The calibration look-back period for mortality projection is 30 years and discount rate is assumed to be 5%
Theoretical liability value: Cohort perspective

Liability values for cohort aged 65 in 1991

Ratio of liability values for different cohorts in 1991

Source: J.P. Morgan, LifeMetrics Index and CMI publications

Note: The calibration period for mortality projection is 30 years and discount rate is assumed to be 5%
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California vs US national population: males

- California population is a affluent subset of the national population
  - Data collected by same process for both

Characterized by:
- Lower mortality rates
- Higher mortality improvements
- Higher life expectancy
- Large subpopulation
- Shorter history

### US vs California population statistics

<table>
<thead>
<tr>
<th></th>
<th>National</th>
<th>California</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (mm)</td>
<td>304.1</td>
<td>36.8</td>
<td>12%</td>
</tr>
<tr>
<td>Over 65 (mm)</td>
<td>38.9</td>
<td>4.1</td>
<td>11%</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>$37,899</td>
<td>$42,064</td>
<td>111%</td>
</tr>
</tbody>
</table>

Source: U.S. Census Bureau and Bureau of Economic Analysis, 2008 figures

Similar relationship to national population as in UK example, but closer match in terms of size and profile
Metric 1: Graduated mortality rates: California state population vs. US national population

2004 mortality rates

- California
- US national

Historical mortality rates age 65

- California
- US national

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications

At face value experience looks comparable
Comparing graduated mortality rates 1980-2004

**Ratio of mortality rates [assured / national]**

- Younger: 40-64
  - 1980: 90%
  - 2004: 94%

- Older: 65-89
  - 1980: 87%
  - 2004: 89%

**Annualized improvements 1980-2004**

- Younger: 40-64
  - California: 1.57%
  - US: 1.44%
  - Difference: 0.13%

- Older: 65-89
  - California: 1.73%
  - US: 1.51%
  - Difference: 0.21%

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications

California has lower mortality and higher improvements
Metric 2: Mortality improvements converge over the long run

Ratio of cumulative mortality improvements*: [California / national]

<table>
<thead>
<tr>
<th>Age group 50-59</th>
<th>Age group 60-69</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio</td>
<td>Ratio</td>
</tr>
<tr>
<td>Age group 70-79</td>
<td>Age group 80-89</td>
</tr>
</tbody>
</table>

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications

* Ratio of annualized improvements
## Aggregate correlations of changes in mortality rates

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<tr>
<td>1-year horizon</td>
<td>1-year horizon</td>
</tr>
<tr>
<td>41%</td>
<td>54%</td>
</tr>
<tr>
<td>68%</td>
<td>60%</td>
</tr>
<tr>
<td>97%</td>
<td>99%</td>
</tr>
<tr>
<td>10-year horizon</td>
<td>10-year horizon</td>
</tr>
</tbody>
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Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications

- Aggregate correlations between California and national population
- Calculated as one correlation across time and age
- Graduated mortality rates, non-overlapping time periods
- Correlations increase with the time horizon
- But long horizons have few data points
Metric 3: Survival rates historically increased broadly in unison

- Ratio of survival rates [California / national]
- Relatively constant through time
- Increases with age
  - 1.00 (age 45); 1.04 (age 65); 1.07 (age 75); 1.09 (age 80)

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications
Metric 4: Period life expectancy has increased broadly in step

### Period life expectancy for age 65

- **California**
- **US national**

### Ratio of period life expectancy

- **Age 45**
- **Age 55**
- **Age 65**
- **Age 75**
- **Age 80**

- Ratio of life expectancy [California / US national]
  - Relatively constant through time
  - 1.03 (age 45); 1.05 (age 65); 1.05 (age 75); 1.05 (age 80)

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications
25-year change in period life expectancy has been approximately the same for all ages

- Period life expectancy over 1980-2004
  - Similar percentage increases between the two populations
  - Greatest percentage increases for higher ages

Increase of life expectancy 1980-2004 (years)

Increase of life expectancy 1980-2004 (%)
Metric 5: Liability cash flows realized over 10-year historical periods

- Lifetime annuity paying $1 annually to survivors of a cohort
- Calculate sum of cash flows over 10 years
- Ratio relatively constant through time
- Ratio increases with age

Source: J.P. Morgan, LifeMetrics Index, U.S. Census Bureau and CDC publications
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Conclusions from the US and UK examples

- **UK Assured Lives**
  - Smallish subgroup of national population
  - Noise in data
  - Age profile centered around people in their 40s, with few lives 65+
  - Basis risk likely to be higher than for a large pension plan / annuity portfolio

- **California**
  - Large subgroup of national population
  - Same process for data collection as national population, so less noise

- **Both**
  - Affluent subpopulations, with lower mortality and higher life expectancy than respective national populations
  - Have larger numbers of lives and longer history than typical insurer annuity portfolios or pension plans
Implications for hedge effectiveness calculations: Case study 1 – Retrospective effectiveness test (backtesting)

- **Case study:** Longevity hedge based on national population index
  - Hedge variability of cash flow
  - Retrospective hedge effectiveness test

**Hedge effectiveness for an index hedge: Historical case study**

![Graph showing hedge effectiveness over years](image-url)
Case Study 2: Prospective hedge effectiveness test

**Case study:** Longevity hedge based on national population index

- Hedge variability of liability value
- 94% correlation between 10-year improvements for pension plan and LifeMetrics hedge

**Distribution of liability value in 10 years: Before and after hedging**

<table>
<thead>
<tr>
<th>Liability value ($ mm)</th>
<th>Unhedged liability</th>
<th>Hedged liability</th>
</tr>
</thead>
<tbody>
<tr>
<td>660</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>740</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>790</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>830</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>870</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>910</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>950</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>990</td>
<td>25</td>
<td>0</td>
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<tr>
<td>1040</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>1080</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>1120</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Risk reduction from hedge**

- 95% VaR of unhedged liabilities: $182 mm
- 95% VaR of hedged liabilities: $22 mm
- Risk reduction: 88.2%
Summary

- **Framework for basis risk analysis:**
  - Focus on
    - Data (metric, long horizon, analytical method)
    - Context

- **Empirical analysis of UK and US case studies:**
  - Significant evidence of stable relationships historically
    - Correlations high when measured appropriately over long horizons
    - Survivor rates, life expectancies, liability cash flows and value have moved proportionately over time
    - Ratios are stable over the medium-to-long term
  - Risk reduction using national population longevity index-based hedges can be significant if hedge optimally calibrated