Longevity Ten

– Santiago, Chile –

Hedging Longevity Risk in Life Settlements Using Biomedical Research-Backed Obligations

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Illinois State University

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Illinois State University
Buddha of longevity...
1 Introduction

2 A Simple Model

3 Numerical Analyses

4 Conclusion
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Introduction

Background

Longevity risk
⇒
Policyholders’ future realized mortality rates
⇒
Liabilities of life insurance market’s participants

Various mortality-linked securities proposed in the longevity market.

- Longevity bonds, mortality forwards, longevity swaps, etc.
- Payments dependent on the longevity/mortality prospect of certain underlying population
  - Reduce asymmetric information
  - Work well for life insurer/pension funds
- Less effective as hedging tools in the life settlement market
  ← Considerable basis risk materializing between the general population and the small settled groups
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A life settlement is a sale of an existing life insurance policy to an outside investor (life settlement company)

- Both the insurance benefit and the liability of future contingent premiums are transferred to the investor in exchange for a lump sum payment (settlement price)

- Emerged form the "viatical settlement" market in the 1980s (AIDS)

- Typically involves senior insured with below average life expectancy [usually with certain disease]

- Priced on a policy-by-policy basis

Specific longevity risk: future biomedical evolution of the underlying disease

- Collapse of the viatical settlement market ⇐ new AIDS drug/therapy

- Medical breakthrough of (chronic) disease acts as an (adverse) longevity shock to the life settlement companies

- Hardly picked up in a population longevity index

Richard MacMinn & Nan Zhu

Medical RBO Hedging
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Fernandez et al. (Nature Bio, 2012) & Fagnan et al. (AER, 2013) propose a business model to finance the research in the biotechnology and pharmaceutical industries

... To solve the current problem of under-funding in biomedical research

- Combining a large number of drug-development projects into a single portfolio – megafund
- Further securitize with different tranches – research-backed obligations (RBOs)
- Senior tranche ratable and accessible to institutional investors

We connect the two strands of seemingly independent literature:

- Biomedical RBOs used by LSCs as (much more) effective longevity hedging tool
- LSCs serve as instinctive buyers of the risky equity tranche
- Promote the healthy development of both markets
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A Simple Model
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No Hedging

Competitive life settlement market with risk-averse companies
Simple three-period model

- Time-0: propose to purchase a whole-life policy (face value 1), policyholder with disease A, one-period survival prob. $p_0$
- Time-1: potential medical research with success rate $\pi$, survival prob. $p_1 \rightarrow p_1 + \Delta$
- Time-2: Every individual deceases by the end

The intrinsic value of the policy:

- With shock:
  \[ V^s = \frac{1 - p_0}{1 + r} + \frac{p_0 (1 - p_1 - \Delta)}{(1 + r)^2} + \frac{p_0 (p_1 + \Delta)}{(1 + r)^3} \]

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No Hedging (cont’)

The *actuarially fair price*

\[ P^a = \pi \times V^s + (1 - \pi) \times V^n \]

- Violates the *individually rational constraint*

⇒ Expected utility

\[ \pi \times U(V^s - P^a) + (1 - \pi) \times U(V^n - P^a) < U(0) \]

With risk averse LSCs, the *equilibrium offer price*

\[ P^* \triangleq \operatorname{arg}_x \left\{ \pi \times U(V^s - x) + (1 - \pi) \times U(V^n - x) - U(0) = 0 \right\} \]

With continuous and monotonic \( U(\cdot) \), \( P^* \) unique and

\[ V^s < P^* < P^a < V^n \]
A Simple Model
Hedge with Longevity Swap

Use standard longevity swap as representative of conventional longevity securities

- Entire population equally composed of two cohorts
  - Disease A: \( p_1 \Rightarrow p_1 + \Delta \) with prob. \( \pi \)
  - Disease B: \( p_1 \Rightarrow p_1 + \tilde{\Delta} \) with prob. \( \tilde{\pi} \)

- LSC be the long party for the float survival probability

Longevity swap payoff:

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<th>Chance</th>
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<td>( p_1 + \frac{1}{2}\tilde{\Delta} )</td>
</tr>
<tr>
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- LSC be the long party for the float survival probability

- The company chooses optimal positions of longevity swap \( n^* \):

\[
EU^* = \max_n \left\{ \pi \tilde{\pi} U \left( V^s - P^* + n \left[ \frac{1}{2} \Delta (1 - \pi) + \frac{1}{2} \tilde{\Delta} (1 - \tilde{\pi}) \right] \right) \\
+ \pi (1 - \tilde{\pi}) U \left( V^s - P^* + n \left[ \frac{1}{2} \Delta (1 - \pi) - \frac{1}{2} \tilde{\Delta} \tilde{\pi} \right] \right) \\
+ \tilde{\pi} (1 - \pi) U \left( V^n - P^* + n \left[ \frac{1}{2} \tilde{\Delta} (1 - \tilde{\pi}) - \frac{1}{2} \Delta \pi \right] \right) \\
+ (1 - \pi)(1 - \tilde{\pi}) U \left( V^n - P^* + n \left[ -\frac{1}{2} \Delta \pi - \frac{1}{2} \tilde{\Delta} \tilde{\pi} \right] \right) \right\}
\]

- \( \frac{1}{2} \Delta \pi (1 - \pi) \left( U'(V^s - P^*) - U'(V^n - P^*) \right) > 0 \) with \( n = 0 \)
A Simple Model

Hedge with Medical RBOs

Simplest form of medical RBOs. Return rate:

- \( R \) when the research is successful \( \mapsto \pi \)
- \(-R\pi/(1-\pi)\) when the research fails \( \mapsto 1-\pi \)

Company chooses optimal investment \( K \):

\[
EU^{**} = \max_K \left\{ \pi U (V^s - P^* + KR) + (1-\pi)U \left( V^n - P^* - K \frac{R\pi}{1-\pi} \right) \right\}
\]

- \( K^* = \frac{rp_0(1-\pi)\Delta}{(1+r)^3 R} \)

- Same payoff: \( V^s - P^* + \frac{rp_0(1-\pi)\Delta}{(1+r)^3} = P^a - P^* \)

Proposition

The company achieves highest expected utility when using medical RBOs to hedge longevity risk, compared with no hedge, or longevity swaps.
Numerical Analyses

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Acquiring a whole-life policy from a 75 year-old female with general cancer, face amount $500,000

- Initially purchased at age 40 ⇒ Premium $5,774.13

- Impact of cancer on the survival rate
  - Statistics from the National Cancer Institute ⇒ increase annual mortality at age 75 by 0.75%
  - 150 independent cancer-related researches, 2% success rate
  - Reduction of mortality rate at 10%, 15%, and 20%, with one, two to three, or more than three successful outcomes

- Actuarially fair price \( P^a = $223,888 \)

\[ U(x) = 1 - \exp(-ax), \text{ with } a = 0.002 \]

- Equilibrium price \( P^e = $223,339 \)
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- Actuarially fair price \( P^a = 223,888 \)
- \( U(x) = 1 - \exp(-ax) \), with \( a = 0.002 \)
- Equilibrium price \( P^e = 223,339 \)
Entire population: 5% cancer patients, the rest 95% move up 0.1%, down 0.1%, or remain unchanged with same probability

12 different scenarios from the longevity swap:

<table>
<thead>
<tr>
<th>Success</th>
<th>Remaining population</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Up</td>
</tr>
<tr>
<td>0</td>
<td>1.61%</td>
</tr>
<tr>
<td>1</td>
<td>4.93%</td>
</tr>
<tr>
<td>2-3</td>
<td>15.04%</td>
</tr>
<tr>
<td>&gt;3</td>
<td>11.76%</td>
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<tr>
<td></td>
<td>Up</td>
</tr>
<tr>
<td>0</td>
<td>$0.8653$</td>
</tr>
<tr>
<td>1</td>
<td>$0.9028$</td>
</tr>
<tr>
<td>2-3</td>
<td>$0.9216$</td>
</tr>
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<td>&gt;3</td>
<td>$0.9403$</td>
</tr>
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Optimal number of positions in the longevity swap $n^* = 13.18$

• Limited participation in the longevity swap

• $EU^* = 1.97 \times 10^{-4}$: marginally improved from no hedging case
Numerical Analyses

Medical RBO

Megafund constructed to support all 150 researches:

- Each one has upfront cost at $1,000,000
- Time-0 discounted return at $60,000,000 if successful
- Securitization with two tranches:
  - Debt tranche: backed by the first successful research
  - Equity tranche: backed by any remaining revenue

<table>
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<tr>
<th>Tranche</th>
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<th>Equity</th>
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<tbody>
<tr>
<td>Volume</td>
<td>$55,000,000</td>
<td>$95,000,000</td>
</tr>
<tr>
<td>$P(\text{Return}&lt;0)$</td>
<td>4.83%</td>
<td>19.61%</td>
</tr>
<tr>
<td>Expected return</td>
<td>$57,102,239</td>
<td>$122,750,148</td>
</tr>
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$K^* = $1,085, \quad EU^* = 0.7701$
Conclusion
For a life settlement transaction, conventional longevity-linked securities:

- Alleviate longevity exposure from the underlying disease
- But also brings in excess basis risk that cannot be hedged
- Limited participation in the life market

By investing in the hypothetical medical RBOs:

- Access to the typically exclusive biomedical researches
- Reduce basis risk by a large scale – directly disease-related mortality movements

⇒ Better longevity hedging performance

- Complete the market:
  - LSCs have natural appetite in the risky equity tranche, compared with general investors
  - Promote both biomedical securitization market and secondary life market
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