Risk-Seeking Behavior and Its Implications for the Optimal Decision Making of Annuity Insurers

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Pension De-risking

- Defined benefit (DB) plans impose significant risk on DB sponsors.
  - Fluctuations in financial markets
  - Low interest rate environments
  - changing pension accounting standards
  - unexpected improvements in life expectancy
- In recent years, there has been a surge of interest from DB pension sponsors in de-risking their plans.

Motivations

- Insurers operating in the buy-in and buy-out annuity markets are assuming a growing amount of pension risk.
- Annuity insurers are vulnerable to fluctuations in financial markets and longevity risk.
  - In 2016, the U.S. life/annuity (L/A) insurance industry reported a significant decline in statutory earnings (A.M.Best, 2016).
- The insurers increase their risk-seeking activities in response to their poor performance.
  - The high-risk assets invested by the U.S. L/A insurers were doubled in the past decade (A.M.Best, 2016).
  - There existed a negative correlation between U.S. L/A insurers' return on assets (ROA) and their weight invested in high-risk assets.

Motivations (Cont')

- How to explain the above performance-dependent risk preference and the negative relation between risk and return of annuity insurers?
  - Changing risk preferences exists at the individual level (Kahneman and Tversky, 1979).
  - Changing risk preferences exists at the firm level (Bowman, 1982; Johnson, 1994; Johnson, 1994; Palmer and Wiseman, 1999; Kliger and Tsur, 2011; Zona, 2012).
  - Bowman (1980) finds a negative relation between risk and return within most industries. ➡ Prospect theory (Kahneman and Tversky, 1979) and cumulative prospect theory (Tversky and Kahneman, 1992)
- There is a lack in our understanding on how risk management changes an insurer's risk preference and optimal decisions.

Contributions

- We empirically test whether an insurer's risk preference is dependent on its performance.

- We add to the annuity literature by studying a bulk annuity insurer's optimal decisions in the cumulative prospect theory (CPT) framework.

- We study how risk management changes an insurer's risk preferences and affects its optimal decisions on annuity business and asset allocation.

Empirical Analyses

❑ Risk-Return Association Analysis (Fiegenbaum and Thomas, 1988)

- **NAIC Data (1997-2016):** 1,571 U.S. L/A insurers
  - 5-year periods: 1997-2001, 2002-2006, 2007-2011 and 2012-2016
  - 10-year periods: 1997-2006 and 2007-2016
  - 20-year period: 1997-2016
- **Measures**
  - *Return*: Average ROA for each insurer
  - *Risk*: Variance ROA for each insurer
  - *Reference Point*: Median of average ROAs of all sample insurers
- **Statistical Tests**
  - Contingency table analysis (Bowman, 1980; Fiegenbaum and Thomas, 1988): Negative risk-return association ratio **ρ** ((HL+LH)/(HH +LL)
  - Spearman rank order correlation coefficients (Hays and Winkler, 1975): Risk-return correlation

Empirical Analyses

- **Risk-Return Association Analysis (Fiegenbaum and Thomas, 1988)**
  - **Results**

TABLE 1. Risk-Return Associations Below and Above Target for Annuity Insurers

	Above Target			Below Target			
Time Period	Spearman Rank Order Correlations	Negative Association Ratios	Number of Firms	Spearman Rank Order Correlations	Negative Association Ratios	Number of Firms	Total Number of firms
1997-2001	0.509**	0.4938	726	-0.609**	2.4598	726	1452
2002-2006	0.565**	0.4124	549	-0.571**	2.7534	549	1098
2007-2011	0.565**	0.4094	421	-0.703**	4.0000	421	842
2012-2016	0.572**	0.3459	358	-0.622**	3.1628	358	716
1997-2006	0.568**	0.3669	603	-0.526**	2.3077	603	1206
2007-2016	0.597**	0.3669	381	-0.639**	2.8776	381	762
1997-2016	0.587**	0.3450	461	-0.569**	2.3824	461	922

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- **The L/A insurers are risk seeking when their performance is below target levels and risk averse when their performance is above target levels.**

Empirical Analyses

L/A insurers in the US are risk seeking when they are below targeted aspiration levels while they tend to be risk averse following their achievement of aspirations and targets, consistent with the behavioral assumption of the prospect theory.

Basic Framework

- **Mortality model**
  - The Lee and Carter (1992)'s model:

$$\ln q_{x,t} = a_x + b_x k_t + \varepsilon_{x,t}$$

$$k_t = k_{t-1} + g + e_t, \quad e_t \sim N(0, \sigma_k)$$

- **Annuity contracts**
  - An annuity insurer sells a buy-out annuity to a DB pension plan with a retired cohort of $N_0(x_0)$ members at age x_0 at time 0.
  - The insurer receives a total premium of $\bar{P}$ at time 0:

$$\bar{P} = N_0(x_0) \cdot B \cdot a_{x_0} \cdot (1 + l_P)$$

Basic Framework (Cont')

Asset allocation

- Suppose the annuity insurer invests its funds in n = 3 asset indices at time 0: the 3-month T-bill (i =1), the Merrill Lynch corporate bond index (i =2), and the S&P 500 index (i =3) with the weights of $\omega = \{\omega_1, \omega_2, \omega_3\}$.
- The dynamic process of asset index i, $S_i(t)$, at time t, follows a geometric Brownian motion:

$$dS_i(t) = S_i(t)[\mu_i dt + \sigma_i dW_i(t)]$$

- The Brownian motions of indices i and j are correlated with covariances equal to

$$\mathrm{Cov}(W_i(t), W_j(t)) = \rho_{ij} t, \quad i = 1, 2, \cdots, n; j = 1, 2, \cdots, n$$

Basic Framework (Cont')

- **Insurance surplus**
  - The insurer's total assets at time t:

$$S(t) = \begin{cases} C_0 + N_0(x_0) \cdot B \cdot a_{x_0} \cdot (1 + l_P) & t = 0 \\ \hat{S}(t) - B \cdot N_0(x_0 + t) & t = 1, 2, \cdots \end{cases}.$$

  - The insurer's total liabilities at time t:

$$L(t) = N_0(x_0 + t) \cdot B \cdot a_{x_0+t} \quad t = 0, 1, 2, \cdots .$$

  - The insurer's total surplus at time t given $B=1$:

$$X(t) = S(t) - L(t)$$

$$= \begin{cases} C_0 + N_0(x_0) \cdot a_{x_0} \cdot (1 + l_P) - N_0(x_0) \cdot a_{x_0} & t = 0 \\ \hat{S}(t) - N_0(x_0 + t) - N_0(x_0 + t) \cdot a_{x_0+t} & t = 1, 2, \cdots \end{cases}.$$

CPT Decision Model

- We model the insurer's changing risk preferences in the CPT framework.
  - The Reference Point
    - Set a benchmark ROA, $\bar{r}$, as the reference point.
    - Assume no dividend payment.
    - The reference surplus level $c(t)$ at time t :

$$c(t) = \bar{r} \cdot \bar{S}(t-1) + \bar{X}(t-1) \quad t = 1, 2, \cdots$$

  - The Value Function
    - The two-part power function (Tversky and Kahneman, 1992):

$$v[X(t), c(t)] = \begin{cases} [X(t) - c(t)]^{\alpha} & \text{if } X(t) \geq c(t) \\ -\lambda[c(t) - X(t)]^{\beta} & \text{if } X(t) < c(t) \end{cases} .$$

CPT Decision Model (Cont')

- The Cumulative Weighting Function (Tversky and Kahneman, 1992):

$$w^+(p(t)) = \frac{p(t)^\varphi}{[p(t)^\varphi + (1-p(t))^\varphi]^{1/\varphi}} \quad \text{if } X(t) \geq c(t)$$

$$w^-(p(t)) = \frac{p(t)^\tau}{[p(t)^\tau + (1-p(t))^\tau]^{1/\tau}} \quad \text{if } X(t) < c(t).$$

- The decision weights:

$$\pi_n{}^+(t) = w^+(p_n(t)), \pi_{-m}{}^-(t) = w^-(p_{-m}(t)),$$

$$\pi_i{}^+(t) = w^+(p_i(t) + \ldots + p_n(t)) - w^+(p_{i+1}(t) + \ldots + p_n(t)), 1 \leq i \leq n-1,$$

$$\pi_i{}^-(t) = w^-(p_{-m}(t) + \ldots + p_i(t)) - w^-(p_{-m}(t) + \ldots + p_{i-1}(t)), 1-m \leq i \leq -1$$

Basic Optimization Problem

- The bulk annuity insurer's total value $V(t)$ at time *t*.

$$V(t) = \sum_{i=1}^{n} [x_i^+(t) - c(t)]^\alpha \cdot \pi_i^+(t) + \sum_{i=-m}^{-1} -\lambda[c(t) - x_i^-(t)]^\beta \cdot \pi_i^-(t), \quad t = 1, 2, \cdots .$$

- The discounted expected utility $\bar{V}$ of the insurer at time 0 over *T* periods:

$$\bar{V} = \sum_{t=1}^{T} \nu^t \cdot V(t)$$

Basic Optimization Problem (Cont')

- Our optimization problem is to solve for the optimal annuity business size $N_0(x_0)$, and weights $\omega = [\omega_1, \omega_2, ..., \omega_n]$ invested in different assets so as to maximize the discounted expected utility in the CPT framework:

$$Maximize_{\{N_0(x_0),\, \omega\}} \ \bar{V}$$

subject to the following constraints:

Constraint 1: Overall risk constraint $VaR_{\hat{\alpha}}[X(t)] \geq R \quad t = 1, 2, \ldots T$

Constraint 2: Budget constraint $\omega_1 + \omega_2 + \ldots + \omega_n = 1$

Constraint 3: Range constraints $0 \leq \omega_i \leq 1, i = 1, 2, \ldots, n; N_0(x_0) > 0$

Numerical Illustration

- An insurer sells a bulk annuity to insure $N_0(65)$ participants at age 65 in a DB pension plan at time 0.
- Initial capital $C_0 = 1000$.
- $\alpha = 0.95, \beta = 0.88$ and $\lambda = 2.25$ for the value function.
- $\varphi = 0.61$ and $\tau = 0.69$ for the weighting function.
- The insurer has The loading of the bulk annuity $l_P = 0.2$.
- Each annuitant will receive an annual survival benefit $B = 1$ as long as he or she survives at the end of each year.

Numerical Illustration (Cont')

- Based on the US male population mortality tables from 1933 to 2010 in the Human Mortality Database, we obtain the parameters $g = -1.46$ and $\sigma_k = 2.44$ for the Lee-Carter model.

- Suppose the annuity insurer invests its funds in n = 3 asset indices at time 0: the 3-month T-bill , the Merrill Lynch corporate bond index , and the S&P 500 index with the weights of $\omega = \{\omega_1, \omega_2, \omega_3\}$.

- Monthly data of asset indices from January 1995 to December 2010 from Datastream.

- Based on the empirical results, we set a constant ROA reference point $\overline{r} = 0.0077$ equal to the median of ROA at the industry level.

Numerical Illustration (Cont')

- Based on the estimated parameters, we maximize the objective function over a 10-year time horizon subject to Constraints 1-3:

$$Maximize_{\{N_0(65),\ \omega\}} \ \bar{V}$$

$$where\ \bar{V} = \sum_{t=1}^{10} v^t \cdot \left(\sum_{i=1}^{n} \left[x_i^+(t) - c(t) \right]^{0.95} \cdot \pi_i^+(t) + \sum_{i=-m}^{-1} -2.25 \left[c(t) - x_i^-(t) \right]^{0.88} \cdot \pi_i^-(t) \right)$$

Numerical Illustration (Cont')

TABLE 6. The Optimal Solution without Reinsurance

	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{V}$
Baseline - No reinsurance	229.3072	7.76%	71.47%	20.76%	809.2994

- The bulk annuity insurer should insure 229 pension participants at the age of 65 at time 0.

Numerical Illustration (Cont')

TABLE 6. The Optimal Solution without Reinsurance

	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{V}$
Baseline - No reinsurance	229.3072	7.76%	71.47%	20.76%	809.2994

- The insurer should invest 7.76% of its funds in the 3-month T-bill, 71.47% in the corporate bond index, and 20.76% in the S&P500 index.

Numerical Illustration (Cont')

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Baseline - No reinsurance	229.3072	7.76%	71.47%	20.76%	809.2994

- In this way, the insurer will achieve the maximum discounted expected utility of 809.2994.

Numerical Illustration (Cont')

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	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{V}$
EUT	564.7489	24.48%	66.39%	9.13%	

Optimal Solution based on Uniform Risk Aversion in Expected Utility Theory

Numerical Illustration (Cont')

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	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{V}$
Baseline - No reinsurance	229.3072	7.76%	71.47%	20.76%	809.2994

	$N_0(65)$	$\omega 1$	$\omega 2$	$\omega 3$	$\bar{V}$
EUT	564.7489	24.48%	66.39%	9.13%	**387.6301**

Utility of a CPT insurer based on the EUT Optimal Solution

Numerical Illustration (Cont')

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	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{V}$
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EUT	564.7489	24.48%	66.39%	9.13%	**387.6301**

- Our numerical example shows that, compared to the maximum utility based on CPT, an insurer with a mixture of risk seeking and risk aversion will have a much lower utility if it adopts the optimal solution based on the expected utility theory (EUT).

Optimal Decision making with Risk Management under CPT

- Suppose the insurer purchases a reinsurance policy to transfer a proportion η of its annuity business.
- We examine how reinsurance changes an annuity insurer's risk preference and optimal strategy.
- The reinsurer requires a loading rate of $l_R = \bar{a} + \bar{b}\eta$.
- The bulk annuity insurer pays a reinsurance premium equal to: $\bar{P}_R = N_0(x_0)B(1 + l_R)\eta a_{x0}$

$$= N_0(x_0)B\eta a_{x_0} + \underbrace{\left(\bar{a}\eta + \bar{b}\eta^2\right) N_0(x_0)Ba_{x_0}}.$$

Reinsurance Loading (Jean-Baptiste and Santomero, 2000)

Optimal Decision making with Risk Management under CPT (Cont')

- We maximize the insurer's discounted expected utility with reinsurance with respect to the annuity business size $N_0(x_0)$, the asset weights $\omega = \{\omega_1, \omega_2, \cdots, \omega_n\}$, and the reinsurance ratio η in the CPT framework:

$$Maximize_{\{N_0(x_0),\ \omega,\ \eta\}} \ \bar{V}_R$$

subject to Constraints 1-3.

- We set the reinsurance loading parameters $\bar{a} = 0.19$ and $\bar{b} = 0.02$.

Numerical Illustration with Risk Management

TABLE 7. The Optimal Solution with Reinsurance

	$N_0(65)$	ω_1	ω_2	ω_3	η	$\bar{V}_R$
Baseline - Reinsurance	413.4291	4.36%	74.21%	21.42 %	0.4204	897.0182

- The insurer should transfer 42.04% of its business to a reinsurer.

Numerical Illustration with Risk Management (Cont')

TABLE 6. The Optimal Solution without Reinsurance

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- Reinsurance allows the insurer to underwrite more pension participants.

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- Reinsurance allows the insurer to underwrite more pension participants.
- The insurer retains a risk of 240 = 413 × (1− 0.4204), 5% higher than that without reinsurance.

Numerical Illustration with Risk Management (Cont')

TABLE 6. The Optimal Solution without Reinsurance

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Baseline - Reinsurance	413.4291	4.36%	74.21%	21.42 %	0.4204	897.0182

- With reinsurance, the insurer achieves a 10.84% rise in utility compared to the utility without reinsurance.

Sensitivity Analyses

TABLE 8. Optimal Strategies with Varied Parameter Values

	$N_0(65)$	ω_1	ω_2	ω_3	$\bar{r}$	η	$\bar{V}$ or $\bar{V}_R$
Baseline - No reinsurance	229.3072	7.76%	71.47%	20.76%	0.0077	–	809.2994
Baseline - Reinsurance	413.4291	4.36%	74.21%	21.42%	0.0077	0.4204	897.0182
Panel A: Discount Rate Parameter							
No reinsurance: $\rho = 4\%$	229.3079	7.76%	71.47%	20.76%	0.0077	–	852.4894
Reinsurance: $\rho = 4\%$	415.0058	4.36%	74.21%	21.42%	0.0077	0.4226	945.2977
No reinsurance: $\rho = 6\%$	229.3072	7.76%	71.47%	20.76%	0.0077	–	769.1451
Reinsurance: $\rho = 6\%$	409.6201	4.36%	74.21%	21.42%	0.0077	0.4151	852.1160
Panel B: Insurance Loading Parameter							
No reinsurance: $l_P = 0.195$	99.3516	0.00%	80.72%	19.28%	0.0077	–	737.5555
Reinsurance: $l_P = 0.195$	319.6893	9.30%	70.23%	20.48%	0.0077	0.2964	772.5049
No reinsurance: $l_P = 0.205$	238.8657	4.57%	74.06%	21.37%	0.0077	–	890.6986
Reinsurance: $l_P = 0.205$	679.0585	0.00%	77.58%	22.42%	0.0077	0.5915	1078.2582
Panel C: VaR Probability Parameter							
No reinsurance: $\hat{\alpha} = 0.0200$	82.5951	11.65%	69.19%	19.19%	0.0077	–	631.5581
Reinsurance: $\hat{\alpha} = 0.0200$	306.1787	1.01%	85.25%	13.74%	0.0077	0.4213	741.3804
No reinsurance: $\hat{\alpha} = 0.0300$	241.2651	0.00%	75.79%	24.21%	0.0077	–	1020.8039
Reinsurance: $\hat{\alpha} = 0.0300$	462.9719	0.00%	75.24%	24.76%	0.0077	0.4226	1099.8866
Panel D: Reference Point							
No reinsurance: $\bar{r} = -0.0023$	229.3072	7.76%	71.47%	20.76%	0.0077	–	1057.0547
Reinsurance: $\bar{r} = -0.0023$	416.3830	4.47%	74.05%	21.49%	0.0077	0.4241	1153.5104
No reinsurance: $\bar{r} = 0.0177$	194.8412	6.03%	73.40%	20.57%	0.0077	–	563.4248
Reinsurance: $\bar{r} = 0.0177$	263.3753	0.00%	79.44%	20.56%	0.0077	0.4167	622.6025
Panel E: Parameter-alpha							
No reinsurance: $\alpha = 0.93$	53.5095	0.00%	78.73%	21.27%	0.0077	–	496.5288
Reinsurance: $\alpha = 0.93$	88.9963	0.00%	78.23%	21.77%	0.0077	0.4284	501.2196
No reinsurance: $\alpha = 0.97$	229.4701	7.87%	71.30%	20.83%	0.0077	–	1287.2326
Reinsurance: $\alpha = 0.97$	411.6318	4.55%	73.91%	21.54%	0.0077	0.4171	1418.6744
Panel F: Parameter-beta							
No reinsurance: $\beta = 0.86$	229.3142	7.77%	71.46%	20.77%	0.0077	–	1085.9617
Reinsurance: $\beta = 0.86$	562.2147	4.35%	85.30%	10.35%	0.0077	0.3259	1204.1864
No reinsurance: $\beta = 0.90$	53.5095	0.00%	78.73%	21.27%	0.0077	–	584.2532
Reinsurance: $\beta = 0.90$	86.3798	0.00%	78.18%	21.82%	0.0077	0.3993	589.5903
Panel G: Parameter-lambda							
No reinsurance: $\lambda = 2.00$	229.3218	7.77%	71.46%	20.77%	0.0077	–	1051.1457
Reinsurance: $\lambda = 2.00$	411.7325	4.50%	74.00%	21.51%	0.0077	0.4175	1155.1250
No reinsurance: $\lambda = 2.50$	54.4915	0.00%	78.76%	21.24%	0.0077	–	602.8303
Reinsurance: $\lambda = 2.50$	418.7079	4.36%	74.21%	21.42%	0.0077	0.4277	638.9621
Panel H: Reinsurance Loading Parameters							
No reinsurance: $\bar{a} = 0, \bar{b} = 0$	229.3072	7.76%	71.47%	20.76%	0.0077	–	809.2994
Reinsurance: $\bar{a} = 0.17, \bar{b} = 0.04$	498.3258	1.30%	76.73%	21.98%	0.0077	0.5000	982.1483
No reinsurance: $\bar{a} = 0, \bar{b} = 0$	229.3072	7.76%	71.47%	20.76%	0.0077	–	809.2994
Reinsurance: $\bar{a} = 0.19, \bar{b} = 0.02$	329.5213	6.68%	72.35%	20.97%	0.0077	0.2944	836.3691

Conclusions

- Our empirical analyses contribute to researchers' understanding on an insurer's risk-return relationship and its changing risk attitudes.
  - Insurers are risk-seeking when suffering losses and risk-averse when above their targets.
- We provide an optimization framework to analyze the optimal decisions of a bulk annuity insurer with changing risk preferences dependent on its performance in the CPT framework.
- We show that risk management, such as reinsurance, can improve an insurer's operating performance and lessen its risk-taking propensity.