# 行政院國家科學委員會專題研究計畫 成果報告

## 保險公司轉嫁長壽風險最適負債管理策略探討
## 研究成果報告(精簡版)

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計畫主持人：王儷玲

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中 華 民 國 99 年 10 月 26 日

# 行政院國家科學委員會補助專題研究計畫 □成果報告 □期中進度報告

（計畫名稱）

計畫類別：□ 個別型計畫　　□ 整合型計畫
計畫編號：NSC　98-2410-H-004-076
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保險公司轉嫁長壽風險最適負債管理策略探討

成果報告類型(依經費核定清單規定繳交)：□**精簡報告**　□完整報告

本成果報告包括以下應繳交之附件：
□赴國外出差或研習心得報告一份
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□出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

處理方式：除產學合作研究計畫、提升產業技術及人才培育研究計畫、列管計畫及下列情形者外，得立即公開查詢
□涉及專利或其他智慧財產權，□一年□二年後可公開查詢

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# I. 中文摘要


中文摘要

本研究依據年金與壽險具有自然避險(natural hedging)的效果，提出一個最低條件風險值模型(minimize Conditional Value at Risk, CVaR)之最適負債配置策略，能夠提供保險公司有效的長壽風險避險之產品策略。本研究參考 Cox et al. (2007)所提出的自然避險策略與 Cairns, Blake and Dowd (2006b) 的二因子死亡率隨機模型建構自然避險的最適負債配置比率，模型中也加入 Milevsky et al. (2006)建議的夏普指數定價模型來計算系統性長壽風險的風險溢酬率用率。不同於過去文獻，本研究考慮死亡率隨機模型中的參數風險，並進一步修正過去研究文獻必須假設死亡率必須平行移動的缺點，此外，本模型也可以應用到三種以上之多角化商品組合。本研究之模擬分析結果顯示，本研究所提出的最低條件風險值模型可以提供較佳的避險結果，因此可以協助保險公司達到較有效的長壽風險避險效果。



關鍵詞 ：死亡率隨機模型、產品策略、自然避險、參數風險、條件風險值


# I. Abstract


This paper proposes a Conditional Value-at-Risk Minimization (CVaRM) approach to optimize an insurer's product mix. By incorporating the natural hedging strategy of Cox and Lin (2007) and the two-factor stochastic mortality model of Cairns *et. al.* (2006b), we calculate an optimize product mix for insurance companies to hedge against the systematic mortality risk under parameter uncertainty. To reflect the importance of required profit, we further integrate the premium loading of systematic risk. We compare the hedging results to those using the duration match method of Wang *et. al.* (2009), and show that the proposed CVaRM approach has a narrower quantile of loss distribution after hedging— thereby effectively reducing systematic mortality risk for life insurance companies.



**Keywords:** systematic mortality risk, product mix, natural hedging, parameter risk, Conditional VaR.

## II. Introduction

Over the past decade, a longevity shock has spread across human society. Benjamin and Soliman (1993) and McDonald *et. al.* (1998) confirm that unprecedented improvements in population longevity have occurred worldwide. The decreasing trend in the mortality rate has created a great risk for insurance companies. The existing literature has proposed a number of solutions to mitigate the threat of longevity risk to life insurance companies. These solutions can be classified into three categories. The *capital market solutions* include mortality securitization (see, for example, Dowd 2003; Lin and Cox 2005; Blake *et. al.* 2006a, 2006b; Cox *et. al.* 2006), survivor bonds (e.g., Blake and Burrows 2001; Denuit *et. al.* 2007), and survivor swaps (e.g., Dowd *et. al.* 2006). These studies suggest that insurance companies can transfer their exposures to the capital markets. Cowley and Cummins (2005) provide an excellent overview of the securitizations of life insurance assets and liabilities. The second set of solutions, the *industry self-insurance solutions*, include the natural hedging strategy of Cox and Lin (2007), the duration matching strategy of Wang *et. al.* (2009), and the reinsurance swap of Lin and Cox (2005). The advantages of these solutions are that the hedging does not require a liquid market and can be arranged at a lower transaction cost. Insurance companies can hedge longevity risk by themselves or with counterparties. The third kind of solution, known as *mortality projection improvement*, provides a more accurate estimation of mortality processes. As Blake *et. al.* (2006b) propose, these studies fall into two areas: continuous-time frameworks (e.g., Milevsky and Promislow 2001; Dahl 2004; Biffis 2005; Schrager 2006) and discrete-time frameworks, *e.g.*, Brouhns *et. al.* 2002; Renshaw and Haberman 2003; Cairns *et. al.* 2006b. Parameter uncertainty and model specification in relation to the mortality process have also attracted more attention in recent years.

Among the industry self-insurance solutions, the *natural hedging strategy* suggests that life insurance can serve as a hedging vehicle against longevity risk for annuity products. Wang *et. al.* (2009) employ duration as a measure of the product sensitivity to mortality change, and propose a *mortality duration matching* (MDM) *approach* to calculate the optimal product mix. Their work, however, is based on several restrictive assumptions. First, they assume that future mortality changes involve parallel shifts in the mean, and do not measure the higher-order moments of the mortality risk distribution. Second, the MDM approach applies to only two products. Third, the MDM approach is a pure risk-reduction method because the profit loading is not considered during the hedging procedure. Fourth, Melnikov and Romaniuk (2006) and Koissi *et. al.* (2006) suggest that parameter risk is crucial when dealing with longevity risk. The parameter uncertainty does not play a role in the MDM approach, since Wang *et. al.* (2009) consider the mortality shift only in terms of its mean.

To overcome these problems, we employ the two-factor stochastic mortality model of Cairns *et. al.* (2006b) and construct the Conditional Value-at-Risk Minimization (CVaRM) approach to control the possible loss. Managing products risk with parameter uncertainty is one feature of the CVaRM approach. The other feature is that we add the profit-loading constraint into the optimization. The premium-pricing principle suggested by Milevsky *et. al.* (2006) is employed to estimate the required profit loadings, *i.e.*, in order to compensate the stockholders bearing systematic mortality risk with the same Sharpe ratio as other asset classes in the economy.

Furthermore, the CVaRM approach could be easily implemented using linear programming (Rockafellar and Uryasev 2000), and insurance companies could adopt it as their own internal risk-management tool.

The results of our simulation reveal that the proposed CVaRM approach yields a less dispersed product distribution after hedging and so effectively reduces systematic mortality risk for life insurance companies. The MDM approach, on the other hand, has a limited effect on the dispersion of the product distribution. In addition, the CVaRM approach considers not only risk reduction but also the required-profit constraint. We found that the required loading substantially changes the optimal product mix and so cannot be ignored.

## III. Data and Methodology

We employ the data from Cairns *et. al.* (2007) and the JPMorgan LifeMetrics model (2006); a sample of US men aged 60-84 from 1968 to 1979 and US men aged 60-89 from 1980 to 2003. There are three types of products in our numerical examples: whole-life annuity, whole-life insurance, and 20-year term-life insurance. The whole-life annuity is issued to men aged 60, and the cohort groups are paid $1 at the end of each year. The whole-life insurance is issued to men aged 40 or 60, and the payout benefit is $100. The term-life insurance is issued to men aged 40, and the payout benefit is also $100. Both premiums are collected in a single premium today. For the sake of simplicity, the deferred periods are zero. The interest rate is 3%, and the mortality process follows the CBD two-factor model. The products' expected values for the whole life annuity, whole life insurance and 20 year term life insurance are $14.94, $54.41/$74.72, and $29.76, respectively. We calculate the expected values of products on the basis of the mortality distributions generated by JPMorgan LifeMetrics (2006).

### 3.1 The Two-Factor Stochastic Mortality Model

Several stochastic models proposed in the literature attempt to capture the mortality processes. We chose the two-factor mortality model, i.e., CBD model, as the underlying mortality process for two reasons. First, the CBD model characterizes not only a cohort effect but also a quadratic age effect. The two factors $A_1(t)$ and $A_2(t)$ in the CBD model represent all age general improvements in mortality over time and different improvements for different age groups. These two factors reflect both the trend effect and the age effect. Thus, the analysis will be economically or *biologically* meaningful when we consider the parameter changes of the factors over time. Second, the CBD model is a discrete time model and can be more conveniently implemented in practice. This paper offers a brief description of the two-factor model; for a more detailed discussion, see Cairns *et. al.* (2006b).

Let $q_{t,x}$ be the realized mortality rate for age $x$ insured from time $t$ to $t+1$. Assume that the mortality curve has a logistic functional form as follows:

$$q_{t,x} = \frac{e^{A_1(t+1)+A_2(t+1)\cdot(x+t)}}{1+e^{A_1(t+1)+A_2(t+1)\cdot(x+t)}} \quad (1)$$

The two stochastic trends $A_1(t+1)$ and $A_2(t+1)$ follow a random-walk process with drift parameter $\mu$ and diffusion parameter $C$:

$$A(t+1) = A(t) + \mu + CZ(t+1), \tag{2}$$

Where $A(t+1) = \left(A_1(t+1),\ A_2(t+1)\right)^{\mathrm{T}}$ and $\mu = \left(\mu_1,\ \mu_2\right)^{\mathrm{T}}$ are 2 × 1 constant parameter vectors. $C$ is a 2 × 2 constant upper-triangular Cholesky square-root matrix of the covariance matrix $V = CC^{\mathrm{T}}$ and $Z(t)$ is a two-dimensional standard normal random variable. To include the uncertainty of $\mu$ and $C$, Cairns *et. al.* (2006b) invoke a normal-inverse-Wishart distribution from a non-informative prior distribution:

$$\begin{aligned} V^{-1} \mid D &\sim Wishart(n-1,\ n^{-1}\hat{V}^{-1}) \\ \mu^{-1} \mid V, D &\sim MVN(\hat{\mu},\ n^{-1}V), \end{aligned}$$

$$\text{where} \quad D(t) = A(t) - A(t-1), \tag{3}$$

$$\hat{\mu} = \frac{1}{n}\sum_{t=1}^{n} D(t),$$

$$\text{and} \quad \hat{V} = \frac{1}{n}\sum_{t=1}^{n}\left(D(t)-\hat{\mu}\right)\left(D(t)-\mu\right)^{\mathrm{T}}.$$

Thus, we can generate $A(t)$ from equation (2) with the parameters $\mu$ and $C$ from equation (3). Then we get $q_{t,x}$, as equation (1) suggests.

### 3.2 The Mortality Duration Matching (MDM) Method

Wang *et. al.* (2009) propose the MDM approach to calculate an optimal life insurance/annuity weight to immunize the value change from mortality risk. They propose the following product mix of life insurance:

$$w^D = \frac{D^a}{D^a + D^l}, \tag{4}$$

where $D^a$ denotes the effective duration of the annuity and $D^l$ denotes the effective duration of the life insurance. Formally, the effective duration can be calculated as follows:

$$D^a = -\frac{V^{a+} - V^{a-}}{2V^a \Delta q} \quad \text{and} \quad D^l = \frac{V^{l+} - V^{l-}}{2V^l \Delta q}.$$

The $\Delta q$ refers to the change in the mortality rate, $V^{a+}$ and $V^{l+}$ represent the product values at higher mortality rate ($q+\Delta q$) and $V^{a-}$ and $V^{l-}$ represent the values at the lower mortality rate ($q-\Delta q$). If the change is small, this strategy leads to the product immunization as follows:

$$\Delta V = w^D D^l - (1-w^D) D^a = 0. \tag{5}$$

Wang *et. al.* (2009) also propose the mortality convexity adjustment for a large change as

$$C^a = \frac{V^{a-} + V^{a+} - 2V^a}{V^a (\Delta q)^2} \quad \text{and} \quad C^l = \frac{V^{l-} + V^{l+} - 2V^l}{V^l (\Delta q)^2}.$$

Then the product-mix weight with convexity on life insurance is

$$w^C = \frac{D^a - \frac{\Delta q}{2} C^a}{D^a + D^l + \frac{\Delta q}{2}\left(C^l - C^a\right)}. \tag{6}$$

Here, the change is set as $\Delta q = \bar{q}(1+s) - \bar{q}$, where $\bar{q}$ is the mean of the mortality process and $s$ is a shift proportion such as 1%. Thus, the change here involves a parallel shift in the mean.

### 3.3 Profit-Loading Estimation: The Sharpe Ratio Method

Milevsky *et. al.* (2006) show that when the mortality rate is stochastic, the standard deviation per policy does not vanish despite the law of large numbers. Rather there exists systematic or market risk even in a large diversified product portfolio. The shareholders of an insurance company request a risk premium for bearing the systematic risk. Milevsky *et. al.* (2006) propose that the risk premium $\pi$, which is used to compensate shareholders, be specified using the Sharpe ratio. The Sharpe ratio for the product premium is defined as

$$SR = \frac{E(V)(1+\pi) - E(V)}{\sigma(V)}, \tag{7}$$

where $E(V)$ is the expected or actuarially fair price of the product under the law of large numbers, and $\sigma(V)$ is the standard deviation of product values. When the capital market is in equilibrium, the SR in equation (7) may be set equal to the Sharpe ratio of some broadly diversified portfolio, such as the S&P500 index; then the risk premium $\pi$ is implicitly specified by (7). For more details please see section 4.2.

### 2.4 The Conditional Value-at-Risk Minimization (CVaRM) Approach

Let the random variable $v^i$ be the value of the $i^{th}$ product. Similarly let $E(v^i)$ be its present value or actuarially fair price. Since $q$ is stochastic, $v^i$ will generate deviations from $E(v^i)$. The loss proportions for each product are denoted as

$$r^i = \frac{v^i - E\left(v^i\right)}{E\left(v^i\right)}, \tag{8}$$

The total loss proportion is

$$r_p = \sum_i w^i r^i, \tag{9}$$

where $w^i$ is the weight of the $i^{th}$ product in relation to the whole product. The $i^{th}$ product could refer to life insurance or an annuity. We engage in natural hedging to minimize the risk $r_p$ by choosing different $w^i$. The Conditional VaR (CVaR) is proposed as a measure of the product risk. CVaR is chosen as a risk measure instead of VaR, because CVaR is a coherent measure, whereas VaR is not; this is shown by Artzner *et. al.* 1997, 1999 and Deprez and Gerber 1985. The CVaRM approach is expressed as

$$\mathbf{Min}_{w^i} \quad E\left[r_p \middle| r_p \geq r_p(\alpha)\right] \tag{10}$$

$$\textit{\textbf{s.t.}} \quad \sum_i w^i \cdot \pi^i \geq \bar{\pi}, \tag{11}$$

$$\sum_i w = 1, \text{ and } 0 \le w^i \le 1. \tag{12}$$

where $E\left\{r_p \middle| r_p \ge r_p(\alpha)\right\}$ is the conditional expected loss that exceeds the threshold, $r_p(\alpha)$, under the specified probability $\alpha$. In equation (11), $\pi^i$ denotes the profit loading on the $i^{th}$ product charged by the insurance company and is estimated using the Sharpe ratio noted in section 2.3. The weighted profit $\sum w^i \cdot \pi^i$ is constrained to be greater than or equal to $\bar{\pi}$. Here we let the target profit $\bar{\pi}$ be exogenously given. We ensure that the sum of the weights is equal to one and prohibit short selling via equation (12). Although CVaR is usually defined in terms of monetary value, here we represent it as a percentage loss; this avoids confusion over magnitude.

In the CVaRM approach, $r_p$ is generated as follows. First, we apply the CBD model to simulate the mortality processes and corresponding distributions of $v^i$. We compute $E(v^i)$ and substitute it into equation (8) to obtain the distribution of $r^i$. We calculate $r_p$ with equation (9). Also note that the CBD model allows parameter uncertainty to be considered and this approach makes it possible to incorporate longevity risk and parameter uncertainty simultaneously.

## III. Research Results and Conclusion

To demonstrate the hedging effect, we construct three examples in two scenarios. In scenario one the insurer cares only about risk reduction and does not consider any profit loading. Here we choose a two-product framework and compare the hedging effects of the CVaRM and MDM approaches. We show that the CVaRM approach has a better hedging effect in terms of the aggregate distribution than the MDM approach does. The analysis is then extended to the multi-product framework in scenario two. We provide a three-product example with a required profit-loading constraint and find the optimal product mix. The results show that the CVaRM approach achieves a better hedging effect than the MDM approach under the required profit-loading constraint.

This article proposes a new approach to optimize the insurer's product mix under systematic mortality risk. By incorporating the natural hedging strategy of Cox and Lin (2007), the two-factor stochastic mortality model of Cairns *et. al.* (2006b), and the Sharpe ratio-loading price of Milevsky *et. al.* (2006), we construct a CVaRM approach to evaluate the product mix. We consider two numerical scenarios: the two-product case without a loading constraint and the multi-product case with a loading constraint. In the first scenario, the CVaRM approach exerts a better risk-reduction effect than the MDM approach. In the second scenario, the three-product example reveals a trade-off between the CVaR and the required loadings. The results show that the proposed CVaRM approach leads to an optimal product mix and effectively reduces the mortality risks associated with forecasting longevity patterns for life insurance companies.

Some important issues for future research and practice clearly deserve further investigation.

First, this paper deals with the parameter risk, but ignores the misspecification or modeling risk. For example, the real mortality process may not follow the CBD model. Second, this paper omits the basis risk of the mortality rate between life insurance and annuities because of the data limitations. Our numerical example assumes that the mortality processes for life insurance and annuities are the same. In fact, the mortality experiences may differ for these products. Third, in this study, the premium loadings for each product are decided individually by means of the Sharpe ratio. To maintain rigidity, they should be priced according to their contributions to the aggregated risk, in a way similar to the beta concept of the Capital Asset Pricing Model (CAPM). This work is beyond the scope of this paper, and so we leave it for future study. Finally, we illustrate the hedging strategy with a mortality term structure, but a flat interest-rate yield curve. An analysis of the combined effects of stochastic mortality and stochastic interest rate would offer more realistic results.

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無衍生研發成果推廣資料

# 98 年度專題研究計畫研究成果彙整表

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 計畫主持人：王儷玲 | | | 計畫編號：98-2410-H-004-076- | | | | |
| 計畫名稱：保險公司轉嫁長壽風險最適負債管理策略探討 | | | | | | | |
| 成果項目 | | | 量化 | | | 單位 | 備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等） |
| | | | 實際已達成數（被接受或已發表） | 預期總達成數(含實際已達成數) | 本計畫實際貢獻百分比 | | |
| 國內 | 論文著作 | 期刊論文 | 0 | 0 | 100% | 篇 | |
| | | 研究報告/技術報告 | 0 | 0 | 100% | | |
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| 國外 | 論文著作 | 期刊論文 | 1 | 1 | 100% | 篇 | ’On the Optimal Product Mix in Life Insurance Companies using Conditional Value at Risk Approach,’ Insurance Mathematic and Economics, 2010, Vol. 46, pp. 235-241.（SSCI 期刊） |
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| | 成果項目 | 量化 | 名稱或內容性質簡述 |
|---|---|---|---|
| 科教處計畫加填項目 | 測驗工具(含質性與量性) | 0 | |
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# 國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

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3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本研究所提出的自然避險策略考慮死亡率隨機模型中的參數風險，並進一步修正過去研究文獻必須假設死亡率必須平行移動的缺點。模擬分析結果顯示本研究所提出的最低條件風險值模型確實提供比過去文獻模型更佳的避險結果，因次可以協助保險公司達到較有效的長壽風險避效果，並提供學術界對長壽風險避險策略有更完備與正確的了解。