



Quantile Risk Management in Equity-Linked Life Insurance with Stochastic Interest Rate

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Introduction

Theoretical and Practical Motivation



Insurance company can issue a *mixed* contract for the period $[0, T]$, where the payoff function is a function of stock prices S_0, \dots, S_T and $T(x)$ (*future lifetime* of a client of age x).

□ Terminology

- Segregated funds (Canada),
- Variable annuities (USA),
- Equity (unit)-linked insurance (Europe).

□ Numbers

According The Insured Retirement Institute (IRI, formerly, NAVA):
“Variable annuity sales for the 3-rd quarter were \$34 billion. Year-to year quarterly sales of variable annuities were up, posting a 9.7% increase from third quarter 2009 sales”.

Introduction

Theoretical and Practical Motivation



□ Types and Features of Contracts

- Death and maturity guarantees.
- Term of the guarantee.
- Resets (policyholder is allowed to reset the guarantee at the current fund value).
- Fund switching (policyholder has the right to switch investments between various funds).

□ Types of Hedging

- *Perfect* hedging:

$$P\{X_T^{\pi^*} \geq H\} = 1$$

- *Mean-variance* hedging:

$$E(X_T^{\pi^*} - H)^2 \text{ is minimal}$$

Introduction

Theoretical and Practical Motivation



➤ *Efficient* hedging:

$$E\{l(H - X_T^{\pi^*})^+\} \text{ is minimal}$$

where l is some loss function.

In particular, for *quantile* hedging, we have $l(x) = I_{(0,\infty)}(x)$ and $P\{X_T^{\pi^*} \geq H\}$ is maximized.

Introduction

Theoretical and Practical Motivation



- Using Hedging for Pricing and Risk Management: construct a strategy that exactly replicates the cash flows of a contingent claim
- Exact replication is not possible: find a strategy with a cash flow “close enough” to the payoff of the contingent claim in some probabilistic sense
- Equity-linked life insurance contracts have a mortality component \Rightarrow the exact replication is not possible

Introduction

References on Equity-linked Life Insurance



- ❑ Brennan and Schwartz (1976, 1979)
- ❑ Boyle and Schwartz (1977)
- ❑ Bacinello and Ortu (1993)
- ❑ Aase and Person (1994)
- ❑ Ekern and Person (1996)
- ❑ Moeller (1998, 2001)
 - Contracts with fixed or deterministic guarantees
 - Reduced them to call/put options
 - Apply perfect or mean-variance hedging to calculate prices

Introduction

References on Equity-linked Life Insurance



- Melnikov (2004)
- Melnikov and Skornyakova (2005)
 - Contracts with stochastic guarantee
 - Reduce them to embedded option $(S_T^1 - S_T^2)^+$
 - Apply quantile hedging to calculate prices
- Quansheng Gao, et.al (2010)
 - Guarantee of the contracts grows exponentially over time
 - Stochastic interest rate
 - Diffusion model

Introduction

Contents



- Briefly review the work of Melnikov and Skornyakov (2005)
- Consider a two-factor jump-diffusion model to describe a financial market and HJM framework for stochastic interest rate
- Study equity-linked pure endowment contracts with a stochastic guarantee
- Use quantile hedging technique for pricing these contracts
- Illustrate our results with actual data

Review: Financial settings

Melnikov and Skornyakova (2005)



- Non-risky asset $B_t = \exp(rt)$, $t \geq 0$, $r \geq 0$
- Risky assets S_t^1 and S_t^2 on (Ω, \mathbf{F}, P) , prices follow the jump-diffusion model

$$dS_t^i = S_{t-}^i (\mu_i dt + \sigma_i dW_t - \nu_i d\Pi_t), \quad i = 1, 2$$

- Market is complete, the unique risk-neutral probability has the density

$$Z_T = \exp \left\{ \alpha^* W_T - \frac{(\alpha^*)^2}{2} T + (\lambda - \lambda^*) t + \ln \frac{\lambda^*}{\lambda} \cdot \Pi_t \right\}$$

$$(\alpha^*, \lambda^*) \text{ are the unique solutions to } \begin{cases} \mu_1 - r = -\sigma_1 \alpha^* + \nu_1 \lambda^*, \\ \mu_2 - r = -\sigma_2 \alpha^* + \nu_2 \lambda^*, \quad \lambda^* > 0 \end{cases}$$

- Conditions:

$$\mu_1 > \mu_2, \sigma_1 > \sigma_2, \nu_1, \nu_2 < 1, \quad \begin{cases} \sigma_2 \nu_1 - \sigma_1 \nu_2 \neq 0, \\ \frac{(\mu_1 - r)\sigma_2 - (\mu_2 - r)\sigma_1}{\sigma_2 \nu_1 - \sigma_1 \nu_2} > 0 \end{cases}$$

Review: Insurance settings

Melnikov and Skornyakova (2005)



- $T(x)$ on $(\tilde{\Omega}, \tilde{\mathbf{F}}, \tilde{P})$ is the remaining life time of a person at age x
- ${}_T p_x = \tilde{P}\{T(x) > T\}$ is a survival probability
- Assumption: (Ω, \mathbf{F}, P) and $(\tilde{\Omega}, \tilde{\mathbf{F}}, \tilde{P})$ are independent
- Mortality risk arises from the dependence of the payoff on the survival status of a client at maturity $H(T(x)) = H \cdot I_{\{T(x) > T\}}$
- The payoff for the model: $H(T(x)) = \max \{S_T^1, S_T^2\} \cdot I_{\{T(x) > T\}}$

Main Results: Theorem



- Financial market is described by two-factor jump-diffusion model
- Equity-linked life insurance contract with a flexible guarantee
- On a set $\{\Pi_T = n\}$, if

$$\frac{(\mu_1 - r)v_1 - (\mu_2 - r)v_2}{\sigma_2 v_1 - \sigma_1 v_2} = \frac{\sigma_1 \sigma_2}{\sigma_2 + (\sigma_1 - \sigma_2)^2}$$

Then

$${}_T p_x = 1 - \frac{\sum_{n=0}^{\infty} p_{n,T}^* \left(v_{n,T}^1 \Phi(b_+(\nu_{n,T}^1, d_n \nu_{n,T}^2, T)) - v_{n,T}^2 \Phi(b_-(\nu_{n,T}^1, d_n \nu_{n,T}^2, T)) \right)}{\sum_{n=0}^{\infty} p_{n,T}^* \left(v_{n,T}^1 \Phi(b_+(\nu_{n,T}^1, \nu_{n,T}^2, T)) - v_{n,T}^2 \Phi(b_-(\nu_{n,T}^1, \nu_{n,T}^2, T)) \right)}$$

where $\nu_{n,T}^i = (1 - v_i)^n e^{v_i}$, $i = 1, 2$, $p_{n,T}^* = \exp\{-\lambda^* T\} \frac{(\lambda^* T)^n}{n!}$

Description of the model: Financial Setting



- Dynamics of risky assets on a filtered probability space $(\Omega, \mathbb{F}, (F_t)_{0 \leq t \leq T}, P)$

$$dS_t^i = S_{t-}^i (\mu_i dt + \sigma_i dW_t - \nu_i d\pi_t)$$

where $\mu_i \in R, \sigma_i > 0, \nu_i < 1$ and $\sigma_1 > \sigma_2$

- HJM framework
 - $f(t, T)$: instantaneous forward interest rate

$$f(t, T) = f(0, T) + \int_0^t \alpha(s, T) ds + \int_0^t \sigma(s, T) dW_s + \int_0^t \beta[d\Pi_s - \lambda ds]$$

- $r(t)$: spot interest rate

$$r(t) = f(t, t) = f(0, t) + \int_0^t \alpha(s, t) ds + \int_0^t \sigma(s, t) dW_s + \int_0^t \beta[d\Pi_s - \lambda ds]$$

Description of the model: Financial Setting



- $P(t, T)$: price of a default-free discount zero-coupon bond at time t with maturity time T $P(t, T) = \exp\left(-\int_t^T f(t, s) ds\right)$
- $B(t)$: accumulated money account $B(t) = \exp\left(\int_0^t r(s) ds\right)$

- ❑ Market is complete if

$$\frac{(\mu_1 - r(t))\sigma_2 - (\mu_2 - r(t))\sigma_1}{\sigma_2\nu_1 - \sigma_1\nu_2} > 0 \quad \text{and} \quad \sigma_2\nu_1 - \sigma_1\nu_2 \neq 0$$

- ❑ The unique martingale measure P^* has the local density

$$Z_t = \frac{dP^*}{dP}\bigg|_t = \exp\left\{\int_0^t \phi_s dW_s - \frac{1}{2}\int_0^t \phi_s^2 ds + \int_0^t (\lambda - \lambda_s^*) ds + (\ln \lambda_t^* - \ln \lambda) \Pi_t\right\}$$

$$(\phi_t, \lambda_t^*) \text{ are the solutions for the equations } \begin{cases} \mu_1 - r(t) + \phi_t \sigma_1 - \nu_1 \lambda_t^* = 0 \\ \mu_2 - r(t) + \phi_t \sigma_2 - \nu_2 \lambda_t^* = 0 \end{cases}$$

Description of the model: Financial Setting



- Explicit representations of $B(t)$ and S_t^i in terms of the parameters of the system:

$$B(t) = \frac{1}{P(0,t)} \exp \left\{ \frac{1}{2} \int_0^t (\sigma^*(s,T))^2 ds + \int_0^t [e^{-\beta(T-s)} - 1] \lambda_s^* ds \right. \\ \left. + \int_0^t \sigma^*(s,T) dW_s^* - \int_0^t \beta(T-s) d\Pi_s \right\} \quad ,$$

$$S_t^i = S_0^i B(t) \exp \left\{ \sigma_i W_t^* + \Pi_t \ln(1 - \nu_i) + \int_0^t \left(\nu_i \lambda_s^* - \frac{1}{2} \sigma_i^2 \right) ds \right\}$$

Description of the model: Insurance Setting



- Assumption: (Ω, \mathbb{F}, P) and $(\tilde{\Omega}, \tilde{F}, \tilde{P})$ are independent.
- A single premium equity-linked life insurance contract with payoff

$$C(t) = \max(S_t^1, S_t^2)$$

S^1 : maximal size of future profit

S^2 : stochastic guarantee for the insured

- The initial price of the contract: (Brennan-Schwartz price)

$$H(0) = E^* \left\{ \tilde{E} \left[C(T) B^{-1}(T) I \{T_x > T\} \right] \right\} = E^* \left[C(T) B^{-1}(T) \right] \cdot {}_T p_x$$

- Perfect hedging is not possible due to a budget constraint

$$H(0) < E^* \left[C(T) \cdot B^{-1}(T) \right]$$

- Find a strategy that will hedge successfully with the maximal probability

Quantile Hedging Definitions



- Self-financing strategy π has a budget constraint

$$H_0^\pi \leq H_0 < E^* C_T e^{-rT}$$

- $A(H_0^\pi, \pi) = \{\omega : H_T^\pi(H_0^\pi) \geq C_T\}$ is a *successful hedging set*

- π^* is a *quantile hedge* if

$$P\{A(H_0^{\pi^*}, \pi^*)\} = \max_{\pi: H_0^\pi \leq H_0} P\{A(H_0^\pi, \pi)\}$$

- How to construct the quantile hedge π^* and the successful hedging set $A(H_0^{\pi^*}, \pi^*)$?

Quantile Hedging Methodology



The answer is given in the following fact (Foellmer and Leukert (1999))

Let $A^* \in F_T$ be a solution to the problem $P(A^*) = \max_{A \in F_T : E^*(C_T \cdot I_A) \leq H_0} P(A)$

Then the quantile hedge π^*

- does exist
- is unique
- is a perfect hedge for a modified claim $C_{A^*} = C_T \cdot I_{A^*}$

The structure of a maximal successful hedging set is $A^* = \left\{ Z_T^{-1} > a \frac{C_T}{B_T} \right\}$, where

A constant a is defined $a = \inf \left\{ c : P^* \left(\frac{dP}{dP^*} > c \right) \leq \alpha \right\}$

Equity-Linked Life Insurance

Connecting Financial and Insurance Risks



- Due to the structure of the price, $H(0) = E^* \left[C(T) B^{-1}(T) \right] \cdot {}_T P_x$

we apply quantile hedging, $H(0) = E^* \left[C(T) I_{\{A^*\}} \cdot B^{-1}(T) \right]$

- Key formulae connecting financial and insurance risks

$${}_T P_x = \frac{E^* \left[C(T) I_{\{A^*\}} \cdot B^{-1}(T) \right]}{E^* \left[C(T) \cdot B^{-1}(T) \right]}$$

Application of Quantile Hedging

Preliminary Calculations



- Maximal successful hedging sets

$$A^* = \left\{ Z_T^{-1} \geq a_n \frac{C_T}{B(T)} \right\} = \left\{ Z_T^{-1} \geq a_n \frac{\max(S_T^1, S_T^2)}{B(T)} \right\}$$

- The price of the contract $H(0) = E^* \left[\max(S_T^1, S_T^2) B^{-1}(T) I_{\{A^*\}} \right]$
$$= E^* \left[\frac{S_T^1}{B_T} I_{\{A^*\}} \cdot I_{\{S_T^1 > S_T^2\}} \right] + E^* \left[\frac{S_T^2}{B_T} I_{\{A^*\}} \cdot I_{\{S_T^1 \leq S_T^2\}} \right]$$
- Further analysis relies on change of measure technique and properties of jump-diffusion processes

Main Results

Theorem 1



- Financial market is described by two-factor jump-diffusion model
- Stochastic interest rate is in HJM framework
- Equity-linked life insurance contract with a flexible guarantee

Then the Brennan-Schwartz price of the contract is

$$H(0) = \sum_{n=0}^{\infty} p_{n,T}^* \left[e^{v_1 \int_0^T \lambda_t^* dt} (1-v_1)^n S_0^1 \Psi_1(\Gamma_1, \Gamma_2) + e^{v_2 \int_0^T \lambda_t^* dt} (1-v_2)^n S_0^2 \Psi_2(\tilde{\Gamma}_1, \tilde{\Gamma}_2) \right]$$

where

$$p_{n,T}^* = e^{-\int_0^T \lambda_t^* dt} \frac{\left(\int_0^T \lambda_t^* dt \right)^n}{n!}$$

Main Results

Theorem 1



$$\Gamma_1 = -\ln \frac{a_n \cdot S_0^1 (\lambda_T^1)^n}{\lambda^n} - \frac{1}{2} \delta_1^2 - \int_0^T (\lambda - \lambda_s^1) ds$$

$$\Gamma_2 = \ln \frac{S_0^1 (1 - v_1)^n}{S_0^2 (1 - v_2)^n} - \int_0^T \lambda_s^* (v_2 - v_1) ds + \frac{1}{2} \delta_2^2$$

$$\tilde{\Gamma}_1 = -\ln \frac{a_n \cdot S_0^2 (\lambda_T^2)^n}{\lambda^n} - \frac{1}{2} \tilde{\delta}_1^2 - \int_0^T (\lambda - \lambda_s^2) ds$$

$$\tilde{\Gamma}_2 = \ln \frac{S_0^2 (1 - v_2)^n}{S_0^1 (1 - v_1)^n} - \int_0^T \lambda_s^* (v_1 - v_2) ds + \frac{1}{2} \tilde{\delta}_2^2$$

$$\lambda_t^1 = \lambda_t^* (1 - v_1) \quad \lambda_t^2 = \lambda_t^* (1 - v_2)$$

Main Results

Theorem 2

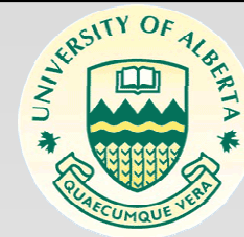


The survival probability of an insured is as following:

$${}_T p_x = \frac{\sum_{n=0}^{\infty} p_{n,T}^* \left[p\Psi(\Gamma_1, \Gamma_2; \rho, \delta_1, \delta_2) + q\Psi(\tilde{\Gamma}_1, \tilde{\Gamma}_2; \tilde{\rho}, \tilde{\delta}_1, \tilde{\delta}_2) \right]}{\sum_{n=0}^{\infty} p_{n,T}^* \left[p\Phi\left(\frac{d_1}{(\sigma_1 - \sigma_2)\sqrt{T}}\right) + q\Phi\left(\frac{d_2}{(\sigma_1 - \sigma_2)\sqrt{T}}\right) \right]}$$

Where $d_1 = \ln \frac{S_0^1 (1 - v_1)^n}{S_0^2 (1 - v_2)^n} - \int_0^T \lambda_s^* (v_2 - v_1) ds + \frac{1}{2} \delta_2^2$, $p_n = e^{v_1 \int_0^T \lambda_t^* dt} (1 - v_1)^n S_0^1$

$$d_2 = \ln \frac{S_0^2 (1 - v_2)^n}{S_0^1 (1 - v_1)^n} - \int_0^T \lambda_s^* (v_1 - v_2) ds + \frac{1}{2} \tilde{\delta}_2^2$$
 , $q_n = e^{v_2 \int_0^T \lambda_t^* dt} (1 - v_2)^n S_0^2$



Remark:

How to determine the constant a

- Fix a probability ε of failure to hedge on each set $\{\Pi_T = n\}$
Or equivalently, fix the probability of successful hedging as

$$P(A^* | \pi_T = n) = 1 - \varepsilon = \Phi(\Delta) \quad \Delta = \Delta_1 \cup \Delta_2$$

Where

$$\Delta_1 = \frac{-\ln \frac{a \cdot S_0^1 (\lambda_T^1)^n}{\lambda^n} - \frac{1}{2} \delta_1^2 - \int_0^T (\lambda - \lambda_s^1) ds}{\delta_1}$$

$$\Delta_2 = \frac{-\ln \frac{a \cdot S_0^2 (\lambda_T^2)^n}{\lambda^n} - \frac{1}{2} \tilde{\delta}_1^2 - \int_0^T (\lambda - \lambda_s^2) ds}{\tilde{\delta}_1}$$

- Using the log-normality of the conditional distribution to estimate a

Numerical Illustration Inputs

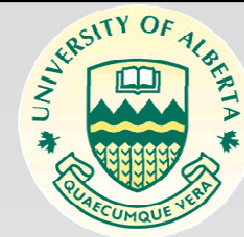


- Contracts with flexible guarantee: Russell 2000 and the S&P 500
- Transfer to One factor Vasicek-Hull-White model
- Estimated parameters for two-factor jump diffusion model (from monthly observations from 09/1987 to 09/2010)

$$\mu_1 = 0.2763 \quad \mu_2 = 0.2898 \quad \sigma_2 = 0.15 \quad \sigma_1 = 0.19$$

$$\nu_1 = -0.27 \quad \nu_2 = -0.2 \quad \lambda = 0.17$$

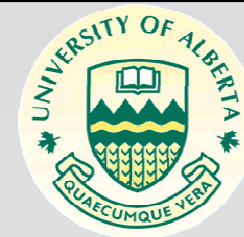
- $S_0 = 1000$ is an initial investment
- $T = 1, 3, 5, 10, 15, 20$ years are terms of the contracts
- Fix different level of financial risks $\varepsilon = 0.01, 0.025, 0.05$



Numerical Illustration

□ Table 1: Survival probabilities ${}_T p_x$ with flexible guarantee

T	$\varepsilon = 0.01$	$\varepsilon = 0.025$	$\varepsilon = 0.05$
1	0.9885	0.9718	0.9447
3	0.9878	0.9705	0.9426
5	0.9874	0.9697	0.9413
10	0.9867	0.9684	0.9391
15	0.9859	0.9667	0.9364
20	0.9853	0.9656	0.9345



Numerical Illustration

□ Table 2: Age of insured with flexible guarantee

T	$\varepsilon = 0.01$	$\varepsilon = 0.025$	$\varepsilon = 0.05$
1	58	69	78
3	45	55	63
5	39	48	56
10	23	39	46
15	12	31	39
20	6	24	33

Numerical Illustration from Melnikov and Skornyakova (2005)



□ Table 1: Survival probabilities with flexible guarantee

T	$\varepsilon = 0.01$	$\varepsilon = 0.025$	$\varepsilon = 0.05$
1	0.9447	0.8774	0.7811
3	0.9511	0.8910	0.8041
5	0.9549	0.9108	0.8387
10	0.9605	0.9108	0.8378

□ Table 2: Age of Insured with flexible guarantee

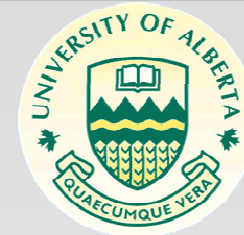
T	$\varepsilon = 0.01$	$\varepsilon = 0.025$	$\varepsilon = 0.05$
1	78	87	94
3	61	71	79
5	53	63	71
10	41	50	58

Numerical Illustration

Conclusions



- Whenever the financial risk level \mathcal{E} increases, the survival probability ${}_T P_x$ decreases, so that the clients' age increases in the same period. The insurance company should attract older clients for the contract with flexible guarantee to compensate increasing financial risk.
- With longer contract maturities, the company is able to attract younger clients while maintaining the same financial risk exposure, as a survival probability is decreasing over time.
- For fixed contract maturity, as the financial risk \mathcal{E} increases, the change of survival probabilities ${}_T P_x$ is not dramatic as the corresponding results in Melnikov and Skornyakova (2005).
- For fixed financial risk \mathcal{E} , as the contract maturity increases, the change of survival probabilities ${}_T P_x$ decreases in small percentage while the results in Melnikov and Skornyakova (2005) shows the opposite way, which is increasing.

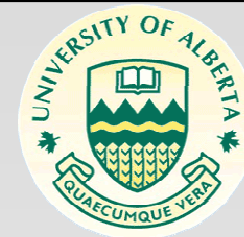


Further Developments Discussion

- Mortality Modeling
 - Use theoretical models of mortality Gompertz, Makeham, Lee-Carter
 - Allows to take into account new tendencies in mortality
- Modeling with other Risk Measures
 - Conditional Tail Expectation:
$$CTE_{1-\varepsilon}(\pi) = E\left(H - X_T^\pi(\pi) \mid H - X_T^\pi(\pi) \geq VaR_{1-\varepsilon}(\pi)\right)$$
 - Rockafellar and Uryasev (2002):

If \bar{z} is a solution to
$$RU(z) = z + \frac{1}{\varepsilon} \left[\inf_{\pi} E\left(H - X_T^\pi(x) - z\right)^+ \right] \rightarrow \min$$

then $VaR_{1-\varepsilon}(\pi^*) = \bar{z}$, $CTE_{1-\varepsilon}(\pi^*) = RU(\bar{z})$



Further Developments Discussion

- Shortfall minimization problem for the claim $H(z) = (H - z)^+$

$$E\left(H - X_T^\pi(x) - z\right)^+ = E\left((H - z)^+ - X_T^\pi(x)\right)^+ \rightarrow \inf$$

over all strategies with initial budget constraints

- $(\tilde{X}_0(z), \tilde{\pi}(z))$ solution to this problem (Foellmer and Leukert (2000)),
where $\tilde{\pi}(z)$ is a perfect hedge to a modified claim

$$\tilde{H}(z) = H(z)I_{\{Z_T^{-1} > \tilde{a}(z)\}},$$

$$\tilde{a}(z) = \inf\left(a \geq 0 : E^* H(z)I_{\{Z_T^{-1} > a\}} \leq X_0\right)$$

- The function $RU(z)$ has the following structure

$$RU(z) = z + \frac{1}{\varepsilon} E I_{\{Z_T^{-1} \leq \tilde{a}(z)\}} H(z), \quad z < z^*, \quad RU(z) = z, \quad z \geq z^*$$

where $E^* H(z^*) = X_0$



References

- ❑ Brennan, M., and E.S. Schwartz, 1976. The Pricing of Equity-Linked Life Insurance Policies with an Asset Value Guarantee. *J. Financial Economics* 3: 195-213
- ❑ Brennan, M., and E.S. Schwartz, 1979. Alternative Investment Strategies for the Issuers of Equity-Linked Life Insurance with an Asset Value Guarantee. *Journal of Business* 52: 63-93
- ❑ Ekern, S. and S. Persson, 1996. Exotic Unit-Linked Life Insurance Contracts. *Geneva Papers on Risk and Insurance Theory* 21: 35-63
- ❑ Foellmer, H., and P. Leukert, 1999. Quantile Hedging. *Finance Stochast.* 3: 251-273
- ❑ Melnikov, A., and V. Skornyakova, 2005. Quantile hedging and its application to life insurance. *Statistics and Decisions* 23: 601-615.
- ❑ Moeller, T., 1998. Risk-Minimizing Hedging Strategies for Unit-Linked Life-Insurance Contracts. *Astin Bulletin* 28: 17-47



References

- ❑ Aase, K. and S. Persson, 1994. Pricing of Unit-Linked Insurance Policies. *Scandinavian Actuarial Journal* 1: 26-52
- ❑ Bacinello, A.R. and F. Ortù, 1993. Pricing of Unit-Linked Life Insurance with Endogenous Minimum Guarantees. *Insurance: Math. and Economics* 12:245-257
- ❑ Shirakawa, H., 1991. Interest rate option pricing with Poisson-Gaussian forward rate curve processes, *Mathematical Finance* 1,4:77-94
- ❑ Kaushik I. Amin and Roberta A. Jarrow, 1992. Pricing options on risky assets in a stochastic interest rate economy, *Mathematical Finance* 2,4:217-237
- ❑ Carl Chiarella and Christina N. Sklibosios, 2003. A class of Jump-diffusion bond pricing models within the HJM framework, *Asia-Pacific Financial Markets* 10: 87-127
- ❑ Quansheng Gao, Ting He and Chi Zhang, 2011. Quantile hedging for equity-linked life insurance contracts in a stochastic interest rate economy, *Economic Modelling* 28:147-156



References

- Moeller, T., 2001. Hedging Equity-Linked Life Insurance Contracts. North American Actuarial Journal 5: 79-95
- Rockafellar, R.T. and S. Uryasev, 2002. Conditional Value-at-Risk for General Loss Distributions. J.Banking&Finance 26: 1443-1471
- Melnikov, A. (2004) 'Quantile hedging of equity-linked life insurance policies', Doklady mathematics **69**: 428-430.