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Review Questions **Volume II, Q-1**

Answers to Review Questions **Volume II, S-1**

HARDY, CHAPTER 8,
DYNAMIC HEDGING FOR SEPARATE ACCOUNT GUARANTEES

I. Black-Scholes Formulae for Segregated Fund Guarantees

A. Black-Scholes Formula for the GMMB

1. $F_T = F_0 (S_T / S_0) (1 – m)^T$.
2. Payoff is $W = (G – F_T)^+$.
3. Let $F_0 = S_0$, then option price $P_0 = e^{-rT} E_Q [(G – F_T)^+] = e^{-rT} E_Q [(G – S_T (1\text{-}m)^T)^+]$.
4. Replace S_0 by $S_0 (1 – m)^T$ in standard Black-Scholes formula.
5. Mortality risk can be hedged by diversification, deterministically.
6. Lapse risk is also treated as diversifiable in most applications.
7. Assume that exits may be treated as independent of guarantee liability.
8. GMMB replicating portfolio: option price X survival probability.
9. If term is long enough, hedge cost is small.

B. Black-Scholes Formula for the GMDB

1. Liability is identical to GMMB.
2. However, maturity date is contingent on policyholder's death.
3. Term of option is a random variable.
4. Cost of hedge portfolio: $H (0) = \sum BSP_0 (t)\ {}_{t-1}p^T_x\ {}_1q^d_{x,t-1}$, for t = 1 to n.
5. Hedge portfolio can be found by splitting BSP_0 (t) into the risky asset part and the risk-free asset part.
6. Cost of hedging a combination of options is sum of individual options.
7. Cost formula can easily be adapted for more complex death benefits by adapting definition of BSP_0 (T).

C. Black-Scholes Formula for the GMAB

1. GMAB is a more complicated option.
2. With 2 straightforward European put-option price formulae, construct option price formula for GMAB benefit.
3. Principle is to take expected value of payout under risk-neutral measure and discount at risk-free rate of interest.
4. Option costs for the GMAB are much higher than the longer-term GMMB and GMDB benefits.
5. Costs without renewal option are simply the sum of GMMB and GMDB for each term and guarantee level.

II. Pricing by Deduction from the Separate Account

A. Charge for option forms part of MER.
B. Part allocated to fund guarantee liability is the margin offset.
C. Resulting price is found by equating the arbitrage-free valuation of fund deductions with arbitrage-free valuation of embedded option.
D. Margin offset rate: $\alpha = B / S_0\, \ddot{a}^T_{x::n|i'}$, where B = value of option and $\ddot{a}^T_{x::n|i'}$ is an n-month annuity factor at rate i'.

III. The Unhedged Liability

A. In practice, experience and experiment indicate that dynamic hedging actually works remarkably well.
B. It is very likely that hedge portfolio indicated by Black-Scholes analysis will be sufficient to meet liability at maturity and will be close to self-funding.
C. Need to estimate transactions costs however.
D. Discrete Hedging Error with Certain Maturity Date

1. Black-Scholes-Merton approach assumes continuous trading.
2. In practice, this is not true.
3. Discrete hedging error or tracking error is then introduced.
4. Apply stochastic simulation only to the part of liability not covered by hedge.
5. Total capital requirement = Hedge cost + Additional requirement for unhedged liability.
6. Frequency with which hedge portfolio is rebalanced is a trade-off between accuracy and transactions costs.
7. Hedging error may be modeled assuming

    a. Time-based strategy: Hedge portfolio is rebalanced at regular intervals.
    b. Move-based strategy: Hedge portfolio is rebalanced when stock price moves by some specified triggering %.

8. Move-based approach has been shown to be more efficient.
9. More straightforward to demonstrate method using regular time steps because it is simpler to incorporate mortality costs.
10. Hedging error = $H(t) - H(t^{-})$.
11. Over large number of simulations, hedging error ≈ 0 on average, if volatility used for projections = Q-measure volatility used for hedging.
12. In dynamic hedging risk is large market movements in either direction.
13. Using actuarial approach, source of loss is poor asset performance.

E. Discrete Hedging Error: Life Contingent Maturity

1. Must take survival into consideration.
2. Hedging error at t given that the contract is in force at t-1

    a. If life survives, it is difference between hedge required at t and hedge brought forward from t-1.
    b. If life dies or lapses, it is difference between benefit at t, if any, and hedge brought forward from t-1.

3. Taking each of these cases and multiplying by appropriate probability gives hedging error at t conditional on surviving to t-1.
4. The unconditional hedging error at t is found by multiplying by the probability that contract is in force at t-1.
5. Not necessary to apply lapse and survival probabilities individually each month.
6. Hedging error, allowing for life contingency, is found by multiplying hedging errors calculated for certain maturity date by probability of survival for entire term of contract.

F. Transactions Costs

1. On bonds are negligibly small for institutional investors.
2. Assume they are proportional to absolute change in value of stock part of hedge.
3. Example: .2% of change in stock component of hedge.

G. Model Error

1. Under any stochastic volatility process, hedge loses self-financing property.
2. Simulation derives distribution of additional hedging costs.
3. It emerges naturally from simulation process as part of hedging error.
4. Approach thus consists of

    a. Calculating hedge using constant volatility assumption.
    b. Projecting hedge using stochastic volatility RSLN model.

5. Another approach: Calculate hedge, using Q-measure consistent with stock model.
6. However, more complex and benefits in terms of accuracy are limited.
7. Also there are infinitely many risk-neutral measures that may be used.

IV. Examples

A. Joint GMMB and GMDB Contract

1. At each month end, outgo is calculated as

    a. Any mortality payout, plus
    b. Transactions costs, plus
    c. Hedge required for future guarantees, minus
    d. Hedge brought forward from previous month.

2. Initial rebalancing hedging error comprises entire cost of establishing hedge.
3. Income = Margin offset X segregated-fund value, at each month end except last.
4. PV is calculated at risk-free rate of interest.
5. Negative values indicate that income exceeds outgo.
6. If stock price process volatility < hedge portfolio volatility: overhedging and average hedging error is negative.
7. Hedging error also generated by deviations from lapse/mortality assumptions.

B. GMAB

1. Most of distribution is in negative cost sector: little probability of future loss.
2. Hedge purchased has reduced future liability risk.
3. All that remains is from hedging error and transactions costs.
4. Hedge portfolio acts to immunize insurer against guarantee liability.
5. GMAB hedge portfolio is more complex than GMMB and GMDB contracts.
6. For simple European option, hedge always comprises long position in bonds and short position in equities.
7. GMAB may be long or short in equities, liable to swing a lot at rollover dates.
8. Transactions costs are high and hedge is very sensitive to stock price movements.
9. This increases potential hedging error compared with standard European option.

SECTION Q

Review Questions

Introductory Note

This section of the study manual contains an array of review questions covering the entire syllabus. These questions were written to serve as an aid in assessing your understanding of the material after you have completely covered it through your studies. It is unlikely that you would see questions of this type on the actual exam, since those questions are developed with an eye toward application of multiple parts of the syllabus in actual job situations.

While these questions were not developed as possible exam questions by themselves, it is entirely possible that you could see some of these questions as parts of actual exam questions.

This section of the manual is entirely new. We would welcome your feedback on it, both as it is presented here and any suggestions you have for improvement.

Source: Desrochers, Chapter 3

Question 9
(6 Points)

Assume that the annual mortality rate q is equal to .24,

(a) Determine the value of q^{monthly} by the arithmetic method.

(b) Determine the value of q^{monthly} by the exponential method.

(c) Determine the equivalent arithmetic COI.

(d) Determine the equivalent exponential COI.

Provide answers with 4 decimals.

Source: Hardy, Chapter 2

Question 11
(14 Points)

With respect to the Modeling of Long-Term Stock Returns, describe the Wilkie Model Structure.

Source: Desrochers, Chapter 3

Solution to Question 8

Statement	**Points**
1. Choice of methodology is driven by administrative system limitations.	1
2. Multiplicative Method (or Ratio Method): Mortality assumption is set equal to substandard rating applied to reasonable mortality applicable to standard contract.	2
3. Additive Method: Assumed mortality equals amount necessary to maintain same margin between guaranteed and current mortality charges as that applicable for standard risk contract.	2
4. Current Substandard Charges: Company may use mortality charges that exceed reasonable charges to the extent it actually expects to impose those higher charges.	2
5. Age Adjustments: Calculations are based on an increased age (set-forward).	2
6. This age set-forward approach raises issues	1
a. It appears to run afoul of the deemed maturity age/date rule.	1
b. It seems to be in conflict with DEFRA Blue Book.	1
TOTAL POINTS	**12**

Solution to Question 9

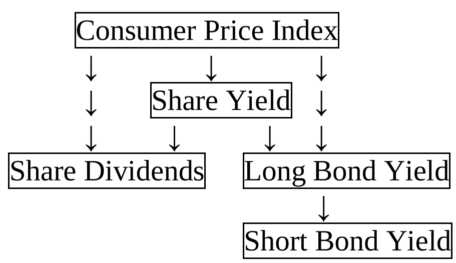
Statement	**Points**
(a) Value of $q^{monthly}$ by the arithmetic method	**1**
1. Arithmetic method: $q^{monthly} = q / 12 = .24 / 12 = .0200$.	1
(b) Value of $q^{monthly}$ by the exponential method	**1**
1. Exponential method: $q^{monthly} = [1 - (1 - q)^{(1/12)}] = .0226$.	1
(c) Equivalent arithmetic COI	**2**
1. Arithmetic COI $= (q / 12) / [1 - (q / 12)]$	1
2. Arithmetic COI $= (.24 / 12) / [1 - (.24 / 12)] = .0204$.	1
(d) Equivalent exponential COI	**2**
1. Exponential COI $= [1 - (1 - q)^{(1/12)}] / [1 - (1 - (1 - q)^{(1/12)})]$	1
2. Exponential COI $= .0226 / .9774 = .0231$.	1
TOTAL POINTS	**6**

<u>Source</u>: <u>Hardy, Chapter 2</u>
<u>Solution to Question 10</u>

Statement	**Points**
1. Stable distributions can be very fat-tailed.	1
2. They are easy to combine, as their sum is always another stable distribution.	1
3. They are related to Levy processes.	1
4. F is stable distribution if for independent, identically distributed X_1, X_2, X, and for any a, b > 0, there exists c > 0, d such that $aX_1 + bX_2 \sim cX + d$, where ~ means having same distribution.	1
5. This is true for Normal distribution but not for the Poisson distribution.	2
6. They cannot be described in terms of their probability or distribution functions.	1
7. They can be used to describe stochastic processes.	1
8. They are not easy to use.	1
9. They do not incorporate autocorrelations arising from volatility bunching.	1
TOTAL POINTS	**<u>10</u>**

<u>Solution to Question 11</u>

Statement	**Points**
1. It is a multivariate model: several related economic series are projected together.	1
2. It is designed for long-term applications.	1
3. It is designed to be applied to annual data.	1
4. It makes assumptions about stochastic processes governing evolution of some key economic variables.	1
5. Structure: (see diagram below)	2



6. Each series incorporates

a. Some factor from connected series higher up the cascade.	1
b. A random component.	1
7. It is widely used in UK and elsewhere.	1
8. It has been fitted to data from many countries.	1
9. Integrated structure has made it useful for actuarial applications.	1
10. It is actually a collection of models.	1
11. Notation can be confusing.	1
12. There are many parameters and 5 integrated processes.	1
TOTAL POINTS	**<u>14</u>**