

 **ACTEX Learning**

CP 351

**Asset Liability
Management
Study Manual**

1st Edition

John Aprill, FSA, MAAA



An SOA Exam



Actuarial & Financial Risk Resource Materials
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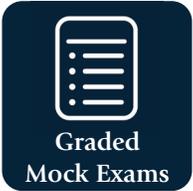
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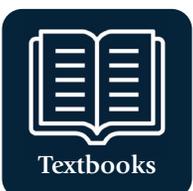
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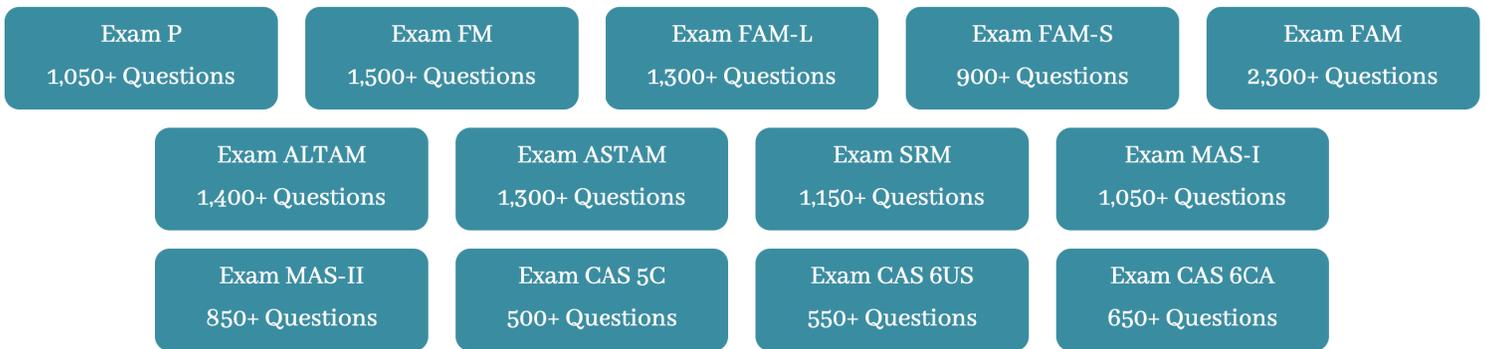
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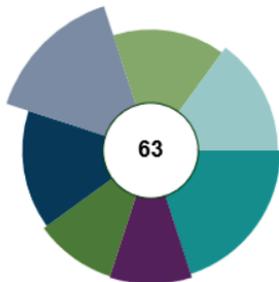
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Question Difficulty: Advanced ⓘ

An airport purchases an insurance policy to offset costs associated with excessive amounts of snowfall. The insurer pays the airport 300 for every full ten inches of snow in excess of 40 inches, up to a policy maximum of 700.

The following table shows the probability function for the random variable X of annual (winter season) snowfall, in inches, at the airport.

Inches	(0,20)	[20,30)	[30,40)	[40,50)	[50,60)	[60,70)	[70,80)	[80,90)	[90,inf)
Probability	0.06	0.18	0.26	0.22	0.14	0.06	0.04	0.04	0.00

Calculate the standard deviation of the amount paid under the policy.

Possible Answers

A 134 **B** 235 **C** 271 **D** 313 **E** 352

Help Me Start Find the probabilities for the four possible payment amounts: 0, 300, 600, and 700.

Solution

With the amount of snowfall as X and the amount paid under the policy as Y , we have

y	$f_Y(y) = P(Y = y)$
0	$P(Y = 0) = P(0 \leq X < 50) = 0.72$
300	$P(Y = 300) = P(50 \leq X < 60) = 0.14$
600	$P(Y = 600) = P(60 \leq X < 70) = 0.06$
700	$P(Y = 700) = P(X \geq 70) = 0.08$

The standard deviation of Y is $\sqrt{E(Y^2) - [E(Y)]^2}$.

$$E(Y) = 0.14 \times 300 + 0.06 \times 600 + 0.08 \times 700 = 134$$

$$E(Y^2) = 0.14 \times 300^2 + 0.06 \times 600^2 + 0.08 \times 700^2 = 73400$$

$$\sqrt{E(Y^2) - [E(Y)]^2} = \sqrt{73400 - 134^2} = 235.465$$

Common Questions & Errors

Students shouldn't overthink the problem with fractional payments of 300. Also, account for probabilities in which payment cap of 700 is reached.

In these problems, we must distinguish between the REALT RV (how much snow falls) and the PAYMENT RV (when does the insurer pay)? The problem states "The insurer pays the airport 300 for every full ten inches of snow in excess of 40 inches, up to a policy maximum of 700." So the insurer will not start paying UNTIL AFTER 10 full inches in excess of 40 inches of snow is reached (say at 50+ or 51). In other words, the insurer will pay nothing if $X < 50$.

Rate this problem Excellent Needs Improvement Inadequate

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NOTES

This study guide is designed to assist candidates preparing for the SOA Exam **CP351: Asset Liability Management**. It summarizes, in outline form, all the required books, study notes and articles listed in the official syllabus. Within each topic, outlines are organized according to the syllabus order

The major topic areas covered include:

- Objectives of Asset Liability Management
- Measuring Risks from Assets and Liabilities
- Tools and Strategies to Manage ALM Risks

To help candidates assess their understanding and prepare for the actuarial exam, a full-length practice exam is included. This mock exam mirrors the structure of the official exam (3 hours, 50 points). Both the questions and the assigned point values are representative of what candidates can expect. Complete solutions are provided for all questions to support self-assessment.

While every effort has been made to ensure the accuracy of the material, errors may remain if you notice any issues or have suggestions for improvement please, contact us at support@actexlearning.com.

Best of luck in your studies and on exam day!

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SECTION A

OBJECTIVES OF ASSET LIABILITY MANAGEMENT

FINANCIAL ENTERPRISE RISK MANAGEMENT, ch. 20**CASE STUDIES**

- I. Introduction
 - A. Case studies illustrate the issues faced in real organizations and the causes of a range of risk management failures
 - B. Unfortunately, failures make up most of the case studies because no one hears about successful risk management initiatives
- II. The 2008 global financial crisis
 - A. The 2008 global financial crisis has repercussions that persist
 - 1. The problems of the US housing market spread to real estate in Europe and the banks with exposures to this market
 - 2. Governments bailed out banks, cut spending, and borrowed heavily
 - 3. The financial crisis was characterized by a lack of liquidity and a corresponding fall in the creditworthiness of firms and governments
 - B. Causes for the crisis
 - 1. The role of China
 - a. The Chinese economy has grown very quickly, driven by exports to the West
 - b. The capacity for growth in China meant that the rise in production occurred in parallel with relatively low rates of inflation
 - c. The large flows of wealth into China did not prompt a strengthening of the Chinese currency
 - d. China deliberately maintained a reasonably stable exchange rate with the US dollar, even though it should have appreciated significantly
 - e. The increasing demand for Chinese exports in the West did not lead to price inflation; increasing demand was stoked by persistently low rates of interest in the US
 - f. The Chinese invested a significant portion of its export income to buy U.S. Treasury bonds; the demand was high and the price was inflated causing its yield to fall

2. The role of the housing markets

- a. The low rates of interest in government meant that banks were able to maintain low interest rates
- b. Mortgages became cheaper causing house prices to rise

3. The role of regulation

- a. Graham Leach Bliley Act allowed commercial and retail banks to carry on investment banking activities
 - i. This was seen as desirable since it allowed banks to benefit from the diversification of carrying both types of business
 - ii. However, in stressed markets, catastrophic losses in the investment banking arm adversely affect retail and commercial account holders
- b. Basel 1 also gave banks incentives to convert credit risk in mortgages to market risk by securitizing loans
 - i. These mortgage-backed securities were a form of regulatory arbitrage
 - ii. It removed the need for arbitrage by improving the allowance for credit risk under Basel 2
- c. The ability to package risk and spread it was considered an important diversification tool
- d. The tranching approach was also seen as a good way to allow investors with different risk appetites to gain exposure to a single pool of risks; however, the main buyers of these securities were other banks that were linked to each other through exposure to the housing market
- e. The holder of an MBS does not have the same level of information on the borrower's underlying security as the bank that sold the mortgage does

4. The role of incentives

- a. Securitization had an adverse impact on incentives
 - i. If a bank makes a loan, it would hold the risk on its balance sheet
 - ii. In securitization, once a loan has been taken, the profit is capitalized by packaging the loan and much of the risk into an MBS
 - iii. This resulted in a reduced incentive to ensure creditworthiness of borrowers and resulted in an overall decline in credit quality
- b. The pricing of CMO tranches was determined by credit rating agencies; there was an incentive for banks to exploit the mispricing by retaining particular underpriced CMO tranches (usually the equity tranche) and selling the overpriced remaining tranches

- c. Incentives were a significant portion of earnings
 - i. Bonuses were paid on results over a relatively short period
 - ii. Bonuses were based on team rather than individual performance
 - iii. There was an incentive to take significant risks to earn these bonuses
 - iv. If a negative bonus resulted, the bonus was set at zero
- d. Because bonuses are short term, there is an incentive to make short-term profits without considering long term impacts of a trade
- e. If bonuses are based on team performance, there is little incentive to do anything differently from the rest of the team
 - i. A good individual result does not have a huge impact on individual's bonus, but a bad individual result may cause an individual to be fired
 - ii. If an individual copies the rest of the team they share the good times and have protection in the bad times

5. The role of models

- a. The models used to produce CDOs and CMOs were not sufficiently accurate
- b. In particular the Gaussian copula was an issue
 - i. Those who recognized this risk updated their models
 - ii. However, due to the bonus structure, many did not
- c. Even improved models cannot exactly replicate the world and should be treated as guides only
- d. Excessive reliance on model output by senior management and a lack of understanding of the model's limitations were important shortcomings

6. Organizational issues

- a. Many banks were exposed to the housing market risks directly through mortgages and indirectly through the MBS
- b. Senior management did not recognize the concentration of risk

C. Evolution of the crisis

1. Underlying mortgages

- a. Mortgages were sold to sub-prime borrowers
- b. This risk was not properly priced; securitization led to reduced incentives to check creditworthiness and correctly price a risk
- c. In addition, mortgages were made at low initial rates that rose sharply
- d. This led to a rise in mortgage defaults
- e. Deal complexity and opacity prevented banks from assessing their exposure

2. Banks relied on short-term funding which was no longer available and threatened bankruptcy
3. Government assistance came in two forms
 - a. Illiquid assets were exchanged for liquid assets
 - b. Some governments also provided cash in exchange for equity stakes in banks
4. Firms and individuals found it hard to borrow; as a result, the liquidity crisis spread from the financial sector to the wider economy
5. The resulting slowdown in economic growth and stabilizing financial institutions resulted in large budget deficits in European governments

D. Lessons from the crisis

1. Organizational structure

- a. The Graham Leach Bliley Act allowed banks to smooth profits over time
- b. This means that commercial and retail account holders, especially those with a low risk tolerance, were exposed to excessive risks
- c. ALM should have a higher status within banks and chief risk officers should have more power, including the authority to stop undue risks from being taken
- d. Those who design and work with complex models should have greater say in the use of the models to make their limitations known

2. Capital structure

- a. Banks continue to borrow on a short-term basis to fund risks with longer terms
- b. However, banks should hold capital in case the economic outlook changes adversely
- c. Banks should also have contingency plans in case normal sources of liquidity dry up
- d. Even liquid capital may not be an alternative to good risk management and should not be regarded as such

3. Bank bonuses

- a. Bonuses should reflect the term of the instruments being traded
- b. Bonuses should not be awarded before the risk inherent in any deal has expired
- c. In securitizations, if a bank transfers the risk to the financial markets, adequate risk should be retained to ensure the credit quality of the loans
- d. Good risk management should be rewarded the same as profit generation

4. Models

- a. Models are essential; they should be used as tools
- b. Model output should be used to help make decisions
- c. Those making decisions using the output from models should understand the model's capabilities and limitations
- d. If models are used for a purpose other than that for which they were designed, they should be used with caution
- e. There are some risks for which simple models are better than complex models

III. Equitable Life

A. The collapse of Equitable Life, the oldest insurance company in the world, is still being felt today

1. Investors fight for compensation
2. Many feel their retirement income was severely damaged by the actions of the firm
3. Operational failures also led to improvements in the actuarial profession

B. Background

1. Equitable Life was a mutual insurance company that followed a successful strategy

- a. A bonus involved distributing as much of its reserves to its with-profits policyholders as possible
- b. In addition to holding a cushion for assets, Equitable Life aimed to ensure that each generation of policyholders received its own asset share; this consisted of cumulative contributions plus investment returns less costs
- c. Equitable Life did not smooth returns between generations which differed from other insurers; however, most insurers accepted a degree of intergenerational transfer and held significant free assets to provide security against adverse financial conditions

2. Even though it was exposed to adverse market conditions in the with-profits pension policies, a significant amount of business was issued at guaranteed annuity rates (GARs) below which the annuity rate will never fall

- a. Whatever the market price of annuities is at retirement, there was a call option on the annuity
- b. Policies were written to allow additional contributions
- c. Many policies were sold when interest rates were high and annuity prices were much lower than the rate provided by the GAR; these options were deeply out of the money

3. Equitable redesigned its terminal bonus system and GARs were dropped for new contracts, but policyholders were never informed and no separate bonus class was created
4. The directors thought they had full discretion over the business to recoup the loss of any guarantees
5. The appointed actuary was made the chief executive officer to ensure consistency; however, the chief executive is more concerned with new business while an appointed actuary is looking at the position of existing policyholders

C. Development of the collapse

1. As interest rates fell, GARs started to appear more attractive
2. Equitable had not quantified nor hedged the options against it and faced significant costs
3. Previous policyholders had been overpaid leading to a state of deficiency by deducting the cost of the guarantee from the terminal bonus
4. Courts ruled that directors should not be allowed to use their discretion to negate a benefit which a policyholder might reasonably be entitled to expect
5. No reversionary bonus was paid and the company was closed to new business

D. Reasons for the collapse

1. Equitable Life held insufficient capital
2. It failed to model accurately the extent of options against it and failed to take action at the appropriate time to separate different types of policies
3. Equitable was arrogant; they took insufficient notice of changes in the financial landscape that affected all insurance companies
4. The company was unwilling to learn from other firms and there was insufficient scrutiny of its own business model
 - a. Culture is determined by risk management; if the position of isolation is adopted at the top, it is reflected throughout the organization
 - b. Combining the chief executive and chief actuary roles made this worse

E. Consequences for the collapse

1. Appointed actuaries should be subject to external peer review
2. The appointed actuary was replaced with two roles
 - a. An actuarial function holder
 - b. A with-profits actuary to give greater protection to the with-profits policyholders by removing the conflicts that existed when the two roles were combined

3. A new body for actuarial standards and robust requirements for appointed actuaries was created
4. A proportion of the CPD must be external and is intended to ensure that actuaries are exposed to a wide range of views and interdisciplinary research

IV. Long Term Capital Management (LTCM)

A. Background

1. Investment strategy

- a. LTCM was a hedge fund that invested in fixed income arbitrage between on-the-run and off-the-run treasury bonds in the US, Japanese, and European markets
- b. This involved taking long and short positions in government bonds of a similar term which are recently issued (on-the-run) and some which have not been issued for some time (off-the-run)
- c. On-the-run bonds are more liquid and more expensive than off-the-run bonds
- d. If an investor buys an off-the-run bond while simultaneously taking a short position and an on-the-run bond, the arbitrage profit will be realized if both positions are held to maturity

2. Expansion of investment strategy to increase profits

- a. Because this is an arbitrage strategy, potential profits are small
- b. To increase profits, trades are levered by money that is borrowed and added to the equity capital invested in the trade
- c. Proceeds are then used to pay off the borrowing with the excess as profit on the initial equity capital invested
- d. As LTCM's asset base grew, there were not enough potential arbitrage trades to maintain levels of profitability
- e. The partners explored a wider range of trades both within and between markets; however, this was not true arbitrage because arbitrage assumes convergence of all markets to some long-term norm

B. Market events

1. Creation of the crisis

- a. A currency crisis started in Thailand and spread throughout Asia; this led to a sharp fall in commodity prices and triggered a crisis in Russia
- b. Investors were concerned that this would spread to Europe and sold European government bonds to buy U.S. Securities

2. Impact on LTCM

- a. These movements caused large losses for LTCM and they were forced to close many of their trades
- b. This large-scale closure caused prices to move against LTCM leading to fears that it might collapse
- c. The Federal Reserve Bank arranged to bail out LTCM with many investment banks and all positions were ultimately liquidated

C. Lessons learned from LTCM

1. LTCM was caught up by unexpected market conditions

2. LTCM relied on models to make decisions rather than simply inform management

- a. These models underestimated the likelihood of a large adverse movement
- b. Over-reliance on models at the expense of good judgment is damaging
- c. The models assumed convergence within a reasonable time.

3. Many of the strategies ultimately did not prove to be profitable and remained unprofitable for too long

4. Large profits that were supposedly arbitrary strategies should have concerned investors

5. It is important to objectively assess the returns available from strategies being advertised and to understand the risks being taken when investing in any fund

V. Robert Maxwell

A. Background

1. Robert Maxwell, owner of the Mirror Group, died in 1991

2. Following his death, it became apparent that assets had been misappropriated from several pension schemes in Maxwell's group of companies to support the group

3. These transfers were not authorized by the trustees and would have been illegal

4. The transfers happened despite the oversight of the scheme's auditors

5. It took many years before pension scheme members' benefits were finally secured

B. How the fraud happened

1. Key positions in the group and the trustee boards were held by the same individuals

2. All assets were held by an in-house manager

3. Maxwell's dominance of the group ensured that assets were transferred when improper

C. Consequences of the fraud

1. The UK government made recommendations aimed at

- a. Improving the independence of trustees and the requirement to have a third of all trustees nominated by scheme members
- b. Clarifying that the only power of investment that could be delegated is management of assets, which could be given to investment managers
 - i. Trustees cannot act as either auditor or actuary to the scheme
 - ii. Two statutory roles were created: scheme actuary and scheme auditor

2. The most important step to be taken is to avoid the concentration of risk at the head of a company

VI. Heartland payment systems

A. Background

1. Heartland Payment Systems is a payment processing company in the United States
2. It processes credit card transactions and deals with a very large volume of personal data
3. In 2009, it disclosed that its security systems were breached in the previous year resulting in information on 100 million cards compromised

B. Details of the data breach

1. Heartland's systems were successfully compromised despite passing multiple audits of its data systems
2. A successful SQL injection attack was made by entering a string code into a form on a web page which results in the security of the database being circumvented
3. Once access to the database is obtained, malware is planted that enabled hackers to obtain credit card data for months
4. Heartland was alerted to the problem when credit card issuers reported an increase in fraudulent transactions
5. Hackers took several measures to avoid detection; however, one was arrested after repeatedly targeting a separate institution from a single location

C. Heartland's response to the breach

1. Heartland's initial response after notifying authorities was openness and transparency
2. Its share price fell sharply in part due to the cost of litigation
3. Heartland addressed the known holes in its security and made significant security upgrades including microchipped credit cards and encryption between readers and servers
4. Heartland published white papers on security measures
5. It offers a breach warranty for businesses that use their most secure systems, which promises to reimburse businesses for any losses incurred if the encryption on secure system card systems fails

D. Lessons to be learned

1. Keep systems up to date and deal with any systems vulnerabilities promptly
2. A proactive approach is advisable
3. The steps taken to prevent losses in the future can create a competitive advantage

E. Recent developments

1. Heartland had another breach from a break in at one of its payroll offices in 2015
2. Network computers were stolen and may have had personal information on them
3. The data risks can also be caused by theft

SECTION B

MEASURING RISKS FROM ASSETS AND LIABILITIES

FIXED INCOME SECURITIES, TOOLS FOR TODAY'S MARKETS, ch. 4**DV01, DURATION AND CONVEXITY****I. Introduction**

- A. Market participants need to understand how fixed income prices change when interest rates change
 - 1. To form a view on the future level or term structure of interest rates
 - 2. To ensure that a portfolio of assets keeps pace with a portfolio of liabilities
 - 3. To hedge one fixed income instrument portfolio with another
- B. There are two overarching trade-offs in defining a change in interest rates
 - 1. Simplicity versus empirical reality and
 - 2. Robustness versus model dependence
- C. For simplicity, two bonds may be assumed to move in parallel; however, a portfolio of swap positions of different terms may require modeling of changes in rates across the term structure
- D. With respect to robustness versus model dependence, a pension fund which hedges the present value of liabilities relative to the value of its assets tends to prefer frameworks that are not very sensitive to assumptions about how rates of different terms vary relative to one another; however, an actively managed fund needs to take views on the level of rates and the shape of the term structure

II. Price-rate curves

- A. A change in interest rates must be defined to compute interest rate risk metrics
 - 1. The base curve is the high-quality market (HQM) weighted par rate curve
 - 2. The spreads are relative to the HQM curve and do not change as the HQM curve changes
 - 3. The change in the HQM par rate of any term is a fixed proportion of the change in the 30-year par rate
- B. To calculate par rates and bond prices
 - 1. Given a basis point change in a 30-year par rate, calculate the change in par rates of all terms
 - 2. For each bond, add spread to the shifted par rates
 - 3. For each bond convert the shifted power plus spread curve into discount factors and
 - 4. Reprice each bond
- C. Prices increase as rates fall and decrease as rates rise
- D. Bonds vary by their sensitivity to interest rates and differences in curvature

III. DV01

- A. DV01 is the dollar value of an '01, that is a change in the price of a bond for a change in rates of one basis point
1. The first step in computing DV01 is to compute the slope of the price rate curve, that is the change in price divided by the change in rate
 2. The current price is not used in this calculation; it is more accurate to estimate the slope of the curve at the current rate with shifts of +1 and -1 which is centered around the current rate
 3. The slope of the price rate curve is not very intuitive; more intuitive and useful is the change in price for a one basis point change in rates
- B. DV01 of the fixed income instrument is estimated by

$$DV01 \approx - \frac{1}{10,000} \frac{\Delta P}{\Delta y}$$

where

P is the price of the fixed income instrument and
 y is the single factor that determines rate changes across the term structure

- C. The limit as the shift shrinks to 0 gives DV01 in terms of the derivative as

$$DV01 \approx - \frac{1}{10,000} \frac{dP}{dy}$$

- D. The derivative of a curve at a particular point is illustrated with tangent lines; the steeper the tangent line the more sensitive it is
- E. DV01 is a local measure of rate sensitivity; the change in the slope of the price rate curve due to rate changes is known as convexity
- IV. Hedging a century bond: Part I
- A. A market maker earns the bid ask spread for providing immediacy or liquidity both to the client who sells the bonds and to the client who later buys the bonds
 - B. The strategy exposes market makers to the risk that the price of corporate bonds falls before the bond can be sold
 - C. A solution is to hedge that risk by
 1. Selling a liquid treasury bond when buying the corporate and
 2. Buying back that treasury bond when selling the corporate

- D. Because the treasury bond has very narrow bid-ask spread, the strategy protects the market maker against falling prices, as the cost of that narrow spread leaves much of the wider corporate bid-ask spread as profit
1. Because rates of different terms behave differently, a reasonable choice is to sell a treasury bond with about the same maturity as the corporate bond being hedged
 2. To determine how much face amount of treasury bonds is needed to sell, a common solution is to ensure that the net $DV01$ of the combined position is zero; that is, choose the face amount of treasuries that, if rates change by one basis point, the value of the net position is unchanged
- E. If the $DV01$ s of bonds A and B are $DV01^A$ and $DV01^B$, then P^A (the face amount of bond A is hedged with P^B (face amounts of bond B) such that

$$P^B = -P^A \frac{DV01^A}{DV01^B}$$

- F. The general solution reveals two important points about $DV01$ hedging
1. A long position in bond a is hedged by a short position
 2. The bond with the higher $DV01$ is traded in a smaller quantity
- G. The assumptions behind the $DV01$ hedge are
1. Rate shifts across terms are assumed to be proportional
 2. The spreads of bonds to the base curve are assumed to be constant

H. Hedging spread risk for short periods of time may be an integral part of corporate bond market making and in turn enters into the determination of bid-ask spreads in that market

V. Duration

- A. Duration measures the percentage change in price for change in rates
- B. Duration is estimated in terms of the slope as

$$D \approx -\frac{1}{P} \frac{\Delta P}{\Delta y}$$

C. In terms of the derivative

$$D = -\frac{1}{P} \frac{dP}{dy}$$

- D. Because both $\frac{\Delta P}{\Delta y}$ and $\frac{dP}{dy}$ represent percentage changes in price, duration is also a percentage change in price for a change in rates
- E. Price sensitivity can also be expressed as

$$\frac{\Delta P}{P} \approx -D\Delta y$$

F. Traders rely on $DV01$ but asset managers rely on duration

1. Traders typically want to ensure that the dollar changes in the value of long and short positions offset each other
 - a. Because the size of their positions can fluctuate rapidly, they typically borrow money to buy the bonds
 - b. They tend to focus on dollar profit and loss rather than on returns on fixed amounts of invested cash
2. Asset managers typically invest in a slowly changing pool of funds and focus on rates of return
 - a. The duration of a portfolio is equal to the weighted sum of the durations of its component holdings
 - b. The weights are percentages of portfolio value

G. Because $DV01$ represents a change in price, while duration represents a percentage change in price

1. $DV01$ of a portfolio is the sum of its component $DV01$ s
2. The duration of a portfolio is the value-weighted sum of component durations

VI. Convexity

A. A curve has a convex shape if a line connecting two points on that curve lies above the curve

1. Price rate curves of coupon bonds are convex
2. The convex shape of the price rate curve explains why $DV01$ falls as rates increase

B. The relationship between $DV01$ and the level of rates is called convexity

1. If $DV01$ falls as rates increase, convexity is positive
2. If $DV01$ rises as rates increase, convexity is negative

C. Mathematically convexity is

$$C = \frac{1}{P} \frac{d^2P}{dy^2}$$

D. Convexity is the second derivative of the price rate function divided by price

1. Convexity values are not as easily interpreted as $DV01$ and duration values
2. A better approximation for price sensitivity uses both a bond's duration and convexity

$$\frac{\Delta P}{P} \approx -D\Delta y + \frac{1}{2}C \Delta y^2$$

3. Because the duration appears in the first term and convexity in the second
 - a. Using duration alone is called a first order approximation
 - b. Using both duration and convexity is a second order approximation
4. The approximation using both duration and convexity is close to the true price for larger changes in rates than the approximation using duration alone
5. The convexity of a portfolio equals
 - a. The weighted sum of the convexities of its component holdings
 - b. The weights are percentages of portfolio value

VII. Hedging a century bond: Part II

- A. The hedge of a century bond leaves the market maker with long convexity
- B. A market maker has a positive convex position and is long convexity because all interest rate changes occur instantaneously
 1. The convexity of the long position is greater than the convexity of the short position and
 2. Its profit and loss are positive whether interest rates rise or fall
- C. However, bonds that are more convex tend to earn less over time

VIII. Yield based $DV01$, duration and convexity

- A. Yield based metrics are those for which a change in rates means a fixed change in bond yields
- B. These metrics have two weaknesses
 1. They are defined only for bonds with fixed cash flows, but not a callable bond or a mortgage
 2. Their use implicitly assumes parallel shifts in bond yields which is not a sound assumption
- C. Important reasons to understand these metrics
 1. They are simple to compare, easy to understand and are reasonable under some circumstances
 2. They are widely used across the financial industry
 3. Much of the intuition gained from understanding these metrics carries over to more general frameworks
- D. Yield metrics are easy to compute because the price can be written as a function of yield for an annual coupon payment of c and the years to maturity of T

E. These equations can be written as

$$P = \frac{c}{2} \sum_{t=1}^{2T} \frac{1}{(1+\frac{y}{2})^t} + \frac{100}{(1+\frac{y}{2})^{2T}}$$

$$P = \frac{c}{y} \left[1 - \frac{1}{(1+\frac{y}{2})^{2T}} \right] + \frac{100}{(1+\frac{y}{2})^{2T}}$$

F. Yield based $DV01$ and duration

1. Yield based $DV01$ and duration can then be calculated explicitly by calculating the derivative of the price yield relationship and divide by negative 10,000 to find $DV01$ or by negative P to find duration
2. Yield $DV01$ is calculated by

$$DV01 = \frac{1}{10,000} \frac{1}{1+\frac{y}{2}} \left[\frac{c}{2} \sum_{t=1}^{2T} \frac{t}{2} \frac{1}{(1+\frac{y}{2})^t} + T \frac{100}{(1+\frac{y}{2})^{2T}} \right]$$

And can be rewritten as

$$DV01 = \frac{1}{10,000} \left[\frac{c}{y^2} \left(1 - \frac{1}{(1+\frac{y}{2})^{2T}} \right) + T \left(1 - \frac{c}{100y} \right) \frac{100}{(1+\frac{y}{2})^{2T+1}} \right]$$

3. Yield duration is calculated by

$$D = \frac{1}{P} \frac{1}{1+\frac{y}{2}} \left[\frac{c}{2} \sum_{t=1}^{2T} \frac{t}{2} \frac{1}{(1+\frac{y}{2})^t} + T \frac{100}{(1+\frac{y}{2})^{2T}} \right]$$

And can be rewritten as

$$D = \frac{1}{P} \left[\frac{c}{y^2} \left(1 - \frac{1}{(1+\frac{y}{2})^{2T}} \right) + T \left(1 - \frac{c}{100y} \right) \frac{100}{(1+\frac{y}{2})^{2T+1}} \right]$$

4. Yield based durations are also known in the industry as modified and adjusted duration
5. The sum of the terms in the brackets can be described as the weighted sum of the times at which cash flows are received, each with a weight equal to the present value of the cash flow received at that time
6. In the case of duration (where the bond price can be moved inside the brackets), each weight can be described as the present value of the cash flow received at that time divided by the bond price which is the sum of all the present values
7. For a zero-coupon bond, $DV01$ and duration are

$$DV01_{C=0} = T / (100(1 + \frac{y}{2})^{2T+1}) = \frac{T}{100 (1 + \frac{y}{2})^{2T+1}}$$

$$D_{C=0} = \frac{T}{1 + \frac{y}{2}}$$

8. For a par bond, DV01 and duration are

$$DV01_{C=100} = \frac{1}{100y} \left[1 - \frac{1}{\left(1 + \frac{y}{2}\right)^{2T}} \right]$$

$$D_{C=100y} = \frac{1}{y} \left[1 - \frac{1}{\left(1 + \frac{y}{2}\right)^{2T}} \right]$$

9. Bond duration

- a. The duration of the zero-coupon bond is approximately equal to its term
- b. The duration of a par bond increases with term but increases less than linearly with term
- c. The duration of a premium bond with a coupon is less than the duration of a par bond
- d. Bonds with higher coupons have lower durations because higher coupon bonds pay a greater fraction of their value earlier, which means lower terms are more heavily weighted in the calculation of duration

10. The DV01 increases with coupon

$$DV01 = \frac{P * D}{10,000}$$

11. There is a price effect in addition to duration effect

- a. The duration effects cause DV01 to increase with term
- b. The price effect can reinforce or counter this duration effect
 - a. Bonds at par have no price effect
 - b. For premium bonds, the price effect reinforces the duration effect forward and the bonds increase more rapidly with term than the DV01 for par bonds
 - c. For discount bonds, were those prices decreased with term, the price effect works against the duration effect and the DV01s of zero-coupon bonds increase more slowly with term than those of par bonds

12. Increasing yields lowers DV01 due to the convex shape of the price-yield curve

13. Increasing yields lowers duration because it lowers the present value of the longer payments the most, which lowers the proportion of bond value in the longer payments, lowers their weights in the duration calculation and lowers the duration of the bond

G. Convexity

1. The equation for yield-based convexity is found by taking the second derivative and dividing by price

$$C = \frac{1}{P(1+\frac{y}{2})^2} \left[\frac{c}{2} \sum_{t=1}^{2T} \frac{(\frac{t}{2})(t+.05)}{(1+\frac{y}{2})^2} + \frac{100T(T+.05)}{(1+\frac{y}{2})^{2T}} \right]$$

2. The terms inside the brackets multiply the present value of payments by function of the term of these payments
3. The major difference from the duration formula is that duration is linear and convexity is quadratic; this means convexity increases much faster with term than duration
4. Convexity for zero-coupon bonds is

$$C_{c=0} = \left[1 - \frac{T(T+.05)}{(1+\frac{y}{2})^2} \right]$$

5. Convexity for par bonds is

$$C_{c=y} = \frac{2}{y^2} \left[1 - \frac{1}{(1+\frac{y}{2})^2} \right] - \frac{2T}{y(1+\frac{y}{2})^{2T+1}}$$

- H. Yields are assumed to move up and down together in parallel, however, over a short period of time, the assumption of parallel shares may be sufficiently reasonable

IX. The barbell versus the bullet

- A. A pension plan will pay out benefits for 60 years
- B. The asset liability problem is to invest cash to cover pension liabilities over time
 1. Since discounting is done at the HQM corporate curve, the pension fund would break even by realizing returns equal to HQM rates
 2. If the pension fund earned lower rates, there would not be enough cash to meet pension obligations
 3. If the pension earned higher rates, then it would have more than enough cash to fulfill its pension obligations; however, there is a significant risk that the investments will perform poorly over the period and leave the pension without enough funds to meet its obligations
- C. Because pension funds make commitments in line with returns and corporate bonds, the pension funds tend to invest a significant portion of their assets in corporate bonds
- D. To hedge against the risk that interest rates will fall which would increase the present value of liabilities

- E. A pension fund can invest in an asset portfolio with a duration that matches its liabilities
1. The profit and loss of the bond is calculated as a shift in its yield, and the profit and loss of liabilities by parallel shifts in the HQM par rate curve
 2. The rates for all the values of both liabilities and the asset portfolio increase by the duration hedge because the duration hedge values of both increase by about the same amount for relatively small rate changes
 3. If liabilities have a higher convexity, the duration of liabilities increases more as rates decline; therefore, for large declines in rates, the increase in value of the liability is greater than the increase in the value of the assets which leaves the pension fund with a net loss in value
- F. A pension plan can manage the negative convexity by adjusting its hedge as rates change
1. As rates fall, the duration of liabilities increases more than the duration of the assets, the fund would increase its asset duration by borrowing more cash and buying more bonds
 2. As rates rise, the duration of the liabilities falls more than that of the assets, the fund could lower its asset duration and by selling bonds and paying off some of its borrowings
 3. This solution works in theory, but is costly with constant portfolio rebalancing
- G. An alternative is to design an asset portfolio to match the duration of the liabilities with convexity that is equal to or greater than that of the liabilities
1. Among portfolios with the same duration, the more spread out the cash flows of a portfolio, the greater its convexity
 2. A portfolio is called a bullet portfolio when the liability cash flows are spread over many years, but are hedged by a single bond with matching duration
 3. Barbell portfolios hedge liabilities using one bond with less duration than liabilities and one bond with more duration
- H. Matched duration portfolios with cash flows that are spread out have greater convexities because duration is roughly linear while convexity is quadratic; a portfolio with more spaced-out cash flows has the greater convexity
- I. The net profit and loss of liabilities under the bullet portfolio is negatively convex and loses value whether rates rise or fall; the barbell portfolio matches the duration and approximately matches the duration of liabilities which gives rise to a profit and loss that is very small over a wide range of rates
- J. A pension fund with a barbell portfolio does not need to rebalance its asset portfolio unless rates fall significantly

- K. Markets recognize the contribution of convexity to profit and loss as rates change, and therefore offer lower yields for highly convex portfolios
1. A portfolio with relatively low convexity and relatively high yield underperforms if rates change a lot, but outperforms if rates stay about the same
 2. By contrast a portfolio with a relatively high convexity and relatively low yield outperforms if rates change a lot, but underperforms if rates stay about the same
- L. The tradeoff between yield and convexity can have a concave shape meaning any line connecting two points on the curve is below the curve
- M. The convexity of the duration yield curve implies that the weighted average yield on portfolios with more spread out component bonds (more convex portfolios) is lower than the yield of bullet portfolios with less spread out (less convex) portfolios
- N. An asset manager must decide whether to trade yield for positive convexity
1. An asset portfolio, with a relatively low yield but convexity exceeding that of liabilities,
 - a. Does not have to be rebalanced often to avoid losses
 - b. Does relatively well when rates move a lot and
 - c. Does relatively poorly when rates do not move much
 2. An asset portfolio, with a relatively high yield but convexity less than that of liabilities,
 - a. Must be rebalanced often to avoid losses
 - b. Does relatively poorly when rates move a lot and
 - c. Does relatively well one rates do not move much

SECTION PEQ

Practice Exam 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.

START OF EXAM

50 Points -- 6 Questions

Question 1 (9 points)

An insurance company writes traditional life and annuity products in Canada. Investments are primarily government and corporate bonds and money market funds.

As the newly appointed chief risk officer of a small insurance company, you are concerned about both current and emerging risks. To become more comfortable with risks the company faces, you consider several options to identify risks.

- (a) (2 points) Describe the processes available to you.
- (b) (3 points) Select processes that are most appropriate to your situation
- (c) (4 points) After reviewing the actuarial literature for risk taxonomy, you find there are too many internal and external risks to consider, and the list must be pared down. Starting with the universe of risk taxonomy, create a checklist appropriate for the organization. Explain which risks should be included or excluded.

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SECTION PES

Solutions to Practice Exam Solutions

Question 1 Solution

Sources: Financial Enterprise Risk Management, ch. 8, 20
Quantitative Enterprise Risk Management, ch. 2

- (a) Possible techniques to gather risk information
- Ask existing personnel
 - Hold brainstorming sessions
 - Perform independent group analysis
 - Take surveys
 - Gap analysis
 - Delphi technique
 - Interviews
 - Use working groups
- (b) After considering all possible options, you choose two options—hold brainstorming sessions followed by discussions with two existing groups—the actuarial reserving group and the ALM group
- You consider these options because they can be implemented quickly at little cost to the organization
 - The other options are rejected because they take time to implement (surveys, Delphi technique, interviews) may be too limited or biased (ask existing personnel, independent group analysis, gap analysis)
- (c) Only operational risks (excluding legal and cyber risk for data breach, ransomware, denial of service attacks, process risks other than model risks) should be included in the brainstorming session because the remaining risks require expertise from other departments, broadens the brainstorming scope, and there is little action an actuary can take in these areas

For the actuarial reserving team, the following operational risks should be included

- People Risk (Behavioral Risk, People Process Risk)
- Cyber Risk (System or Provider Failure, Accidental Data Loss, Unidentified Bugs)
- Project Risks (Scope, Defect, Schedule, Resource Risks)
- Pricing Risk (Model Risk, Parameter Risk, Adverse Selection)
- Model Risk (Model Risk)
- Reputational Risk

For the ALM team, in addition to the risks considered by the actuarial reserving team, the following additional risks should be included

- Interest Rate Risk
- Credit Risk (Market, Sovereign, Default, Concentration Risks)
- Spread Risk
- Systemic Risk
- Liquidity Risk (Market Liquidity Risk, Funding Liquidity Risk)
- Macroeconomic Risks (Business Cycles, Inflation)