UNIT 11.6- MARKET RISK MEASUREMENT

Market risk management framework is heavily dependent upon quantitative measures of risk. The market risk measures seek to capture variations in market value arising out of uncertainties associated with various risk elements. These provide an objective measure of market risk in a transaction or of a portfolio. **Market risk measures** are based on –

- **Sensitivity**
- **Downside Potential**

A. **Sensitivity**

Sensitivity captures deviation of market price due to unit movement of a single market parameter. Supply-demand position, interest rate, market liquidity, inflation, exchange rate, stock prices, etc., are the market parameters, which drive market values.
For example, change in interest rate would drive the market value of bonds and forward foreign exchange held in a portfolio. If liquidity in the market increases that may result in increased demand that in turn may increase market price.
Sensitivity is measured as change in market value due to unit change in the variable.
For example, where market value of a portfolio changes by Rs 100,000 for 1% change in rate of interest, interest rate sensitivity of the portfolio is Rs 100,000. This gives us a measure of risk associated with the portfolio vis-a-vis change in rate of interest.
This measure suffers from the fact that it does not consider impact of other parameters, which may also change simultaneously. Secondly, the measure does not remain constant for all the values of the variable. Say, the interest rate sensitivity of a bond is Rs 100 when the yield on the bond is 5%. If the yield on the bond rises to 8%, its interest rate sensitivity would not remain at Rs 100.
Nevertheless, *sensitivity is relied upon as a measure,* particularly those that are based on changes in interest rates. Two of them, *Basis Point Value (BPV)* and *Duration* used quite frequently, are discussed below.

1. Basis Point Value (BPV)
It is the change in value due to 1 basis point (0.01%) change in market yield. This is used as a measure of risk. ***The higher the BPV of a bond, higher is the risk associated with the bond. Computation of BPV is quite simple.***
For example, a 5 year 6% semi-annual bond @ market yield of 8%, has a price of Rs 92, which rises to Rs 92.10 at a yield of 7.95%. So, for one BP fall in yield, market price changes by Rs 0.02 or gains by Rs 2,000 per Rs 1 crore face value. BPV of the bond is, therefore, Rs 2,000 per crore face value.
This also helps us to quickly calculate profit or loss for a given change of yield. If the yield on a bond with BPV of 2,000 declines by 8 BPs, then that would result in a profit of 8 X 2000 = Rs 16,000 per crore of face value. If one is holding Rs 10,00,000 face value of this bond, he makes a profit of Rs 1,600.

BPV changes with remaining maturity. Suppose the bond described above has 5 years to mature and present BPV is 2000, the BPV will decline with time and on the day of maturity it will be zero.

2. Duration

McCauley's Duration was first proposed by ***Frederick McCauley*** in 1938 *as a means of describing a bond's price sensitivity to yield change with a single number* This is equivalent to time, on average, that the holder of the bond must wait to receive the present value of the cash flows. In other words, this represents cash flow 'Centre of Gravity'. It implies that if a five-year 6% bond face value of Rs 100 with semi-annual interest has McCauley's duration say 3.7 years, then total cash flow to be received over the five year period of Rs 130 from the bond would be equivalent to receiving Rs 130 at the end of 3.7 years as a bullet payment. Duration or Modified duration is McCauley's duration discounted by 1 period yield to maturity.

The longer the duration of a security, the greater will be the price sensitivity to yield changes and higher would be the risk associated with the bond.

Bond price changes can be estimated using modified duration using the following relationship.

Approx % change in price = - modified duration X yield change

McCauley Duration

WHAT IT IS:

The Macaulay duration **(named after Frederick Macaulay, an economist who developed the concept in 1938) is a measure of a bond's sensitivity to interest rate changes. Technically, duration is the weighted average number of years the investor must hold a bond until the present value of the bond's cash flows equals the amount paid for the bond.**

HOW IT WORKS (EXAMPLE):

There is more than one way to calculate duration, but the Macaulay duration is the most common. The formula is:

$$\text{Macaulay duration} = \frac{\sum_{t=1}^{n} \frac{tC}{(1+y)^t} + \frac{nM}{(1+y)^n}}{P}$$

where:

t = period in which the coupon is received
C = periodic (usually semiannual) coupon payment
y = the periodic yield to maturity or required yield
n = number periods
M = maturity value (in $)
P = market price of bond

The formula is complicated, but it boils down to:

Duration = Present value of a bond's cash flows, weighted by length of time to receipt/ bond's current market value.

For example, let's calculate the duration of a three-year $1,000 Company XYZ bond with a semi-annual 10% coupon.

Period	Cash Flow	Period x Cash Flow	PV of $1 at 5%	Present Value of the Cash Flow
1	$50	$50	0.95238	$47.62
2	$50	$100	0.90703	$90.70
3	$50	$150	0.86384	$129.58
4	$50	$200	0.82270	$164.54
5	$50	$250	0.78353	$195.88
6	$1,050	$6,300	0.74622	$4,701.16
			1.00000	
Total				$5,329.48

Notice in the table above that we first multiplied the cash flows by the periods in which they occurred and then calculated the present value of each of these weighted cash flows.

To ***calculate the Macaulay duration, we then divide the sum of the present values of these cash flows by the current bond price*** (which we are assuming is $1,000):

Company XYZ Macaulay duration = $5,329.48 / $1,000 = 5.33

Duration can help investors understand how sensitive a bond is to changes in prevailing interest rates. By multiplying a bond's duration by the change, the investor can estimate the percentage price change for the bond. For example, consider the Company XYZ bonds with a duration of 5.33 years. If for whatever reason market yields increased by 20 basis points (0.20%), the approximate percentage change in the XYZ bond's price would be:

-5.33 x .002 = -0.01066 or -1.066%

Note that this is an approximation. The formula assumes a linear relationship between bond prices and yields (that is, they always change by the same degree) even though the relationship is actually convex (meaning that when one changes, the other changes but to varying degrees). Thus, the formula is less reliable when there is a large change in yield.

- In general, six things affect a bond's duration:
- **Bond's Price:** Note that if the bond in the above example were trading at $900 today, then the duration would be $5,329.48 / $900 = 5.92. If the bond were trading at $1,200 today, then the duration would be $5,329.48 / $1,200 = 4.44.
- **Coupon:** The higher a bond's coupon, the more income it produces early on and thus the shorter its duration. The lower the coupon, the longer the duration (and volatility).

Zero-coupon bonds, which have only one cash flow, have durations equal to their maturities.

- **Maturity:** The longer a bond's maturity, the greater its duration (and volatility). Duration changes every time a bond makes a coupon payment. Over time, it shortens as the bond nears maturity.
- **Yield to Maturity**: The higher a bond's yield to maturity, the shorter its duration because the present value of the distant cash flows (which have the heaviest weighting) become overshadowed by the value of the nearer payments.
- **Sinking Fund:** The presence of a sinking fund, which is a scheduled prepayment of the bond before it matures, lowers a bond's duration because the extra cash flows in the early years are greater than those of a bond without a sinking fund.
- **Call Provision:** Bonds with call provisions also have shorter durations because the principal is repaid earlier than a similar non-callable bond.

WHY IT MATTERS

The greater duration of the bond, the greater its percentage price volatility.

By providing a way to estimate the effect of certain market changes on a bond's price, the *investor can choose investments that will better meet his future cash needs.* Macaulay duration also helps *income investors who want to take on minimal interest rate risk (that is, they believe interest rates might fall) understand why they should consider bonds with high coupon payments and shorter maturities*.

Definition of 'Modified Duration'

The term modified duration is based on the concept that security prices and interest rates are inversely related.

Definition: The term modified duration is based on the concept that security prices and interest rates are inversely related. It measures the sensitivity of bond price to the interest rates.

Description: Following is the formula used for calculating the same:

$$\text{Modified Duration} = \left[\frac{\text{Macauley Duration}}{\left(1 + \frac{\text{YTM}}{n}\right)} \right]$$

where,

n = number of coupon periods per year

YTM = the bond's yield to maturity

Following is the formula to calculate the Macaulay Duration:

Macaulay Duration:

$$MacD = \sum_{i=1}^{n} t_i \frac{CF_i \cdot e^{-y \cdot t_i}}{V}$$

PVi is the present value of the *i*th cash payment from an asset.

CFi is the cash flow of the *i*th payment from an asset.

y is the yield to maturity (continuously-compounded) for an asset.

ti is the time in years until the *i*th payment will be received.

V is the present value of all cash payments from the asset until maturity. This formula is used to ascertain the effect of 1% change in interest rates on the price of security.

B Downside Potential

Risk materializes only when earnings deviate adversely. *Downside potential only captures possible losses ignoring profit potential.* Downside risk is the most comprehensive measure of risk as it integrates sensitivity and volatility with the adverse effect of uncertainty. ***This is the measure that is most relied upon by banking and financial service industry as also the regulators.***

Value at Risk (VaR)

Management of market risk is concerned with the question - How much can we lose? The answer to it is that there is a possibility that we can lose everything, although it may have a very low probability. VaR attempts to create a more useful answer by altering the question - How much can we expect to lose? Or, what is the loss potential? The answer could be that we can lose a maximum of Rs X (the VaR) over the next week (time horizon) and may expect that with 99% confidence (i.e., it would be so 99 times out of 100).

VaR is defined as the predicted worst-case loss at a specific confidence level over a certain period of time assuming 'Normal Trading Conditions'.
A bank having 1 day VaR of Rs 10 crore with 99% confidence interval means that there is only one chance in 100 (or 2.5 days per year based on 250 working days in a year) that daily

loss will be more than 10 crore under normal trading conditions. This also means that there is 1% chance that the daily loss may exceed Rs 10 crore under normal trading conditions. It does not estimate losses in abnormal situations.

VaR measures the potential loss in market value under normal circumstances of a portfolio using estimated volatility (rate or price move) and correlations (how rates or prices move in relation to each other), for a given horizon (longer the time horizon, more is the VaR) measured with a given confidence interval. In calculating VaR we consider the volatility of prices and correlation of prices with respect to all other assets/liabilities in the portfolio. Normal circumstances refer to the fact that VaR is not a measure when market is under abnormal conditions.

Yield Vs Price Volatility

Yield volatility is degree of variance in yield. This is largely unaffected by time and duration. *It rises as yields fall*.

Price volatility is degree of variance in price. This is largely unaffected by yield and substantially affected by time and duration.

Price Volatility = (Yield volatility X BPV X Yield)/Price

Three main approaches to calculating value-at-risk:
1. The correlation method, also known as the variance/covariance matrix method
2. Historical simulation
3. Monte Carlo simulation

All three methods are based on three basic parameters - *holding period, confidence interval and the historical time horizon* over which the asset prices are observed.

Under the ***correlation method, the change in the value of the position is calculated by combining the sensitivity of each component to price changes in the underlying asset(s), with a variance/covariance matrix of the various components' volatilities and correlation.*** It is a deterministic approach.

The ***historical simulation approach calculates the change in the value of a position using theactual historical movements of the underlying asset(s), but starting from the current value of the asset.*** It does not need a variance/covariance matrix. The *length of the historical period chosen does impact the results* because if the period is too short, it may not capture the full variety of events and relationships between the various assets and within each asset class, and if it is too long, may be too stale to predict the future. *The advantage of this method is that it does not require the user to make any explicit assumptions about correlations and the dynamics of the risk factors because the simulation follows every historical move*.

Monte Cario simulation method calculates the change in the value of a portfolio using a

sample of randomly generated price scenarios. Here the user has to make certain assumptions about market structures, correlations between risk factors and the volatility of these factors. He is essentially imposing his views and experience as opposed to the naive approach of the historical simulation method.

At the heart of all three methods is the model. The closer the models fit economic reality, the more accurate the estimated VaR numbers and therefore the better they will be at predicting the True VaR of the firm. There is no guarantee that the numbers returned by each VaR method will be anywhere near each other.

Why VaR is Useful?
1. Good tool for all banks, financial institutions, multinationals, fund managers for protection of customers, shareholders, employees and overall franchise of the business
2. Translates portfolio exposures into potential P and L impact
3. Aggregates and reports multi-product, multi-market exposures into one number
4. Meets external risk management disclosure and expectations
5. A vital component of current best practices in risk measurement
6. Embraced by practitioners, regulators and academics
7. Valuable as a probabilistic measure of potential losses

Limitation of VaR
VaR *is not worst-case scenario*. It *does not measure losses* under any particular market conditions. VaR by itself- *is not sufficient for risk measurement*. ***Measures to get over the limitation*** include ***back testing, model calibration, scenario analysis and stress testing.***

Role of VaR in Control and Monitoring - VaR is used as a
-***MIS tool in the trading portfolio*** 'slice and dice' risk by levels/ products/geographic/level of organisation, etc.
- ***to set risk limits***
- ***for decisions as to what business to do and what not to do***.

VaR as a useful MIS tool has to be 'back tested' by comparing each day's VaR with accruals and necessary re-examination of assumptions needs to be made so as to be close to reality. VaR, therefore, cannot substitute sound management judgment, internal control and other complementary methods. It is used to measure and manage market risks in trading portfolio and investment portfolio.

Estimating Volatility
VaR uses past data to compute volatility. Different methods are employed to estimate volatility.
-One is arithmetic moving average from historical time series data.
-The other is the exponential moving average method. In the exponential moving average method, the volatility estimates rises faster to shocks and declines gradually.
-Different banks take different number of days of past data to estimate volatility. Volatility also does not capture unexpected events or "event risk". All these complicate the estimation

of volatility. ***VaR, therefore, should be used in combination with "stress tests"*** to take care of event risks. Stress test takes into account the worst-case scenario.

Back Testing

It is a process where model based VaR is compared with the actual performance of the portfolio. This is carried out for evaluating a new model or to assess the accuracy of existing models. Back testing for evaluating a new model requires comparison with actual performance on a continuous basis for a given period.
Assessment of accuracy of an existing model needs back test on a regular basis. Banks should generally back test risk models on a monthly or quarterly basis to verify accuracy. In these tests, they should observe whether trading results fall within pre-specified confidence bands as predicted by the VaR models. If the models perform poorly, they should probe further to find the cause (e.g., check integrity of position and market data, model parameters, methodology).

Stress Testing
Market value of a portfolio varies due to movement of market parameters such as interest rate, market liquidity, inflation, exchange rate, stock prices, etc. Movement in market parameters, on a day-to-day basis causes the change in the market value of the portfolio. This represents the normal risk that is associated with normal day-to-day movements. There remains the risk of large non-normal movement in market parameters that signifies abnormal market conditions. Risks arising due to such movements fall beyond the day-to-day risk monitoring but that could potentially occur.
Stress testing essentially seeks to determine possible changes in the market value of a portfolio that could arise due to non-normal movement in one or more market parameters.
The process involves *identifying market parameters* to stress, *the quantum of stress and determine the time frame*
Market value of a portfolio varies with Stress Testing Techniques.The four Stress testing techniques discussed here are listed here:
1. Simple Sensitivity Test
2. Scenario Analysis
3. Maximum Loss
4. Extreme Value Theory
Simple Sensitivity Test
A simple sensitivity test isolates the short-term impact on a portfolio's value of a series of predefined moves in a particular market risk factor For example, if the risk factor is exchange rate, the shocks may be exchange rate changes of+/-2%, 4%, 6% and 10%.
Scenario Analysis
A scenario analysis specifies the shocks that might plausibly affect a number of market risk factors simultaneously if an extreme, but possible, event occurs. It seeks to assess the potential consequences for a firm of an extreme, but possible, state of the world. A scenario analysis can be based on an historical event or a hypothetical event. Historical scenarios employ shocks that occurred in specific historical episodes. Hypothetical scenarios use a

structure of shocks thought to be plausible in some foreseeable, but unlikely circumstances for which there is no exact parallel in recent history. ***Scenario analysis is currently the leading stress testing technique.***

Maximum Loss

A maximum loss approach assesses the risks of a portfolio by identifying the most potentially damaging combination of moves of market risk factors. Risk managers who use such 'maximum loss' approaches find the output of such exercises to be instructive but they tend not to rely on the results of such exercises in the setting of exposure limits in any systematic manner, an implicit recognition of the arbitrary character of the combination of shocks captured by such a measure.

Extreme Value Theory

Extreme value ***theory is a means to better capture the risk of loss in extreme but possible circumstances.*** EVT is the statistical theory on the behaviour of the 'tails' (i.e., the very high and low potential values) of probability distributions. Because it focuses only on the tail of a probability distribution, the method can be more flexible. For example, it can accommodate skewed and fat-tailed distributions. A problem with the extreme value approach is adapting it to a situation where many risk factors drive the underlying return distribution. Moreover, the usually unstated assumption that extreme events are not correlated through time is questionable. Despite these drawbacks, ***EVT is notable for being the only stress test technique that attempts to attach a probability to stress test results.***

Good Stress Test - A good stress test should -

• Be relevant to the current position
• Consider changes in all relevant market rates
• Examine potential regime shifts (whether the current risk parameters will hold or breakdown)
• Consider market illiquidity
• Consider the interplay of market and credit risk

It should help the management to be forward looking in managing disasters mooted by market factors.

How Should Risk Managers Use Stress Test

The ***role*** of risk managers in the bank ***should be assembling and summarising information*** *to enable senior management to understand the strategic relationship between the firm's risk-taking (such as the extent and character of financial leverage employed) and risk appetite.*

Specific ways stress tests used to influence decision-making are to:

-Manage funding risk
-Provide a check on modelling assumptions
-Set limits for traders
-Determine capital charges on trading desks' positions

Limitations of Stress Tests

Stress testing can appear to be a straightforward technique. In practice, however, *stress tests are often neither transparent nor straightforward.* They are based on large number of

practitioner choices as to what risk factors to stress, how to combine factors under stress, what range of values to consider, and what time frame to analyse. Even after such choices are made*, a risk manager is faced with the considerable tasks of sifting through results and identifying what implications, if any, the stress test results might have* for how the bank should manage its risk taking activities.
There are no probabilities attached to the outcomes. Stress tests help answer the question "How much could be lost?" The *lack of probability measures* exacerbates the issue of transparency and the seeming arbitrariness of stress test design. *Systems incompatibilities across business units make frequent stress testing costly for some banks.*

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