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Using Principal Components Analysis to Model Interest Rate Moves and Measure Delta Exposure: A Comprehensive Breakdown of a Lebanese Commercial Bank's Portfolio

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Abstract

This paper quantifies exposure to all the possible ways the Lebanese yield curve changed since 2006. It studies the interest rate risk impact on a portfolio consisting of interest-rate depending assets belonging to a Lebanese commercial bank using principal components analysis or risk decomposition strategy. TBs monthly yields are used with five different maturities since 2006. Deltas for the portfolio are calculated using partial duration and the DV01. The first factor identified corresponds to a parallel shift in the yield curve and the second to a change of slope of the yield curve. Both factors account for 95% of the variance. Delta exposure calculations showed absence of hedging against these shifts.

JEL classification numbers: C10, C18
Keywords: Interest Rate Risk; Lebanese banks; Delta Exposure; Delta Hedging; Principal Components Analysis; Risk Management; Partial Duration

1 Introduction

Risk management is now a must for all corporations and particularly for financial institutions. They have no choice but to increase the resources they allocate to risk management. "Subprime" losses at banks would have been avoided if risk management techniques had been properly implemented to detect the unacceptable level of risks taken and accurately take the right decisions to minimize the total risk they have faced. Regulators have refined their requirements in order to avoid bankruptcy - that arises from

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incurred losses - and bankruptcy costs and recently most financial institutions are heavily regulated. Throughout the world, and after the large bail-outs of financial institutions in 2008, governments seek financial stability. Financial stability involves confidence in financial institutions. In other words, regulators want to ensure that capital held by a bank is sufficient to provide a cushion to absorb the losses with a high probability (Basel Committee on Banking Supervision, July 2009 [1], and December 2010 [2]). They are in fact concerned with total risks. Two approaches to risk management are open to financial institutions to manage market risk: risk decomposition and risk aggregation.

The purpose of this paper is to use the risk decomposition strategy in order to study the interest rate risk impact on a portfolio consisting of interest-rate depending assets belonging to a Lebanese commercial bank, classified as "Alpha[2]" bank. Factors affecting the interest rate moves are identified. Zero-coupon yield curve are used to consider both parallel and nonparallel shifts. The paper implements the principal components analysis to handle the risk arising from highly correlated variables. TBs monthly yields[3] are used with five different maturities since 2006. Given that there is a complete absence of academic work dealing with delta exposures of the Lebanese banks' portfolios, this paper serves as a guide for the implementation of delta exposure using the principal components analysis.

The paper proceeds as follow: Section 2 presents a panoramic review of managing market risk techniques through delta, gamma and vega. It also covers the VaR technique together with the three methods of estimating the VaR. The portfolio structure together with the model implementation using the principal components analysis and delta exposure calculation are evaluated and analyzed in section 3. Assessment of the importance of the different yield curve shifts is also depicted in section 3. The paper then concludes the empirical findings.

2 Review on Market Risk and Market Risk Management

Market risk is the uncertainty of cash flows and potential for loss associated with movements in an underlying source of risk such as interest rates, foreign exchange rates, stock prices, or commodity prices. When analyzing interest rate risk, there is the risk of short-, intermediate-, and long-term interest rates. Within short-term interest rate risk, there is the risk of LIBOR changing, the risk of the Treasury bill rate changing, the risk of the commercial paper rate changing and many other risks associated with specific interest rates [3]. The extent to which those rates are correlated must be considered by risk managers. The effect of changes in the underlying source of risk will be reflected in movements in the values of spot derivative positions. Delta, Gamma and Vega are all risk measures equally applicable to many instruments in addition to options and stocks. They are some of the tools used by risk managers to control market risk [4].

Delta hedging consists of making the portfolio be unaffected by small movements in interest rates. Delta calculation is needed by taking the mathematical first derivatives of

[2]An Alpha bank is classified among the top ten banks in Lebanon in terms of total assets and liabilities.

[3]It is quite impossible to obtain time series data due to the lack of transparency and data availability.

the swap or option value with respect to interest rates. Therefore a delta-hedged position is one in which the combined spot and derivatives positions have a delta of zero. The portfolio would then have no gain or loss in value from a small change in the underlying source of risk. Larger movements, however, can bring about additional risk not captured by delta. This requires a Gamma[4] hedge by combining transactions so that the delta and gamma are both zero. The portfolio would then have no gain or loss in value from a small change in the underlying source of risk. Moreover, the delta itself would be hedged, which provides protection against larger changes in the source of risk [5]. Unfortunately the use of options introduces a risk associated with possible changes in volatility. This risk is hedged by Vega[5]. A portfolio of derivatives that is both Delta and Gamma hedged can incur a gain or loss even when there is no change in the underlying as a result of a change in the volatility.

In spite of a dealer's efforts at achieving a delta-gamma-vega neutral position, it is impossible to achieve an absolute perfect hedge. The vega hedge is accurate only for extremely small changes in volatility. Large changes would require yet another adjustment. In addition, all deltas, gammas, and vegas are only valid over the next instant in time. Rarely will the end user engage in the type of dynamic hedging of delta-gamma-vega neutral position. In fact the end is not typically a financial institution like the dealer. Financial institutions can nearly always execute transactions at lower cost and can afford the investment in expensive personnel, equipment, and software necessary to do dynamic hedging. Most end users enter into derivatives that require little or no adjustments. However, many suffered losses from being unhedged at the wrong time or from outright speculating. Most end users could have obtained a better understanding about the magnitude of their risk and the potential for large losses had they applied the Value at Risk, VaR [6&7].

VaR is widely used by dealers, even though their hedging programs nearly always leave them with the little exposure to the market. The basic idea behind VaR is to determine the probability distribution of the underlying source of risk and to isolate the worst given percentage of outcomes. Loosely, VaR summarizes the worst loss over a target horizon that will not be exceeded with a given confidence level. Using 5% as the critical percentage, VaR will determine the 5% of outcomes that are the worst. The performance at the 5% mark is the VaR. There are three methods of estimating the VaR [8].

The analytical method, also called the variance-covariance method, makes use of knowledge of the input values and any necessary pricing models along with an assumption of a normal distribution. In other words, it uses knowledge of the parameters of the probability distribution of the underlying sources of risk at the portfolio level. Since the expected value and variance are the only two parameters used, the method implicitly is based on the assumption of normal distribution. If the portfolio contains options, this assumption is no longer valid because option returns are highly skewed and the expected return and variance of an option position will not accurately produce the wished result. In

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[4]Using the Black-Scholes-Merton Model: $\text{Call Gamma} = \dfrac{e^{-d_1^2/2}}{S_0\sigma\sqrt{2\pi T}}$

[5]Using the Black-Scholes-Merton Model: $\text{Call vega} = \dfrac{S_0\sqrt{T}e^{-d_1^2/2}}{\sqrt{2\pi}}$

this case, another alternative is used and employs the delta rather than the precise option pricing model to determine the option outcome. This is called the delta normal method and is only approximate. It linearizes the option distribution by converting the option's distribution to a normal distribution. This is useful when a large portfolio is concerned. For long periods, the delta adjustment is sometimes supplemented with a gamma adjustment [9].

Secondly, the historical method estimates the distribution of the portfolio's performance by collecting data on the past performance of the portfolio and using it to estimate the future probability distribution. It assumes that the past distribution is a good estimate of the future distribution. Obviously it matters greatly whether the probability distribution of the past is repeated in the future. Also the portfolio held in the future might differ from the one held in the past. Another problem is that the historical period may be badly representative of the future.

Monte Carlo Simulation Method combines many of the best properties of the previous two methods. It is the most widely used method by sophisticated firms. It generates random outcomes based on an assumed probability distribution to obtain the VaR. Portfolio returns can be easily simulated. This requires inputs on the expected returns, standard deviations, and correlations for each financial instrument. It is a flexible method since it allows the analyst to assume any known probability distribution and can handle complex portfolios. It is also the most demanding method in terms of computer requirements and the most efficient among risk management techniques.

In this paper, we will focus on following the risk decomposition strategy to measure the interest rate risk of an interest-rate dependant asset portfolio of a Lebanese commercial bank using principal component analysis.

3 Principal Components Analysis and Delta Exposure

3.1 Data, Sample Selection, and Partial Duration

The selected portfolio, belonging to a Lebanese commercial bank rated among the top 10% in terms of total assets among all the operating commercial banks in Lebanon, consists of long positions in interest-rate dependent assets and is worth USD 10 million. We considered the monthly changes of the Lebanese TBs with maturities of 3 months, 6 months, 1 year, 2 years and 3 years from January 2006 up to June 2014. Table 1 depicts the summary statistics of these rates during the mentioned period.

Table 1: Summary Statistics for the Lebanese TBs for the Period Jan 2006 through June 2014

	3 Months	6 Months	1 Year	2 Years	3 Years
Mean	4.6575	5.873	6.249	6.974	7.964
Variance	0.2530	1.352	1.546	1.944	2.163
Std. Dev.	0.5030	1.163	1.243	1.394	1.471
Skewness	-0.1670	0.1441	0.2099	0.2353	-0.1915
Median	4.4400	5.230	5.400	5.930	8.850
Mode	5.2200	7.240	7.750	8.680	9.540
Minimum	3.8900	4.430	4.790	5.410	5.970
Maximum	5.2200	7.240	7.750	8.680	9.560
Range	1.3300	2.810	2.960	3.270	3.590
1st Quartile	4.4300	4.990	5.350	5.930	6.610
3rd Quartile	5.2200	7.240	7.750	8.680	9.540

Table 2 depicts the partial duration of the portfolio. The partial duration calculation is based on the selected zero-coupon yield curve for the chosen maturities based on the median corresponding percentages and a 1% change for each point on the zero curve. Rates on the shifted curve are calculated using linear interpolation.

Table 2: Partial Duration for the Portfolio

Maturities	3 Months	6 Months	1Year	2 Years	3 Years	Total
Duration (D_i)	0.1	0.12	0.2	0.6	1.2	2.22

Where $D_i = -\frac{1}{P}\frac{\Delta P_i}{\Delta y_i}$

3.2 Deltas for the Portfolio using DV01

Analysts usually calculate several deltas to reflect their exposures to all the different ways in which the yield curve can move. We will compute the impact of a one-basis-point change for each point on the yield curve. A measure related to this delta is DV01. This delta is the partial duration multiplied by the value of the portfolio multiplied by 0.0001 as shown in table 3.

Table 3: Deltas for the Portfolio

Maturities	3 Months	6 Months	1Year	2 Years	3 Years
Delta	100	120	200	600	1200

Unfortunately, the Lebanese banks do not use interest rate deltas to hedge their portfolios despite the simple structure of those portfolios. Some banks divide the yield curve into a number of segments to calculate the impact of changing the zero rates corresponding to each segment by one basis point while keeping all other zero rates constant.

3.3 Deltas for the Portfolio using Principal Component Analysis

Principal Component Analysis is a standard tool with many applications in risk management. It takes historical data on changes in the market variables and attempts to define a set of factors that explain the movements. The aim is to replace the five variables by a smaller number of uncorrelated variables. The market variables we will consider are the TB rates with the above defined maturities. We first calculated a covariance matrix from the data. This is an *5x 5* matrix where *(i,j)* entry is the covariance between variable *i* and variable *j*. We then calculated the eigenvectors and eigenvalues for this matrix. The eigenvectors are chosen to have length 1. The eigenvector corresponding to the highest eigenvalue is the first principal component.

The interest rate move for a particular factor is the factor loading. Factor loadings have the property that the sum of their squares for each factor is 1.0. The interest rate changes observed on any month is expressed as a linear sum of the factors by solving a set of five simultaneous equations. The first factor, PC1, in table 4 corresponds to a parallel shift in the yield curve. One unit of that factor makes the 3-month rate increase by 0.352 basis points, the 6-month rate increase by 0.542 basis points, the one, two and three-year rates by 0.517, 0.529, and 0.181 basis points respectively. The second factor corresponds to a change of slope of the yield curve. Rates between 3 months and 1 year move in one direction, the remaining move in the other direction. The third factor is obviously not significant. This is shown by the standard deviation of its factor score. The standard deviations of the factor scores are shown in table 5 and the factors are listed in order of their importance. It can be seen that the first factor accounts for 57.46% of the variance[6] in the original data and the first two factors account for 95% of the variance.

Table 4: Eigenvector Factor Loadings[7] for TBs Data

	PC1	PC2	PC3	PC4	PC5
3 Months	0.352673	-0.07694	-0.69177	0.618004	-0.09606
6 Months	0.542451	-0.0717	-0.37647	-0.7464	-0.0419
1 Year	0.517475	-0.10497	0.513261	0.164123	-0.65637
2 Years	0.529925	-0.10865	0.340836	0.181715	0.747118
3 Years	0.181022	0.982911	0.010877	0.03154	0.001911

In other words, a quantity of the first factor equal to one standard deviation corresponds to the 3-month rate moving by 5.66[8] basis points. Same analysis is applied to the remaining variables. Table 6 illustrates those moves for the first two factors. It is worth mentioning that the factor scores are uncorrelated across the data: the parallel shift is uncorrelated with the change of the slope of the yield curve.

[6]Which is 449.23

[7]A factor is not changed if the signs of all its factor loadings are reversed.

[8]0.352*16.066 = 5.65 bp.

Table 5: Standard Deviation of Factor Scores[9]

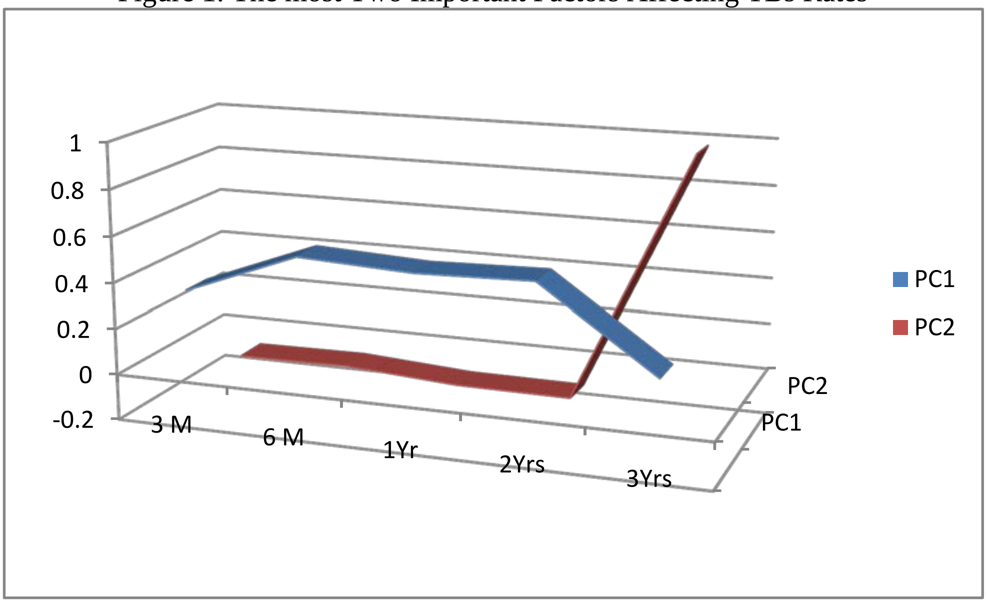
PC1	PC2	PC3	PC4	PC5
16.066	12.986	3.2856	2.6711	2.1212

Table 6: TBs rate Moves

In basis points	PC1	PC2
3 Months	5.666044	-0.99914
6 Months	8.715018	-0.9311
1 Year	8.313753	-1.36314
2 Years	8.513775	-1.41093
3 Years	2.908299	12.76408

We conclude that most of the risk in interest rate moves is accounted for by the first two factors (figure 1) and that we can solely relate the risks in this Lebanese portfolio to movements in these factors instead of all five rates.

Figure 1: The most Two Important Factors Affecting TBs Rates



4 Discussion and Conclusion

The advantage of using principal components analysis is that it indicates the most appropriate shifts to consider while providing information on the relative importance of these shifts [10]. Also, it gives an alternative way of calculating deltas. After measuring a one-basis-point change in the five different maturities of the portfolio, it becomes

[9]The square root of the i^{th} eigenvalue is the standard deviation of the i^{th} factor score.

straightforward to use the first two significant factors to model rate moves and calculate the delta exposure of the portfolio. Therefore, delta exposure to each of the selected factors can be measured in dollars per unit of the factor with the factor loading being assumed to be in basis points[10]. Both deltas are positive and greater than one and consequently the portfolio lacks all hedging plans and strategies. Despite the limitations of this study regarding the absence of daily data and the absence of transparency as to the hedging strategies, we were able to quantify in a detailed manner the exposure to all the possible ways the Lebanese yield curve changed since 2006. This constitutes an absolute added value to the very limited existing academic work covering risk management in Lebanon.

There is a lot to be done for Lebanon in the area of risk management. So far what has been discussed in this paper has been of an analytical and quantitative nature. However, the Lebanese banks did not yet recognize that there is a great deal to know about risk management that is not based on words and wishes. We are not sure if the Lebanese banks' infrastructure is conductive to the practice of risk management. All of the quantitative models and analytical knowledge would be wasted if banks cannot implement sound risk management. Risk management is effective only if people apply these techniques in a truthful and responsible manner with the required controls. We are not sure how far the Lebanese banks are accurately practicing risk management.

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[10]For instance, Delta Exposure to Factor 1 (PC1) = $\sum_{i=1}^{5} \Delta_i x PC1_i$ where Δ_i represents the change in the portfolio value for a 1-bp move for each of the five maturities, and $PC1_i$ are the factor loading values per maturity and in bp.