Quarterly Review
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PIMCO

Risk Measurement at PIMCO

In June of 1998, we wrote "Measuring Risk in Bond Portfolios – A Primer" to describe the important portfolio level risk metrics that PIMCO had developed to measure and control risk in client portfolios. In that paper we advocated separate measurement of the many risk factors impacting bond portfolios, rather than the increasingly popular single measure approaches such as VAR or tracking error. The ensuing months proved turbulent as Russia defaulted and triggered extreme dislocation in global bond markets. Correlations of most spread product soared, and players who invested on the assumption that history would eventually repeat itself experienced trouble, Long Term Capital being the most notorious. The robustness of PIMCO's risk metrics enabled us to endure that and subsequent volatile periods relatively unscathed. Since risk measurement is a continually evolving field, we would like to take this opportunity to update you on our efforts.

Vineer Bhansali is the new head of domestic analytics at PIMCO. He joined us early in 2000 to assume many of Pasi Hamalainen's responsibilities, in anticipation of Pasi's move to Munich to head up portfolio management there. Vineer is an Executive Vice President of PIMCO and a senior member of PIMCO's portfolio management group. He was previously associated with Credit Suisse First Boston, where he was Vice President of proprietary fixed-income trading. Prior to that, he was a proprietary trader for the Salomon Brothers arbitrage desk in New York and worked in the global derivatives group at Citibank. He is the author of numerous scientific and financial papers, and is the author of the book *Pricing and Managing Exotic and Hybrid Options* published by McGraw-Hill in 1998. He currently serves as an associate editor for the *International Journal of Theoretical and Applied Finance*. Vineer has ten years of investment experience, and holds a bachelor's and master's degree in physics from the California Institute of Technology, and a Ph.D. in theoretical particle physics from Harvard University.

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Individual Security Level Valuation and Risk Measurement Models

All portfolio level risk measures are simply an aggregation of the risks of each individual security held in a portfolio. Therefore, accurate portfolio level risk measurement depends on accurate individual security risk measurement. PIMCO has developed a library of proprietary models to value and measure risks in virtually every fixed income security type including:

- Government Bonds (both domestic and international)
- Corporate Bonds (including callable and floating rate)
- MBS pass-throughs and CMOs (includes our own proprietary mortgage prepayment models)
- ARMs
- FHA loans
- Danish Mortgages
- Futures
- Options/Options on Futures
- Municipal Bonds
- Convertible Bonds
- Interest Rate Swaps and Options
- Default Swaps and Asset Swaps
- High Yield
- Emerging markets
- TIPS
- Foreign Currency forwards and Options
- Short term futures and options (Fed Funds, Eurodollars)
- Equity Index Futures and Options

These relative value and risk models are designed to permit stress testing of all embedded assumptions in order to provide portfolio managers with the widest spectrum of outcomes, from very likely to most unlikely. Our models are unbiased by PIMCO's market views, and where possible, we allow for calibration of important variables such as volatility and future interest rates using traded security prices. We embed a common interest rate or term structure model in all our analytics, so that all our risk measures are comparable across sectors and can be legitimately aggregated. The Financial Engineering Group, led by Vineer, continually upgrades PIMCO models to reflect the latest advances in theoretical finance and responds to innovation on Wall Street by creating new risk measurement models for newly developed fixed income instruments.

Measuring Benchmark Risk

PIMCO computes the risk characteristics of all the major benchmarks used by our clients. In practice, this entails using the models listed above to analyze each and every bond in large indices such as the Lehman Aggregate or the Lehman Global Aggregate (6000+ securities), on a daily basis. The proprietary portfolio level risk measures that we describe below are then computed for each benchmark, so that portfolio managers have targets against which they can manage portfolios. Frequently our proprietary systems identify risks (such as effective durations for mortgages) that are different from the index provider's own values, and we can use those insights to enhance performance and lower the tracking error of our portfolios. On any given day, we are re-computing the risk measures using our own analytics for more than 500 primary and secondary benchmarks.

Interest Rate Risk

Until 15 or 20 years ago, average maturity was used to gauge a portfolio's price sensitivity to changes in interest rates. Maturity's major shortcoming – only considering a bond's final due date, and not the dates of the intervening cashflows – is now well understood. Effective duration, which does consider all cashflows, is now the standard way to measure interest rate risk. However, duration, while useful, has its shortcomings too, and must be augmented with other measures of interest rate risk:

Effective Duration – Effective duration is a weighted average maturity calculation that incorporates all of a bond's expected cashflows, and weights them according to the present value of each cashflow. It is used to measure a bond's price sensitivity to changes in interest rates. However, it is only an accurate predictor of price for small, parallel shifts in the yield curve. For a small parallel interest rate fluctuation, the percentage change in a bond's price is approximately equal to its duration multiplied by the size of the shift. For example, a portfolio with a duration of 2 years would be expected to go up in price by 2 basis points for every 1 basis point drop in interest rates.

Effective Convexity – When moderate to large changes in interest rates occur, effective duration cannot accurately predict the change in value of a bond because its duration

will change. The duration of an option free bond, such as a treasury, will increase as rates fall and decrease as rates rise because the discount rate used in the duration calculation falls and rises, respectively. Convexity captures the price effect resulting from the duration change. Positive convexity is always favorable to bond investors, however, one can rarely get it for free – investors generally pay for positive convexity by accepting lower yields.

The duration of a mortgage security will increase as rates rise because prepayments will be slower than originally assumed, swamping the favorable impact of the change in the discount rate. Conversely, in a bull market, when interest rates fall, a mortgage will generally become shorter in duration because prepayments will speed up. This perverse characteristic of becoming longer in bear markets and shorter in bull markets is referred to as negative convexity, and is the main reason why mortgage investors are paid higher yields than treasuries, which have similar credit quality.

For non-optionable securities, the calculation of convexity includes the simple discounting of known, fixed cashflows. However, for mortgages and other optionable bonds, the calculation of convexity is not so simple because it involves behavioral assumptions (e.g. future prepayment patterns). Moreover, convexity assumes that duration extension or contraction in response to interest rate changes is symmetrical. In other words, the change in duration induced by a rise in rates, will be identical in magnitude (though opposite in direction) to the change induced by a similar fall in rates. In the real world, optionable bonds rarely exhibit symmetry.

Bull and Bear Market Durations – Because of the shortcomings of effective convexity, PIMCO's risk management process does not rely on the common approach of using a combination of effective duration and effective convexity to predict the response of our portfolios to a large parallel shift in interest rates. Instead, we have developed proprietary measures known as bull and bear market durations. To calculate these durations, we shock the portfolio with a 50 basis point rise and 50 basis point drop in rates. Each security in our portfolios is then individually re-analyzed using the appropriate security valuation tool (e.g. our adjustable rate mortgage model, our mortgage pass-through model or our callable corporate bond model), to calculate the expected duration under the "shock" scenarios. Those durations are then averaged to arrive at the portfolio bull and bear durations. Each of PIMCO's security specific models is designed to reflect real world behavior, and are therefore not exposed to the erroneous assumptions of the standard convexity calculation.

While PIMCO typically uses shock scenarios of plus or minus 50 basis points, we have the ability to run scenarios of different magnitudes. A portfolio with a +50 Bear Duration of 5 years, versus an effective duration of 4.5 years, tells the portfolio manager the portfolio is exposed to extension risk. An effective portfolio convexity calculation would not usually measure that risk accurately.

Yield Curve Risk Measures

Yield curve risk gauges price exposure to non-parallel shifts in the yield curve. It is critical to evaluate yield curve exposure because two portfolios with identical effective durations can perform very differently. For example, a 5 year duration portfolio that contains only 5 year duration bonds (called a bullet structure) can perform very differently from a 5 year duration portfolio that contains 50% cash and 50% 10 year duration bonds (called a barbell). Barbelled portfolios will typically outperform bulleted portfolios if the yield curve flattens (spreads of long rates narrow relative to short rates), and vice-versa. PIMCO measures and monitors yield curve exposure with the following tools:

Curve Durations – Empirical evidence suggests that more than 95% of the fluctuations of the yield curve can be described in terms of parallel shifts and twists. PIMCO tries to capture the effect of these two factors with our curve duration risk measures. We assume the 10 year point of the curve as the pivot point, and then our **2-10 Duration** measures the price sensitivity of a portfolio to a steepening or flattening in the 2 to 10 year part of the curve, while our **10-30 Duration** measures the impact of changes to the slope of the 10 to 30 year part of the curve.

However, since no single measure can accurately capture all the curve exposure in our portfolios, we also decompose our exposures along the yield curve into multiple duration classification matrices.

Duration Classification Matrices – Each holding within a PIMCO portfolio is individually analyzed daily in order to populate a variety of duration classification matrices. We can also create a similar matrix for any client benchmarks, as shown for the Lehman Aggregate Index on the next page. The matrix sorts the portfolio or benchmark into "duration buckets" that can be customized by the user.

Duration Weighted Exposure (Years) – Lehman Aggregate Index as of 12/31/00

	<0	0 to 1	1 to 3	3 to 5	5 to 7	7 to 8	8 to 11	11+	Total
Treasury/Tsy Future	0.00	0.00	0.12	0.28	0.25	0.05	0.37	0.46	1.54
Agencies/Swaps	0.00	0.01	0.09	0.17	0.03	0.00	0.18	0.17	0.65
GNMA Mtg/CMOs	0.00	0.01	0.11	0.11	0.00	0.00	0.00	0.00	0.23
Conventional Mtges/CMOs	0.00	0.01	0.25	0.53	0.00	0.00	0.00	0.00	0.79
NonAgency Mtges/CMOs	0.00	0.00	0.00	0.03	0.05	0.00	0.00	0.00	0.07
Corporates	0.00	0.01	0.13	0.09	0.36	0.06	0.34	0.25	1.24
High Yield	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
Emerging Markets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	**0.03**	**0.70**	**1.21**	**0.70**	**0.11**	**0.92**	**0.88**	**4.54**

The matrix can be run on a market value weighted basis, a duration weighted basis or using one of our sector risk measures, enabling portfolios managers greater insight into the nature of their exposure along the yield curve. To drill deeper, portfolio managers can click on any cell in the matrix and identify all the individual securities that contribute to that cell.

Sector Exposure

Sector Classification Matrix – Just as the classification matrix is used to depict portfolio exposure along the yield curve, it also shows portfolio exposure to each sector. The sample matrix above shows eight different sector buckets, but portfolio managers have unlimited ability to customize them. This enables PIMCO's mortgage specialist, for example, to drill deeper into our mortgage holdings by defining finer slices. A sample matrix with more sector detail is shown on the following page.

While the matrix provides in-depth insight into the distribution of our sector allocations, there is still a need for summary risk measures that gauge a portfolio's sensitivity to the important sector related performance variables.

Volatility Duration – Fixed income securities that contain embedded options, including all mortgages and most corporates, are exposed to interest rate volatility risk. That is, a rise or fall in interest rate volatility will impact the price of a bond with embedded options. Volatility duration is computed by shocking the implied volatility in the common underlying term structure model embedded in all our analytics by 1%, thus arriving at a risk measure that is comparable across sectors. We cumulate the results from analyzing individual securities in a portfolio to arrive at a portfolio level sensitivity measure that predicts the price impact resulting from changes in volatility. For example, all else being equal, a portfolio with a volatility duration of 0.1 would be expected to decline 10 basis points for every 1% (or 100 basis point) rise in interest rate volatility.

Mortgage Spread Duration – Option adjusted spread (OAS) is the net spread over the Treasury curve that optionable securities offer, in addition to compensating for the embedded option. For example, a current coupon GNMA may have a nominal yield spread of 150 basis points over similar duration Treasuries, but analysis of the prepayment option embedded in the GNMA values it at 50 basis points, so the OAS would be 100 (150-50). When interest rate volatility rises, the value of the option will increase, pushing spreads wider, but the OAS may stay the same. The OAS demanded by investors tends to be more stable than the nominal spread, but it does vary with market conditions. PIMCO's mortgage spread duration gauges the price sensitivity of a portfolio to changes in the OAS for mortgages, all other things being equal. If OAS across all mortgage sectors increased by 1 basis point, a portfolio with a mortgage spread duration of 1 would be expected to lose 1 basis point, all other things being equal.

Prepayment Duration – When analyzing mortgage securities, calculation of the volatility duration and spread duration involve forecasting future prepayment patterns for each type of mortgage security. Prepayment forecasting has evolved into a very complex science, and we have developed our own proprietary prepayment models that capture short term fluctuations and long term trends of prepayments based on our macroeconomic forecasts. To know the impact on our portfolios of an unforeseen change in prepayments, we shock the parameters of our models to gauge the effect of faster or slower prepayments.

Corporate Spread Duration – PIMCO's corporate spread duration, similar to our mortgage spread duration,

measures a portfolio's overall price sensitivity to changes in corporate OAS. Corporate and mortgage spread durations need to be calculated separately because different factors impact spreads in those sectors, and therefore, they can behave differently from one and other. Similarly, spreads of differently rated bonds do not move in perfect synch, so our corporate spread duration model adjusts for this by refreshing the rating "betas" embedded in our model on a quarterly basis to reflect current market conditions.

Other Sector Spread Durations – As our participation in the universe of fixed income securities grows, we have stuck to our desire to develop rigorous models for each market we invest in. To achieve this, we have developed new models for valuation and risk management of emerging markets, inflation protected securities (TIPS), municipal bonds and convertible bonds. To capture the risks due to the specific factors that affect the relative value of these bonds, we have added EM, TIPS, muni and convertible spread durations to our risk management arsenal.

Credit Risk

Measuring credit risk is more art than science, but PIMCO is equally rigorous in this area. We rely on in-house research, rather than the rating agencies, for assessing credit risk. Our staff of seasoned credit analysts rate every credit held in our portfolios. Our analysts specialize by industry, and in many cases, have covered particular industries and issuers for a decade or more.

For non-corporate issues that have an element of credit risk, we marshal the resources of other departments within PIMCO. For example, commercial mortgage backed security (CMBS) analysis involves both the credit team and the mortgage team, who undertake the structural cashflow analysis. In assessing sovereign credit risk, our international group plays a leading role.

Credit risk at the portfolio level is tracked in two ways:

Duration Weighted Average Credit Quality – Investors often look to an average credit quality statistic, calculated using market value weights, to give them a snapshot of their portfolio's quality profile. However, a market value weighted approach fails to recognize that the credit risk imparted by short duration securities is less than for identical quality long duration ones. This is because one can predict an issuer's financial performance over shorter horizons with greater confidence. Moreover, if an issuer's credit quality does deteriorate and its yield spread widens, the detrimental price impact on shorter bonds is more muted than on longer bonds. By calculating average quality on a duration weighted basis, PIMCO is able to get a much truer picture of a portfolio's overall exposure to credit risk.

Quality Matrices – An average quality statistic, whether duration weighted or not, does not impart any information about quality distribution within a portfolio. For example, a portfolio comprised 50% of BB rated bonds and 50% AAA rated bonds would have the same average quality rating, single A, as a portfolio comprised of only A rated bonds. To get a clearer picture of quality distribution, we have created matrices that show quality distribution across sector, industry and yield curve buckets.

Duration Weighted Exposure (Years) – Lehman Aggregate Index 12/31/00

sector_desc	<0	0<1	1<3	3<5	5<7	7<8	8<11	11+	Total
ABS	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	**0.01**
AGCY	0.00	0.01	0.09	0.17	0.03	0.00	0.18	0.17	**0.65**
CORP-A	0.00	0.00	0.04	0.06	0.22	0.01	0.14	0.11	**0.59**
CORP-AA	0.00	0.00	0.04	0.02	0.05	0.00	0.04	0.02	**0.18**
CORP-AAA	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	**0.06**
CORP-B	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	**0.03**
CORP-BB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
CORP-BBB	0.00	0.00	0.05	0.01	0.07	0.04	0.14	0.11	**0.41**
EmMkt-A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
FHLMC-PT	0.00	0.00	0.12	0.23	0.00	0.00	0.00	0.00	**0.35**
FNMA-PT	0.00	0.00	0.13	0.30	0.00	0.00	0.00	0.00	**0.44**
GNMA-PT	0.00	0.01	0.11	0.11	0.00	0.00	0.00	0.00	**0.23**
NONAGY-CMO	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.00	**0.06**
TSY	0.00	0.00	0.12	0.28	0.25	0.05	0.37	0.46	**1.54**
	0.00	**0.03**	**0.70**	**1.21**	**0.70**	**0.11**	**0.92**	**0.88**	**4.54**

Total PIMCO Exposure Report – Credit exposure at the firm level is also monitored closely because of liquidity considerations. While we adhere to prudent diversification standards within each portfolio, a high level of exposure to a particular issuer across all PIMCO portfolios could present trouble in the event of illiquid market conditions.

Counterparty Risk Report – Given our frequent use of swaps and forward settled trades to generate excess returns and minimize risk, it becomes important that we manage our exposures to specific counterparties. A counterparty risk management system that provides detailed exposures to counterparties, broken down by the different types of outstanding trades, is used for actively monitoring counterparty exposure.

Global Risk Measures

The portfolio risk measures described above are available for both U.S. and non-U.S. portfolios. In the case of most non-U.S. securities, the models embedded in our risk measures, such as term structure and prepayment models, have had to be adapted to the nuances of specific countries.

Global Exposures Matrices – The risk of a non-U.S.bond can be separated into two related components – the country or region risk (exposure to changes in foreign interest rates) and the currency risk. As with yield curve, sector, and credit risk, it is difficult to quantify these risks with just one measure. Therefore, PIMCO's customizable global exposures matrix aggregates all holdings by country and currency, sector and yield curve, etc. We also enable portfolio managers to create groupings of regions and countries to identify correlated concentrations of risk.

Liquidity Risk

The degree of liquidity in a portfolio is managed carefully by PIMCO Portfolio Managers, subject to client investment guidelines and liquidity needs. Most PIMCO clients are long-term investors, so they typically do not have significant liquidity needs. Therefore, the purchase of relatively less liquid securities may be warranted due to the higher yield (often called liquidity premium) that less liquid issues offer. PIMCO monitors near term liquidity needs and manages cash optimally using a proprietary model that incorporates exposure to unsettled trades, as well as futures and swaps. The risk of having exposure to sectors that have the potential to lose significant value due to deteriorating liquidity is controlled largely by adhering to relatively conservative diversification and maximum exposure guidelines.

Tracking Error

Expected tracking error ventures to predict how well a portfolio will track its benchmark. It is the annualized expected standard deviation of the monthly return difference between the portfolio and the benchmark. For example, if the expected tracking error is 1.2, then the yearly portfolio return is expected to be within 120 basis points of the expected return two thirds of the time, and within 240 basis points 19 out of 20 times. As mentioned earlier, PIMCO does not advocate the use of a single risk metric as an alternative to our more robust approach of separately tracking multiple metrics that measure the many sources of risk in a bond portfolio. However, we do use an expected tracking error model to supplement our insight into portfolio allocations versus benchmark, both domestically and globally. Our tracking error model overcomes the obvious shortcomings of most VAR or tracking error models in two ways. First, it can be run with both historical and forecast variance-covariance matrices. Second and most important, it is run against the comprehensive menu of proprietary portfolio risk metrics described above (duration, curve durations, spread durations, etc.) instead of against individual portfolio holdings. Because our risk metrics are aggregated at the portfolio level, they are much smoother over time, making the validity of results from our tracking error model more robust.

Conclusion

Measurement and management of overall portfolio risk is a major effort at PIMCO. It involves all portfolio managers, who interact with our Financial Engineering Group to ensure that the models they develop are not only theoretically sound, but also reflect market realities. It involves a "technology workbench" of seasoned programmers who help to upgrade existing models and implement new ones. And it involves many other technologists who work to integrate our risk measurement tools with our other PIMCO systems, including accounting, compliance and client reporting. The scope and cost of this effort is huge, but it has helped enable PIMCO to avoid inadvertently introducing unwanted risks into our clients' portfolios.