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QUANTITATIVE PORTFOLIO STRATEGY AT MID-DECADE: REVIEW AND OUTLOOK

Introduction

We have had the good fortune, over many years, of working with our clients in exploring the frontiers of quantitative fixed income portfolio management. In this article, we review our progress in this effort at mid-decade and reflect on likely future developments in our exciting field.

Our team helps fixed-income investors structure optimal portfolios relative to Lehman bond market indices and conducts empirical studies in support of managers' investment decisions. We do not offer investors market advice but rather look for ways to implement investors' own views in an optimal portfolio structure.

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Portfolio analysis tools such as appropriate indices, risk budgeting, risk evaluation, and performance attribution models are essential components of the portfolio management process. Here, we provide an update on the recent evolution of these Lehman tools (delivered to investors via the POINT platform or as custom spreadsheets) and our experience in using them.

Empirical studies usually address concerns many investors share during a particular period. For example, in the midst of the 2001-2002 credit turmoil, we examined such issues as sufficient diversification in credit portfolios, issuer caps in credit indices, performance of distressed investment-grade securities, and replication of MBS indices with TBAs. With the sharp rebound of the global credit markets beginning in October 2002, we shifted our focus to studies of sufficient concentration in credit picks given an alpha target, empirical durations of high-yield securities during periods of tight spreads, and replication of index returns with liquid derivatives including portfolio CDS products.

The shifts in investor focus and the resulting inquiries are driven by the business cycle, availability of new asset classes and hedging instruments, and globalization of the geography of asset management. An example of the latter is the growth of in-house MBS portfolio management in Europe that resulted from the spread of Global Aggregate mandates. Below, we provide a brief overview of those of our recent empirical studies that we believe have lasting value.

A major new theme for us in 2004, in both the tools and empirical studies, was our increased interaction with long-horizon investors such as insurance companies or banks, who often manage assets on a book accounting basis.

Historically, we have worked mostly with total return investors benchmarked to standard or customized Lehman indices and focused on month-to-date returns. A major new theme for us in 2004, in both the tools and empirical studies, was our increased interaction with long-horizon investors such as insurance companies or banks, who often manage assets on a book accounting basis. We have developed new methods for optimizing portfolio risk and benchmarking performance for such investors.

Another market development that affected our research agenda in 2004 was the emergence of CDX, offering an opportunity to improve significantly the tracking of Lehman spread indices with these liquid derivatives.

The reach for yield and diversification kept investors interested in core-plus allocations to high yield, hedged non-U.S. bonds, and FX. As typical portfolios grew more diversified, it became more important to have global frameworks for risk optimization and performance attribution, to size these core-plus allocations optimally and hedge them on a beta-adjusted basis.

Portfolio Risk Optimization

Perhaps the most important decision any asset manager makes is how to apportion risk among various competing strategies.

Perhaps the most important decision any asset manager makes is how to apportion risk among various competing strategies. We have developed tools to assist investors with this process in managing portfolios for total return or for long-horizon buy-and-hold strategies. These tools are summarized in Figure 1.

At the macro level, investors may hold a number of views relative to their benchmarks in both core and core-plus assets. Very often, these are directional views rather than basis point projections. Tools are required to create a portfolio that optimally combines an investor's views given the total risk budget of a portfolio. Even at a macro decision level, value added from security/issuer selection should be considered in building the optimal portfolio. For the total return investor, we developed in 2003 the **O**ptimal **R**isk **B**udgeting with **S**kill (ORBS) framework and, for the long-horizon investor, **A**sset Allocation for **L**ong-horizon **P**ortfolio**S** (ALPS) portfolio optimization tools.

At the issue-selection level, a finer level of detail is required. Each security in a portfolio is a possible source of idiosyncratic (i.e., non-market, security-specific) risk, which may be correlated with other security-specific risks (especially in the case of default). There is of course nothing wrong with idiosyncratic risk as long as it is intended and the investor expects to be rewarded for bearing it. For total return investors, the Lehman Global Multi-factor Risk Model contained in the Lehman POINT system allows investors to measure and optimize risk at the security/issuer level, while a separate tool, the Credit Optimized Portfolio Selection System (COMPASS) achieves the same objective for long-horizon credit investors.

Optimal Risk Budgeting with Skill (ORBS)

Risk budgeting is a quantitative method for finding the optimal allocation of risk to different investor views.

Risk budgeting is a quantitative method for finding the optimal allocation of risk to different investor views. At the macro level, portfolio management consists of translating the views of many analysts into portfolio exposures to various risk factors. The fundamental decisions in a fixed income portfolio revolve around interest rates, sector allocation, exchange rates, and volatility. Beneath these macro-level decisions lies the

Figure 1. **Risk Optimization Tools for Total Return and Buy-and-Hold Portfolios**

	Total Return Portfolios	Buy-and-Hold Portfolios
Macro Allocations	**ORBS** Optimal Risk Budgeting with Skill	**ALPS** Asset Allocation for Long-Horizon Portfolios
Issuer/issue-level Portfolio Optimization	**POINT** Lehman Multi-factor Risk Model	**COMPASS** Credit Optimized Portfolio Selection System

We developed the ORBS model for finding the optimal allocation of portfolio risk exposures, prompted by our research on the value of skill at different portfolio management styles.

domain of security selection, where asset class allocations become holdings in specific bonds and issuers. The Lehman Brothers ORBS model provides a setting in which to examine the optimal risk allocations to macro decisions and security selection. We developed the ORBS model for finding the optimal allocation of portfolio risk exposures, prompted by our research on the value of skill at different portfolio management styles. Due to the differences in portfolio management styles, benchmarks, allowed asset classes, and investment constraints, this has been a highly customized effort, with a separate implementation for each investor. The customization included investor-specific choice of macro strategies, funding and hedging techniques, and the inclusion of security selection risk and alpha at the macro decision level.

In a 2003 paper,[1] we examined empirically the characteristics of various macro decisions that a fixed-income manager, faced with a broad menu of investment choices, might make. The study used a so-called imperfect foresight approach to examine the information ratios (excess return/volatility of excess returns) across each strategy. We examined core strategies, in which the investor is able to go long and short (versus benchmark), as well as core-plus strategies, where the investor is able to go long only. We found that once each trade was sized to equalize the forecast risk across strategies, the information ratios for all core strategies were nearly double those for all core-plus strategies. This does not imply that core-plus strategies, one of the most popular general portfolio management tactics in our industry, do not have merit. This simply reflects the reduced opportunity to exercise a manager's skill because of the inability to act on negative views (go short) on core-plus assets. Additionally, within the core and core-plus styles, information ratios varied not by strategy, but rather with the skill the investor possessed in a given strategy. This study, therefore, concluded that the information ratio was a function of both skill and breadth (in our study, the ability to go short, as well as long increased breadth).
The information ratio (IR) of an investment strategy is defined as the ratio of portfolio outperformance (α) over tracking error (TE) or active risk.

$$IR = \alpha / TE$$

Grinold and Kahn[2] have shown conceptually that the information ratio of a strategy is essentially determined by skill and breadth, validating the results of our own empirical analysis. Skill can be measured as the "information coefficient," i.e., the correlation between investment forecasts and the realized market movements. Breadth refers to the number of independent decisions that the strategy implements and is a function of two factors: how often the strategy is executed (e.g., weekly, monthly) and how many independent decisions are made each time it is executed. The information ratio achieved by a strategy should roughly follow the law:

$$IR = Skill \times \sqrt{Breadth}$$

[1] *Value of Skill in Macro Strategies*, Lehman Brothers, May 2003.
[2] *Active Portfolio Management*, Richard Grinold and Ronald Kahn, McGraw-Hill, 1999.

Putting these two formulas together yields the following formulation for the portfolio alpha:

$$\alpha = TE \times IR = TE \times Skill \times \sqrt{Breadth}$$

That is, the expected active return of a portfolio is a function of active risk, investment skill, and the diversity of positions that it implements. A key implication of this is that a risk budgeting framework can make allocation decisions based on directional views, without requiring strategists to specify precise basis point forecasts of market movements.

In the presence of skill, risk eventually translates into outperformance.

At first glance, this may seem odd: how can we assume that outperformance is proportional to tracking error? The answer is that in the presence of skill, risk eventually translates into outperformance. So the alpha in our formulas should be understood as the expected long-term payoff for assigning a risk budget to a certain strategy or strategist. The information ratio, projected based on skill (from historical track record or some other estimation method), tells us the magnitude of outperformance to expect per unit of risk when following a strategist's directional views. Total portfolio outperformance is the sum of contributions of individual strategies and reflects the information ratio of each active strategy on a standalone basis, as well as the risk budget allocated to it.

The portfolio active risk, or tracking error volatility (TEV), combines the tracking errors generated by each individual strategy but reflects the correlation structure between the payoffs of individual strategies. We can optimize the mix of active strategies in much the same way as one would optimize a static asset portfolio. However, in contrast to traditional mean-variance optimization, the optimal allocation is not defined strictly in terms of market value weights to asset classes. Rather, we find the optimal allocation of active risk to a set of individual alpha generation strategies. Then, this allocation is translated into a market value allocation. The objective of the optimization is always to achieve the best trade-off between risk and return, but this can be formulated in several different ways. One approach is to minimize tracking error variance for a given expected outperformance. Another is to find the allocation that gives the highest information ratio. Yet another is to generate the highest possible alpha subject to the constraint that the portfolio tracking error volatility stays within the risk budget.

Even when the asset class is not expected to perform well, holding small allocations to our most favored security selection picks may be justified.

Very often, the macro level asset allocation problem is addressed independently of security selection. However, it is the combination of the two that will ultimately determine both the risk and the return of the portfolio. As an example, consider a portfolio, benchmarked to a global treasury index, that is allowed to hold credit as a non-core position. Typically, a view that credit will outperform treasuries would be the reason for taking a position in this asset class. But may an allocation to credit be appropriate when one does not expect credit to have a positive excess return? Many would say no, because credit is not included in the benchmark. Why include a credit position that will increase tracking error with no expected benefit in terms of outperformance? The reason could be security selection. In our global treasury mandate example, we would forego the value of name selection skill if we let the strategist determine the optimal credit allocation and set it to zero in the absence of a bullish view on the asset class. In fact, even when the asset class is not expected to perform well, holding small allocations to our most favored security selection picks may be justified. Yet to make a credit allocation worthwhile despite the neutral sector view, the expected alpha from security selection must compensate for both the systematic risk of the sector exposure and the idiosyncratic risk from the individual issuer exposures. The ORBS model can be used to determine the optimal allocation between the two exposures.

Lehman Global Multi-Factor Risk Model (POINT)

A portfolio is constructed of individual securities, and it is therefore desirable to examine risk not just from a top-down macro perspective (as the ORBS model does), but from a bottom-up perspective also, in which risk is estimated down to the level of individual security positions.

The Multi-Factor Risk Model is based on the historical returns of individual securities in Lehman Bond Indices, in many instances dating back to the late 1980s. Lehman's position as the leading global provider of bond market indices gave us both the reason to develop the risk model for investors benchmarked to these indices and the data necessary for its construction. Given our extensive proprietary database, our model possesses a decisive competitive advantage. The model derives historical magnitudes of different market risk factors and the relationships among them. It then measures current mismatches between the portfolio and benchmark sensitivities to these risks and multiplies these mismatches by historical volatilities and correlations ("covariance matrix") to produce its key output, tracking error volatility. Tracking Error Volatility (TEV) is defined as the projected standard deviation of the monthly return differential between the portfolio and the benchmark.

In the new Global Risk Model, implemented by the POINT development team, we have retained our time-tested approach to analyzing all sources of bond returns, as well as revised all asset class-specific risk models and expanded security coverage to include the global investment-grade, U.S. high-yield, and global inflation markets. This new model also handles out-of-index instruments such as interest rate futures, interest-rate swaps, credit default swaps, caps, and floors.

Consistent with past practice, our new risk model considers all sources of performance differential between a portfolio and a benchmark. Market risk falls into two broad categories: risk due to sensitivities to common market risk factors (e.g., yield curve durations, spread durations, sector allocations, etc.), and diversification risk (i.e., security selection) that is present in the portfolio even when all the portfolio's common market sensitivities match the benchmark. The first category of risk is called systematic risk, the second security-specific, or idiosyncratic, risk. Both are considered in our risk model. In addition, for high-yield securities, the new risk model goes one step further to include default risk. The new Global Risk Model also expands from a single currency (USD) to all securities in the Lehman Global Aggregate Index, which covers 19 currencies (as of June 2004) and a wide spectrum of spread asset classes. The model has been expanded to include additional currencies that will join the Lehman Global Aggregate on January 1, 2005.

Asset Allocation for Long-Horizon Portfolios (ALPS) [3]

Investors with long time horizons face the tradeoff between risk and return from a very different viewpoint than their total return counterparts. Especially in credit, the longer horizon carries with it a much more asymmetric return distribution in which the

[3] A more detailed description of the model can be found in "Optimal Credit Allocation for Buy-and-Hold Investors," *Global Relative Value Weekly*, Lehman Brothers, January 2004

maximum return is the yield earned and the maximum loss is represented by default. Diversification can help mitigate the exposure to default risk, but issuer correlations reduce the benefit of diversification and create a systematic component of un-diversifiable default risk.

The standard tools used by total return portfolio managers for top-down asset allocation (e.g., mean-variance optimization) and bottom-up security selection (e.g., multi-factor risk models) do not fill the needs of buy-and-hold investors.

The standard tools used by total return portfolio managers for top-down asset allocation (e.g., mean-variance optimization) and bottom-up security selection (e.g., multi-factor risk models) do not fill the needs of buy-and-hold investors. We have developed an approach to help such investors answer some of the most important issues concerning investment in credit: evaluation of current credit spreads versus default risks, the optimal allocation between A-rated and Baa-rated credit, the number of issues that should be held in a portfolio to outperform Treasuries, and the effect of issuer correlations. Rather than providing specific recommendations, we offer a method for achieving a customized solution given each investor's individual situation: the types of assets used and their spreads, views on expected default probabilities and correlations, and the precise formulation of the constraint on default risk.

We begin with a very simple model of a buy-and-hold portfolio. We consider an equally weighted portfolio of n bonds and approximate the portfolio return as a function of the number of bonds defaulting over the period. Using this approximation, any distribution of the number of portfolio defaults can be transformed into a distribution of portfolio return. The simplest is the binomial distribution, which assumes that each issuer is equally likely to default and that what happens to one issuer is independent of what happens to any other. The major shortcoming of this model is that it assumes a constant default rate. In reality, observed overall corporate bond default rates can vary significantly over time. This gives rise to correlations between the default probabilities of different issuers, which need to be incorporated into our model.

As shown by Vasicek,[4] assuming a constant asset return correlation among all pairs of issuers is equivalent to assuming correlations with a single market variable. The model is equivalent to using the binomial model, but with the default probability itself modeled as a random variable instead of being specified as a constant. As the assumed correlation increases, the shape of the distribution of default probabilities becomes the main driver of portfolio performance, and the number of securities in the portfolio plays a smaller role. In the limit when the portfolio contains a large number of bonds (i.e., n is large), the realized portfolio default rate exactly follows the outcome of the random market default probability. The large homogeneous portfolio (LHP) approximation, based on this assumption, allows us to broadly characterize the risk and return of a credit rating class.

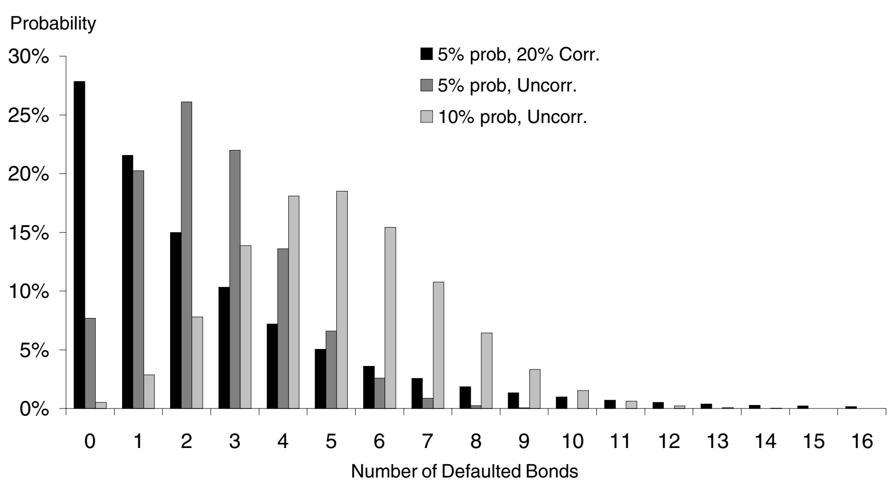
In Figure 2, we plot a default distribution for a 50-bond Baa portfolio with an expected market default rate of 5% and a correlation assumption of 20%. We compare this distribution with those produced by the uncorrelated case (the plain binomial distribution) using market default rates of 5% and 10%. First, let us compare the correlated and uncorrelated cases using the same 5% value for the expected default rate. In this case, for

[4] *Probability of Loss on Loan Portfolio*, Oldrich Vasicek, KMV Corporation, 1987.

a 50-bond portfolio, the expected number of defaults is 2.5 for both the correlated and uncorrelated cases. The binomial distribution with no correlations has its peak near this value and a relatively short tail. In the correlated case, the distribution shows a decreased probability of realizing the average default rate and increased probabilities of either extremely high or extremely low defaults.

We can extend this model to cover two (or more) distinct groups of credits, which could correspond to different quality ratings. Each group of issuers is homogeneous, and all issuers are linked to the same central asset return variable, but each group can have a different spread, an expected default probability, and a different correlation. Under this set of assumptions, the LHP approximation gives us a very simple one-dimensional characterization of the return distribution of a portfolio defined as a weighted blend of these asset classes. Given the ability to project the entire distribution of long-term returns for a given set of asset weights, we can offer several different approaches to finding the optimal allocation for a given set of risk tolerances. One can maximize expected return given a specific limit on some measure of tail risk. Tail risk can be measured by lower partial moments: shortfall probability, expected shortfall, or target semi-variance. Alternatively, a utility function incorporating risk aversion can be used to evaluate a given distribution as a whole. We apply this model to the example problem of allocation between A and Baa debt, detailing the optimal allocations for different assumptions about spreads, default probabilities, correlations, and risk limits.

Figure 2. **Distribution of Number of Defaulted Bonds in a 50-Bond Portfolio: 5% Expected Default Probability with 20% Correlation, Uncorrelated Model With Market Default Rates of 5% and 10%.**



In Figure 3, we show how the optimal allocation between A and Baa rated bonds changes as we vary the spread differentials between the two. Naturally, an increase in the spread advantage of Baa over A (without any adjustment of the expected default rates) increases the optimal allocation to Baa. When this advantage goes below a certain level (here shown to be about 30 bp) the expected return is higher for A, and there is no longer any incentive to take on Baa risk.

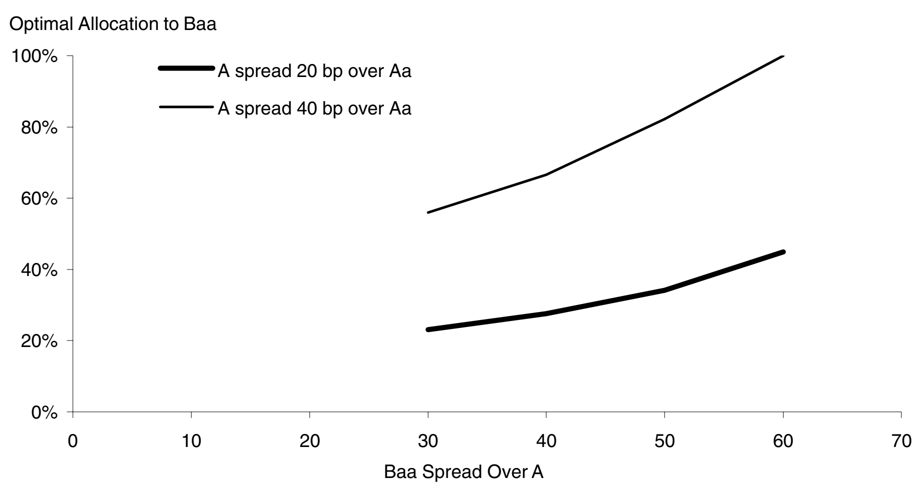
Credit Optimized Portfolio Selection System (COMPASS)[5]

The above analysis is appropriate for examining credit from a macro buy-and-hold perspective. COMPASS, Lehman's portfolio simulation tool developed by the Quantitative Credit Research group, is more appropriate for examining issuer allocations from a long-horizon investor's perspective.

COMPASS works as follows. Individual issuer default rates are mapped to historical default rates based on the issuer's credit rating. COMPASS then uses historical equity return correlations to estimate joint default correlations between issuers depending on their respective sectors, then generates a joint default probability distribution for all assets in a portfolio. Using this default distribution and applying a model of default recovery rates, COMPASS can generate a portfolio's loss distribution. For a given level of expected return, COMPASS generates various possible portfolio loss distributions using as inputs various combinations of the available assets. COMPASS then finds the single portfolio with the smallest expected shortfall given the level of expected return.

[5] The models and assumptions underlying COMPASS are described in "Tail Dependence and Portfolio Risk," O'Kane and Schloegl, Quantitative Credit Research Quarterly, Lehman Brothers, September 2002.

Figure 3. **Optimal Allocation to Baa as a Function of Spread Differentials**



In Figure 4, we use COMPASS to examine the risks of various "macro" allocations when the assets come from heterogeneous sectors. A-rated and Baa-rated assets are assumed to have a spread over Treasuries of 100 bp and 200 bp, respectively and a fixed recovery rate of 20% for both. For the first COMPASS run, we match all of the distributional assumptions of the ALPS model as well: a normal distribution, uniform correlations of 20%, and fixed 20% recovery rates. We find an expected loss of 2.7%, expressed as the total cumulative losses due to defaults, net recoveries, as a percentage of starting value. The VaR of such losses at the 99% level is 16.2%, and the expected shortfall is 19.3%. For the purpose of comparison, we backed out similar numbers from the results the ALPS model. The results agree quite closely with the COMPASS results for normal returns and uniform correlations; this is expected because the underlying models are the same.

We then investigate the effect of introducing some more complex assumptions. The introduction of a more fat-tailed asset return distribution (the Student-t distribution) is found to increase both VaR and Expected Shortfall (ES) by a substantial amount. However, the introduction of a non-uniform correlation matrix based on equity market sector correlations leads to a decrease in both VaR and ES in this example. It is interesting that when we include both of these effects (Student-t distribution and sector-based correlations), they tend to cancel each other out, leaving the VaR and ES only mildly higher than in the macro model. Overall, the fact that the results from COMPASS are similar to those from the ALPS model support the use of the "macro" model for A – Baa allocation, while using COMPASS for portfolio issue selection.

ALPS and COMPASS are both valuable tools for long-horizon investors considering allocations to credit either at the macro or micro level.

ALPS and COMPASS are both valuable tools for long-horizon investors considering allocations to credit either at the macro or micro level. The worth of these tools lies in their ability to enable investors to use own expectations for return distributions, default losses, and default correlations to generate optimal portfolio allocations.

Performance Measurement

Risk attribution is designed to provide an ex-ante analysis of potential sources of return volatility, in absolute terms or relative to a benchmark. Performance attribution analyzes the actual (ex-post) sources of return, in absolute or relative terms. In this section, we update two new developments at Lehman in the area of performance measurement and attribution.

Figure 4. **Comparison of Macro Model Results With COMPASS Results, in Terms of Overall Default Loss Statistics, under Various Assumptions (50/50 Blend of A and Baa Credits; 10-year Horizon; Default Rates 2% for A, 5% for Baa; Spreads 100 and 200 bp For A and Baa, Constant 20% Recovery)**

Modeling Assumptions	Expected Loss	VaR (99%)	Expected Shortfall (1%)
Macro model	2.9%	15.1%	19.3%
Gaussian; uniform correlation = 0.2	2.7	16.2	19.3
Student-t dist, (12 degrees of freedom); uniform correlation = 0.2	2.6	20.8	25.1
Gaussian; sector-based correlation matrix	2.7	13.0	14.8
Student-t dist (12 degrees of freedom); sector-based correlation matrix	2.7	17.4	20.6

We have developed a new method to create performance benchmarks for long horizon buy-and-hold investors.

First, we have developed a new method to create performance benchmarks for long horizon buy-and-hold investors. Existing Lehman indices often do not reflect the constraints faced by managers of buy-and-hold portfolios. The performance objective in these portfolios is not outperforming total return indices on a monthly basis; rather, it is to lock in a higher book yield than the market and preserve this advantage over a long horizon. Accordingly, we have been developing a set of "book-yield" indices (BOOKINs), which will allow a more relevant performance comparison for these portfolios.

The Lehman POINT modeling team completed the development of the Hybrid Performance Attribution Model for global portfolios.

Second, the Lehman POINT modeling team completed the development of the Hybrid Performance Attribution Model for global portfolios. Total-return managers have long compared returns with appropriate indices. The attribution model allows them to go beyond mere comparisons towards explaining the reasons for the difference. The separation of decisions into "sector allocation" and "security selection," to which performance is attributed, is under the control of the investor. Sectors can be defined in a flexible manner to reflect the actual investment strategies.

The Lehman Brothers Book Accounting-Based Indices

Fixed-income investors typically measure portfolio performance by calculating returns using market prices at the beginning and end of the performance period. This calculation implies that the contents of a portfolio may not be held until maturity, as market prices correctly track the portfolio's cash value in the event of liquidation. A consequence of using market prices is that the portfolio's market value fluctuates with changing market conditions. Another consequence is that the standard fixed-income indices were designed as market return-based indices to allow investors to discern their investment skill amid all the noise of normal market fluctuations. Many portfolio tools have been built to analyze a market based portfolio against similar indices.

However, there is a large class of investors (e.g., insurance companies and banks) that is less concerned about monthly market fluctuations. These investors purchase fixed-income assets to match a set of liabilities whose net present value is not marked to market. Typically, these fixed-income portfolios are relatively static as bonds are held until maturity. Investors expect the portfolio to earn an adequate spread over the cost of the liabilities, provided that the assets do not default or prepay at a rate unanticipated at the time of purchase. Given that liabilities are valued using book accounting, these investors (and their regulators) prefer to measure portfolio performance similarly, either by the portfolio's "book return," which is book income divided by book value, or the portfolio's "book yield," which is its internal rate of return calculated at time of purchase. However, how can the investor measure investment skill? Standard fixed-income indices are unsatisfactory yardsticks because their returns and yields fluctuate with the market, whereas the book return and book yield are relatively stable. In addition, the composition of market indices changes each month, whereas the portfolio for the book-accounting investor is relatively static until maturity.

BOOKINs allow book accounting investors to benchmark their portfolio performance because they are, in theory, replicable investment portfolios. For example, suppose in January 2005 an investor (who is restricted to, say, assets in the Lehman Aggregate Index) must invest to fund a newly acquired liability. The investor could passively invest in the JAN05 Aggregate BOOKIN. The composition of this BOOKIN is initially fixed (it is the Aggregate Index itself as of January 2005), and its book yield and book return (using standard book accounting) is calculated every month. Over the month, the BOOKIN will generate cash flow (coupon, prepayments, or proceeds from maturities) that is re-invested in the February 2005 Aggregate Index. Consequently, by February 2005, the JAN05 Aggregate BOOKIN becomes a conglomeration of the initial investment in the January Aggregate Index plus a smaller investment in the February Aggregate Index. This process is repeated every month. The performance of the JAN05 Aggregate BOOKIN reflects what the investor could have achieved (using book accounting) if the investor had passively invested in the Aggregate Index starting in January 2005 and can be directly compared with the performance of the actual portfolio.

Not only will BOOKINs allow investors and their clients to measure how a book accounting based investor is performing, but they will also permit better (book) return attribution and portfolio risk analysis. For example, investors will be able to see why the book yield on their performance BOOKIN is changing over time (e.g., due to a change in MBS prepayment estimates or impaired credit bonds). They will then be able to examine if their own portfolios are experiencing the same effect.

The Lehman Brothers Hybrid Performance Attribution Model

A portfolio's outperformance relative to its benchmark results from differences in exposures to a number of systematic (market) factors and from the manager's choices in security selection. Among the most relevant market factors are allocation to multiple currencies and debt markets, exposures along all the relevant yield curves, distribution of portfolio market value among various credit sectors and qualities, etc. A powerful attribution model ascribes portions of outperformance to each factor without omitting important sources of return and without ambiguity about the precise contribution of each factor.

The Lehman model is called "hybrid" because it combines the direct modeling of market risk (FX, interest rates, volatility) with the traditional use of user-defined partitions (spread exposure, sector allocation, security selection).

The Lehman model is called "hybrid" because it combines the direct modeling of market risk (FX, interest rates, volatility) with the traditional use of user-defined partitions (spread exposure, sector allocation, security selection). Accordingly, the model quantifies outperformance at the following levels:

- Currency decisions
- Allocation to local markets
- Within each local market, the outperformance may be further attributed to:
    - Treasury (or swap) curve exposure,
    - Implied volatility,
    - Spread exposure,
    - Asset allocation, and
    - Security selection.

There is also a separate allocation of outperformance resulting from trading and market timing activities, stemming mostly from intra-day trading (a security bought and sold within a single day) and transactions conducted at prices different from the day's closing price.

The model takes the currency hedge approach to the calculation of FX-related outperformance; i.e., currency return includes both the effect of changes in the FX rate and the return on the appropriate cash deposit. The model branches into all relevant currencies and analyzes local contributions, producing individual reports for each. The exact content of each report depends on the important risk factors in the particular market and on the available analytics. Typically, reports for developed markets such as the U.S. or euro bloc will contain all of the five local market factors listed above.

In many portfolios, the largest risk and the biggest source of return often arises from exposure to interest rates. In the Lehman model, yield curve exposure is described in terms of key rates (six for the major markets, fewer for smaller ones) and the corresponding key-rate durations. The way to describe the curve profile of a portfolio is to construct a hypothetical "curve-matched" portfolio consisting of the appropriate number of quasi-treasury bonds with the coupon and maturity equal to those of the corresponding key rate. Such portfolios are built for all securities in the benchmark and the portfolio and then weighted accordingly. The curve-related outperformance has two main components: one due to rates changes (usually the dominant one), and one due to the curve carry, which includes "rolldown."

To the extent that the portfolio and benchmark have instruments with embedded optionality (e.g., callable bonds, mortgages, derivatives), discrepancies in exposure to changes in implied volatility will give rise to return differences. Every day, all positions are repriced, holding everything but volatilities at the previous day levels to ensure that returns are due only to changes in volatility. Then, vegas are used to provide further insight by computing the component due to the parallel move in the volatility surface. The difference between the two is attributed to the reshaping of the volatility surface.

After accounting for the outperformance due to currency, yield curve, and implied volatility, the hybrid model switches modes, from direct modeling of market risk factors to the use of partitioning. A partition is a user-imposed single- or multi-level sampling scheme that, ideally, should reflect the granularity of decision-making in the portfolio. In the partition mode, the hybrid model handles the remaining parts of the total outperformance, related to credit spreads and security selection. In credit portfolios, spreads play just as important a role as interest rates. Therefore, the hybrid model provides a comprehensive and flexible mechanism to account for spread (OAS)-related outperformance. Somewhat similar to its treatment of the curve-related outperformance, the hybrid model recognizes two components of the spread return: one due to the spread carry and one due to the exposure (measured by spread duration) to spread changes.

The carry outperformance is attributed to individual partition cells at the asset allocation level.

Typically more important than the mismatch in yield between portfolio and benchmark is the mismatch in spread exposure, measured by spread duration. The deviation of the portfolio spread duration from that of the benchmark can be either a top-level decision made for the portfolio as a whole or a set of decisions taken in individual sectors. Accordingly, the model may report a distinct component of the spread-change outperformance, based on the duration mismatch for the portfolio as a whole. Spread duration decisions are made within individual cells such as sectors or credit ratings.

The last component of the overall outperformance comes from security selection. At the lowermost level in the partition, individual cells may still perform differently from their counterparts in the benchmark because in most cases they include a different set of securities. Therefore, each security present in the portfolio cell, as well as each security absent from the portfolio (but present in the benchmark) cell, contributes to outperformance. Just like an individual cell at the asset allocation level, each security may differ from its peers in the cell by a superior or inferior carry and by a larger or smaller spread change. Accordingly, the model computes these two components separately for every security in the portfolio. For amortizing securities such as U.S. MBS, the model also calculates security-level outperformance due to excess prepayments.

Index Replication

The wider use of risk attribution and performance attribution has led money managers and their clients to a greater understanding of where alpha is being generated (as a result of skill), as well as which strategies are contributing much more to return volatility than alpha. "Portable alpha" strategies, which separate market exposure from alpha, help managers and plan sponsors maximize alpha. Replication of indices with derivative instruments is then required to achieve or eliminate a desired market exposure.

While index replication has been of interest to a small group of managers for a number of years (our earliest published study of index replication dates back to 1997), we have witnessed a substantial increase in interest in replication strategies during 2004. Though a desire to achieve index returns is a perfectly reasonable goal of replication, we have found that demand for replication strategies has been driven primarily by two very different needs.

First, low yields in fixed income markets and concerns over the likely future performance of equity markets have spawned a "rush for alpha." This trend has notably manifested itself in the surge of inflows to hedge funds; but another side-effect has been a broadening interest in "portable alpha" strategies. Typically, a portable alpha strategy involves the transfer of alpha from one asset class to another. For example, an equity manager uses equity futures to eliminate the "beta" from stock market exposure, but preserves the alpha. The manager then uses non-cash instruments to achieve the desired bond market exposure (e.g., matching the Lehman Brothers Aggregate Index).

Second, the increasing use of the Global Aggregate Index, a broad index of investment grade multi-currency fixed-income securities, has caused many managers to look for strategies to replicate its sub-components. A European-based manager may be adept at managing European credit and government securities, but may have less resources or expertise in managing U.S. fixed income. In particular, we find some non-U.S. managers choosing to refrain from offering a Global Aggregate product because they doubt their ability to manage U.S. mortgage-backed securities effectively. Since the Global Aggregate Index has become the international debt benchmark of choice for many plan sponsors, we believe that such managers will be forced to forgo the possibility of participating in much of the growth in global fixed-income assignments. Instead, a strategy of replicating segments of the U.S. Aggregate Index can allow such a manager to offer a Global Aggregate product. Indeed, derivatives can be used to create a "portable alpha" strategy for the Global Aggregate, in which the alpha from a 100% Euro fixed-income portfolio is "transported" to a Global Aggregate Index.

Plan sponsors engaged in asset allocation shifts are increasingly using transition managers to minimize implementation shortfall, which can involve transactions in multiple asset classes spread across more than a week. If the target portfolio is fixed income, it may be optimal to gain the desired exposure to fixed income at the beginning of the transition, before the liquidation of assets has even begun. If the legacy portfolio is fixed income, there may be a desire to retain fixed-income exposure throughout the transition. In both cases, a replicating portfolio of derivative instruments can achieve these objectives.

Derivative replication strategies are attractive because minimal cash outlay is required, and this can then be used to fund the alpha strategy.

Derivative replication strategies are attractive because minimal cash outlay is required, and this can then be used to fund the alpha strategy. These strategies involve either the use of a total return swap, or the purchase of a portfolio of derivative instruments. Under a total return swap, the investor is guaranteed to receive the total return on the index selected, in return for paying the counterparty floating-rate LIBOR, plus a spread, to compensate the dealer for the risk in hedging the index exposure. This approach is appropriate for relatively long (one year and longer) time horizons, owing to the limited liquidity and higher transaction costs associated with a swap. For other investors, unless their degree of risk aversion is high, the derivatives portfolio approach will be more appropriate.

In a recent study,[6] we replicated the returns of the Lehman Brothers U.S. Aggregate Index and sub-components of the Index with derivatives using several strategies in isolation and in combination. These strategies made use of Treasury futures, interest-rate swaps, TBAs, and portfolio credit default swaps (CDX). We performed an empirical analysis, constructing portfolios of derivatives to match the duration exposures of the relevant indices. The results of this study are summarized in Figure 5.

We can see how the tracking error of the Aggregate Index improves as we add more replicating instruments. The most notable improvement would seem to be the addition of CDX to match the index exposure to credit spreads (relative to LIBOR). We caution that the period over which we conducted the empirical analysis was 25 months, given the limited data available for CDS; however, the validity of the results was confirmed by the proximity of the empirical results to ex-ante data generated by the Risk Model (see the referred paper for details).

Non-Core Exposures: High Yield and Non-U.S. Bonds

We noted above that the information ratio is a function of both skill and breadth. Accordingly, while an investor may possess less skill in making allocations to high yield or to non-U.S. bonds, such allocations will tend to increase breadth and therefore can increase an overall portfolio's information ratio (IR). The degree to which these strategies do so will depend upon the skill the manager has in that strategy, the risk that is allocated to the strategy, and to its correlation with other active strategies. In the case of both high-yield and non-U.S. bonds, care must be taken to ensure that the appropriate durations are assigned. If this is not done, the performance of the trades, and their effect on total portfolio performance may be determined by the direction of U.S. Treasury yields, rather than the direction of high-yield spreads and non-U.S. bond markets. Since most active

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[6] *Replicating the Lehman Brothers Aggregate Bond Index with Liquid Instruments*, Lehman Brothers, October 2004.

Figure 5. **Index Replication Results 8/02 - 8/04 (bp per month)**

Figure 5a. **U.S. Treasury Index Replication**

Replication Methodology	Mean Outperformance	Tracking Error Volatility	R^2
Treasury Futures	4.4	10.6	0.997

Figure 5b. **U.S. MBS Index Replication**

Replication Methodology	Mean Outperformance	Tracking Error Volatility	R^2
Treasury Futures	1.1	36.0	0.811
Interest-Rate Swaps	-1.9	39.3	0.774
TBAs	0.0	4.1	0.998

Figure 5c. **U.S. Credit Index Replication**

Replication Methodology	Mean Outperformance	Tracking Error Volatility	R^2
Treasury Futures	-25.4	64.0	0.878
Interest-rate Swaps	-27.0	59.0	0.896
Interest-rate Swaps + CDX	1.6	29.3	0.974

Figure 5d. **U.S. Aggregate Index Replication 8/02-8/04**

Replication Methodology	Mean Outperformance	Tracking Error Volatility	R^2
Treasury Futures	-5.4	23.1	0.972
Interest-Rate Swaps	-7.6	17.8	0.983
Futures+Swaps	-7.3	17.6	0.984
Futures+Swaps+TBAs	-6.4	17.2	0.984
Futures+Swaps+CDX	0.3	11.0	0.994
Futures+Swaps+TBAs+CDX	1.2	9.4	0.995

managers will already have active exposures to U.S. bond yield movements, these trades may not increase breadth to any degree. Notably we find that for U.S. high yield, empirical durations are a small fraction of their analytical durations, while for Bunds, they are about 50% (relative to U.S. Treasuries) of their analytical durations.

High Yield

It is widely acknowledged that the interest rate sensitivity of high-yield securities is not necessarily what their stated cash flows imply; at times, high-yield debt exhibits rather more equity than fixed income-like behavior. We have seen a wide range of opinion on this issue among portfolio managers. At one extreme, there are those who account for the full analytical duration of the high-yield component. At the other are those who ignore the duration contribution of high yield debt entirely and base their assumed exposure to interest rates on investment-grade instruments alone. The majority in between usually have some heuristic rule of thumb, for example, to consider 25% of the analytical duration for high-yield bonds.

Empirical durations fall close to zero in the case of B and Caa and below rated instruments.

In a recent paper,[7] we examined this issue for various rating categories from two perspectives. We calculated the empirically derived durations by regressing daily price returns of whole-letter-grade components of the Lehman Investment Grade and High Yield Credit indices against daily changes in the 10-year U.S. Treasury yield. The (negative of the) regression coefficients can be interpreted as empirical durations, i.e., the return realized per unit of yield change. The results are plotted in Figure 6. We see that empirical durations decline sharply for high yield as a whole and, indeed, fall close to zero in the case of B and Caa and below rated instruments.

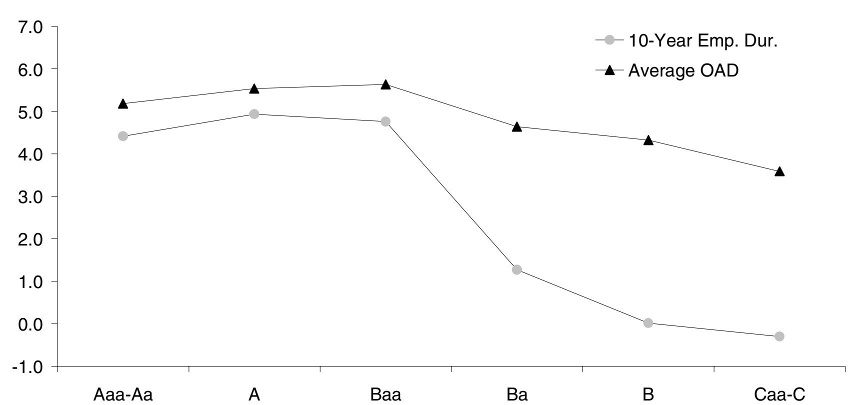
The second method is to use betas derived from the Lehman Global Risk Model. We calculated the key rate durations (KRD) of the index (the full analytical values) and then constructed an all-treasury portfolio with the same KRD profile. We then used the risk model to analyze the two against each other, using the all-treasury portfolio as the benchmark and the credit index as the portfolio. The risk model calculates beta of the portfolio relative to the index, defined as the ratio of the covariance of portfolio and benchmark returns to the benchmark return variance. The profile of the betas is very similar to that derived from our empirical study.

Non-U.S. Bonds

Adding non-U.S. bonds to a U.S. portfolio (or, in general, any venturing outside of an investor's local market) presents a similar problem. What is the appropriate duration to use for a non-U.S. bond? A manager who wishes to express a view on the Treasury-Bund spread, for example, will typically hedge currency exposure using foreign exchange forwards. Asset managers will frequently express a view on the spread by selling 10-year U.S. Treasuries for 10-year Euro government bonds (we assume the trade is executed through the sale of 10-year U.S. Treasuries and a purchase of Bunds). The most obvious way to execute the trade is by dollar duration-matching, but that doesn't make it the right

[7] "Empirical Duration of High Yield Credit," *Global Relative Value Weekly*, Lehman Brothers, November 2004.

Figure 6. **Empirical 10-Year Duration: versus OAD**
Daily Observations, 8/98 - 9/04



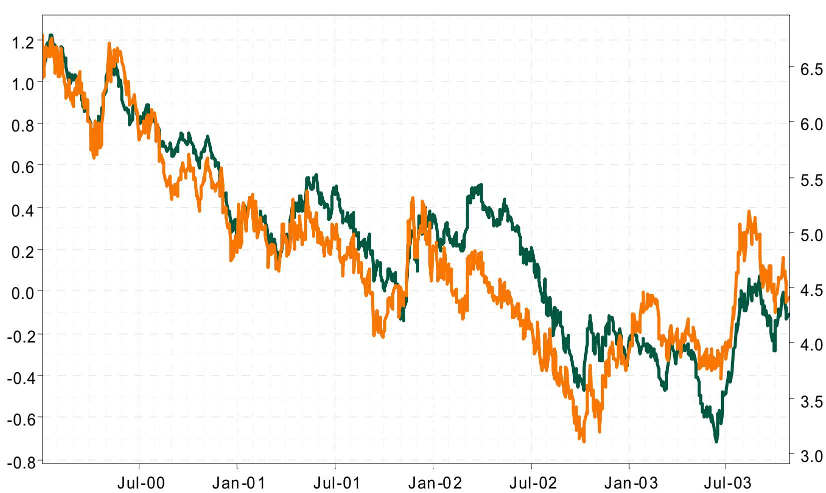
way. Duration is a measure of price sensitivity with respect to yield. The problem in this case is that for U.S. Treasuries, duration measures the sensitivity with respect to U.S. yields, and for Bunds, the sensitivity with respect to Bund yields.[8] What we need instead is a measure of the sensitivity of a change in Bund prices with respect to Treasury yields.[9] Fortunately, we do not need to invent one, since beta-weighted duration will perform admirably in this respect. It is computed by dividing the covariance of changes in Euro and U.S. yields by the variance of the changes in U.S. yields.

The usefulness of beta as a measure can be seen in Figure 7, which demonstrates that over the past four years, the movement of the Bund-Treasury spread has been highly correlated with absolute movements in U.S. Treasury yields. Over this period, more than 60% of movements in the Bund-Treasury spread were explained by absolute movements in U.S. 10-year yields.

Therefore, historically, a manager who established a Bund-Treasury trade on a duration-weighted basis was essentially expressing a U.S. interest rate view. If U.S. yields declined, the U.S. yield spread to Bunds tended to narrow, while if U.S. yields rose, the yield spread widened. The chart suggests that the spread narrowed by around 5 bp for every 10 bp fall in U.S. yields (a beta of 0.5).

[8] It is for this reason that many global managers ignore average portfolio duration as a statistic, since this measure combines duration sensitivities to shifts in different yield curves.
[9] Using Euro bonds as the "base," we could also compute beta-weighted durations of U.S. Treasuries with respect to Bund yields.

Figure 7. **Movements in the 10-Year Treasury-over-Bund spread Relative to US 10-Year.**



Source: LehmanLive.com

Legend	Axis	03-Jan-00 to 27-Oct-03	Last	Minimum	Maximum	Mean	Std. Dev
	Right	U.S. 10-Year On-the-Run	4.263	3.103 13-Jun-03	6.788 21-Jan-00	4.936	0.849
	Left	Spread 10 yr Bunds to 10 yr U.S.T	-0.027	-0.718 09-Oct-02	1.222 03-Jan-00	0.180	0.439

When cross-country trades are made on an unhedged basis, the risk profile of the portfolio is very different. In some cases, portfolio managers will purchase non-U.S. bonds on an unhedged basis in order to gain desired currency exposure. In many cases, they will use foreign exchange forwards to express a currency view. Since the dollar peaked in 2002, currency exposure has been an increasingly popular addition to U.S. fixed-income portfolios.

The tactical case for including foreign exchange exposure may simply rest on the expected return on various currencies, either absolute or measured relative to a relevant risk metric. But many investors will also be concerned about the implications for portfolio risk of adding currency exposure. In a recent paper,[10] we found that the optimal foreign exchange exposure for a U.S. fixed-income portfolio depends upon both the nature of the U.S. fixed income exposure, as well as the choice of foreign currency exposure. For a diversified exposure to foreign exchange (since January 1990 based on monthly observations), the minimum variance exposure for a U.S. Aggregate portfolio was 12.8%, but for a U.S. credit portfolio was 22.6%. This suggested that foreign exchange was a better diversifier for a credit portfolio than for a government portfolio.

The choice of currency exposure also has important implications for its overall contribution to portfolio risk. Figure 8 suggests that the diversification benefit varies greatly depending on the currency. The Swiss franc and Japanese yen returns against the U.S. dollar are negatively correlated with U.S. credit spreads, but that correlation is relatively low. Interestingly, the correlation of the Swiss franc with credit rises when credit excess returns have been most negative, increasing its attractiveness as a hedge for credit risk. The Australian dollar, however, is less attractive, with a higher and positive correlation to credit.

While we are not expressing any view on the attractiveness of these core plus asset classes at this time from an alpha generation perspective, there is a clear and relatively persistent case for these strategies from the risk diversification perspective. The optimal size of risk

[10] "The Case for Foreign Exchange Exposure in U.S. Fixed Income Portfolios," *Global Relative Value Weekly*, Lehman Brothers, December 2004.

Figure 8. **Monthly FX Returns and Correlations with U.S. Credit Index Excess Returns** January 1, 1990-October 31, 2004, percent

	CHF-USD	**JPY-USD**	**AUD-USD**	**CHF-JPY**	**CHF-AUD**	**Credit Excess**
Average	0.19	0.23	0.01	-0.04	0.19	0.04
ST Dev	3.16	3.41	2.71	3.43	3.89	0.57
Worst 5	1.60	4.54	-2.51	-2.94	4.11	-1.58
Worst 10	1.08	2.02	-1.56	-0.95	2.64	-1.10
Correlation with Credit	-19.83	-18.79	33.34	0.39	-39.36	
Correlation worst 10	-31.76	-16.53	48.79	0.03	-60.83	

allocations to these asset classes needs to be produced in a framework such as ORBS, considering all views expressed in a portfolio within a single framework. These allocations need to be beta-hedged considering the correlations between the excess returns of these asset classes and movement of the U.S. Treasury curve.

Conclusion

While it is always difficult to predict trends in quantitative portfolio strategies, we see a few of them already emerging.

There is a growing investor demand for rigorous frameworks of top-down portfolio optimization and optimal budgeting of risk across macro investment strategies.

Quantitative methods have long been employed by investors for security selection and bottom-up portfolio construction. Now, there is a growing investor demand for rigorous frameworks of top-down portfolio optimization and optimal budgeting of risk across macro investment strategies. In our view, the most successful approach to this problem is a highly customized framework based on directional forecasts rather than any standard optimization tool. Improvements in technology and a larger available data set should help investors make more accurate risk forecasts and identify appropriate alpha-generating and risk-moderating strategies.

With FX exposure becoming increasingly mainstream for U.S. portfolio managers, there is an increased demand for global risk models and global performance attribution models. We feel that the analytical suite of the Lehman POINT platform offers strong choices for both types of analysis across a wide spectrum of securities. While we are fairly certain that the increase in demand for detailed attribution of portfolio performance is a secular trend, the recent increase in foreign exchange exposure in U.S. domestic portfolios may reflect the cyclical decline of the U.S. dollar, rather than a new secular trend. Other than the expanded use of all types of derivatives (CDS, options on CDS, and new derivatives on securitized product in the offing), it is difficult to generalize about the kinds of exposures/strategies that will be popular among fixed-income managers between now and the end of this decade. And, as with any science, the availability of more precise data and more refined quantitative techniques will facilitate the re-investigation of old portfolio management topics. For example, what are the most consistent sources of alpha?

Our ever-expanding index map of the global debt markets (see the accompanying Index section in this publication) inevitably will lead to the creation of new macro indices (i.e., a possible Global Aggregate Fixed and FRN Index) and the research of new bond portfolio management strategies.

2000-2002 was a particularly trying time for investors with long-duration liabilities, especially pension funds. The vast majority of funds had and continue to have substantial duration mismatches, with larger allocations to equity than fixed income, and fixed-income portfolios with much shorter durations than the liabilities they are supposed to fund. With the declines in interest rates and in equity markets, liability values rose while asset values fell.

The adoption of IAS 19 in much of Europe in 2005, and its likely adoption in the United States within the next few years, may have a profound effect on pension fund behavior.

The adoption of IAS 19 in much of Europe in 2005, and its likely adoption in the United States within the next few years, may have a profound effect on pension fund behavior. Previous national standards (e.g., FAS 87) allowed the effect of changes in asset and liability values to be smoothed over time, minimizing their effect on financial statements.

IAS 19 requires changes in both assets and liabilities to be recognized and reported in financial statements (not in net income, but in a measure of comprehensive income). This may lead many funds to increase exposure to fixed income (by a combination of higher allocations and longer durations).

We see this trend manifesting itself in two ways: increased demand for customization of indices to reflect the investment horizon (for buy-and-hold portfolios) and the nature of liabilities; and increased use of overlay strategies, particularly using interest-rate swaps, which help reduce the sensitivity of the plan's funded status to interest rates. At the same time, these strategies free up cash to be used in generating alpha.

The difficulty of alpha generation in the current market environment is perhaps responsible for the surging interest in portable alpha strategies, often involving hedge fund investments. Hedge funds differ from "traditional" managers in a number of ways. They operate with fewer constraints; for example, they can employ leverage, have the ability to short, and invest in less liquid instruments. Essentially, this means an increase in investment breadth, which, as we have demonstrated above, helps generate higher information ratios, even if hedge fund managers have no greater skill than their long-only counterparts. In coming years, we will likely continue to see traditional managers moving to hedge funds, or perhaps fighting to reduce constraints that make it difficult for them to compete with hedge funds. Arguably, one can take a long-only manager, eliminate the benchmark and the constraints, and be left with an absolute-return hedge fund.

Portable alpha strategies combine absolute return strategies with replication of indices, typically with baskets of liquid derivatives.[11] The emergence of CDX has significantly reduced the tracking errors of such replication techniques and increased their appeal in asset allocation shifts and portfolio transition management.

If the second half of the decade presents as challenging and as interesting an environment as the first, then quantitative portfolio management will have no shortage of opportunities to make worthwhile contributions to the broader science of bond portfolio management.

[11] In recent years, derivative instruments have been created that allow essentially the opposite strategy: investing cash to meet investor's objective or match liabilities and purchase derivatives linked to the return on hedge funds.

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