Fixed-Income Research

The Lehman Brothers Global Risk Model: A Portfolio Manager's Guide

April 2005

Modeling
212-526-8035

Dev Joneja
Dick Kazarian
Vasant Naik
Marco Naldi
Antonio Silva
Gary Wang

Quantitative Portfolio Strategy
212-526-6302

Lev Dynkin
Albert Desclée
Tony Gould
Jay Hyman
Hui Ou-Yang
Bruce Phelps
Jeremy Rosten

LEHMAN BROTHERS

POINT

Access to the Lehman Brothers Global Risk Model is available via POINT, Lehman's proprietary multi-currency portfolio analytics platform. POINT is designed to deliver quantitative content produced by Lehman Brothers' industry leading Fixed Income Research department. In addition to the Global Risk Model, POINT provides access to Lehman's:
- Valuation models for credit, mortgages and rates
- Performance attribution model
- Global Family of Indices.

POINT supports all 23 currencies underlying the Global Aggregate Index. Security coverage is broad and includes:
- Treasuries/Agencies
- Credit (investment grade and high yield)
- MBS – Fixed Rate and Hybrid ARMs, CMOs
- ABS/CMBS
- Interest rate and credit derivatives
- FX forwards and cross-currency swaps

Other Key Features:
- Custom index creation
- Index dynamics and turnover reports
- Scenario analysis
- Flexible reports with multi-dimensional breakdowns of portfolios and indices
- Portfolio summary and transaction history
- Ability to create user defined instruments

Lehman has dedicated significant resources to the development of POINT and provides substantial support to POINT users. Our ultimate objective is to enable investors to better identify and quantify risk within their fixed income portfolios. For more information on POINT, please contact:

POINT Help: pointhelp@lehman.com; (212)526-1234

United States:	Nick Gendron	212-526-6758	ngendron@lehman.com
	Andy Sparks	212-526-5588	asparks@lehman.com
Europe:	Robert Campbell	44 20 710 22639	rcampbel@lehman.com
	Lee Phillips	44 20 710 21624	leephill@lehman.com
	Joe Nehorai	44 20 710 22837	jnehorai@lehman.com
Asia (Tokyo):	Tago Tadashi	81 3 6440 1416	ttago@lehman.com
Asia (Hong Kong):	Norman Tweeboom	852 2252 6233	ntweeboo@lehman.com

Lehman Brothers Global Risk Model

- The Lehman Global Risk Model allows a portfolio manager to quantify the expected performance deviation ("tracking error volatility") between a portfolio and benchmark and find optimal transactions to reflect specific views.
- With the globalization and increasing complexity of fixed-income portfolios, risk models (which Lehman has made available to investors since 1991) have become an indispensable portfolio management tool.
- We present a portfolio manager's guide to the new Lehman Brothers Global Risk Model for global and single-currency portfolios. The Model incorporates the latest in Lehman fixed-income analytics, improved modeling techniques, and expanded security coverage to include global investment-grade credit, U.S. and Euro high-yield, emerging market securities, inflation-linked securities, derivatives and structured securities.
- Lehman's Risk Model offers several advantages to investors: calibration using Lehman's state-of-the-art analytics and high-quality Lehman Index price data, selection of intuitive risk factors, and quantification of security-specific risk.
- We present detailed risk factor model descriptions for all asset classes covered by the Model.
- For Baa-rated and high-yield securities, the Risk Model measures, in addition to market risk, the risk due to issuer default, including correlated defaults.
- We show how to use the Risk Model, and interpret its output to analyze a U.S. Aggregate, a Euro (and Sterling) Aggregate and a Global Aggregate portfolio.
- We discuss several applications of the Risk Model: structuring efficient active and index-replicating portfolios; defining plausible market scenarios for stress testing; and risk budgeting.
- We discuss the relationship between the Risk Model and other portfolio management tools: scenario analysis, Value-at-Risk, Monte Carlo simulation, performance attribution, and optimal risk budgeting.
- The Appendices include a brief tutorial on the multi-factor approach to modeling bond and portfolio risk as well as a basic review of risk model mathematics.

The authors would like to thank Ravi Mattu, Jack Malvey, Steve Berkley, Anthony Lazanas, Nick Gendron, Hua He, Vadim Konstantinovsky, Jordan Mann, Arik Ben Dor, Bill Lu, Lee Phillips, Andy Sparks, Nancy Roth, Lea Carty, Ivan Gruhl, Rachel Gelman, and Bruce Moskowitz for their valuable assistance. 6-07/06

INTRODUCTION

Managing a fixed-income portfolio was once a reasonably simple endeavor. Total return portfolio managers generally kept their portfolios overweight in spread-sector assets, in the form of a well-diversified group of issuers, and occasionally took modest duration bets. Also, up until the early 1980s, homeowners had yet to use repeated mortgage refinancings to supplement monthly income—helping to keep mortgage prepayments reasonably predictable and durations relatively stable. Sure there was market volatility and the occasional credit horror story, but by and large, life for the portfolio manager was not so bad.

In such an environment, quantifying the risk of a fixed-income portfolio was not a major preoccupation for most managers or plan sponsors. An intuitive feel for how much a duration or sector over- or underweight could go "wrong" in a month was usually enough to measure the portfolio's overall risk. This intuitive approach to risk is no longer sufficient for several reasons.

First, after the 2000-2002 equity market rout, there was a renewed understanding that even long-horizon investors must be concerned with fluctuations in portfolio valuations. Companies, states, and municipalities have considerable future pension obligations and analysts (both equity and debt) are giving increasing attention to fluctuations in the funded status of pension plans. Consequently, as a liability-management tool, fixed-income securities are regaining some of their popularity lost during the equity market boom. However, accompanying this increased attention and greater fixed-income asset allocation is very strong consultant, investor, and plan sponsor demand for better risk measurement. Investors have learned (the "hard way") that return must be adjusted for the risk exposure.

Second, with the poor equity returns in 2000-2002 and forecasts of only modest future equity returns over the balance of this decade, sponsors are paying increasing attention to returns on fixed-income assets. In a world of lower annual equity returns, excellent fixed-income returns are, more than ever, integral to a portfolio's overall performance. Fixed-income returns are too important to ignore. Underperforming a fixed-income benchmark by 100 bp, for example, is a serious issue for the overall portfolio and must be explained and justified. Was such underperformance the result of a well-calculated bet that at least offered the possibility of good risk-adjusted performance, or did the manager just make a major mistake? Plan sponsors and consultants now demand a full explanation.

Third, the array and complexity of fixed-income products have grown substantially. This has occurred during a period when the world economy has changed, and old, long-term relationships seem less reliable. Imagine a corporate portfolio manager who took a sabbatical from the business in 1996 and returned in 2004. In 1996, Ford (A-rated), Deutsche Telekom (Aa-rated), PG&E (A-rated), AT&T (Aa-rated), J. C. Penney (A-rated) and the highly-regarded pipeline company, Enron (Baa2/BBB+) were considered solid credits. An overweight to these names and sectors was considered an unremarkable, low-risk credit portfolio. In 2004, an equivalent overweight to these names (if available) would give even the most experienced credit portfolio manager some anxiety. In addition, what do recent developments such as credit derivatives, equity volatility, correlated defaults, and "leveraged" capital imply about credit sector volatilities and correlations?

Investors familiar with Lehman's risk modeling methodology can go directly to the new Global Risk Model annotated Risk Reports:

Fourth, the growth of financial leverage (e.g., via hedge funds) has transformed the marketplace, even for investors in Treasuries and highly-rated credit debt. As learned during the 1998 collapse of Long Term Capital Management, leverage (especially, the rapid unwinding of leverage) can exacerbate spread volatility. Ironically, sponsors who prohibited their asset managers from using leverage nevertheless suffered during this period. Measuring risk is everyone's priority.

Fifth, portfolios have become increasingly globalized. Plan sponsors and their managers have learned the importance of having a range of less correlated bets in a portfolio as a way to improve risk-adjusted performance. Consequently, many plan sponsors have adopted highly diversified benchmarks such as the Lehman Global Aggregate Index, which allows managers to express a wide range of low-correlation views. However, moving to a global benchmark raises a number of new questions. In particular, should the plan sponsor hire individual managers for each currency market or hire global managers? Global managers have argued that a single manager can better allocate assets across markets to take advantage of investment opportunities and to better track overall portfolio risk. How can the traditional domestic fixed-income manager compete in a world moving to more global benchmarks?

For a fixed-income portfolio, all of these developments imply the following: more varied risk exposure; less predictable volatilities and cross-market correlations; less reliance on intuition; and increased demand for more objective risk quantification. The increased attention to the quantification of risk has generated considerable interest in risk models—a tool to estimate either the total return volatility of a portfolio or the volatility of the relative return of a portfolio versus an index, over a particular holding period. Lehman's risk model development effort began in the mid-1980s and culminated in the launch, via *PC Product*, of its first fixed-income risk model in 1991.[1] Over the subsequent years, as new asset classes (e.g., ABS and CMBS) emerged in the marketplace, they were added to the risk model. As new security analytics were developed, new modeling techniques were incorporated as well. Today, given the growing numbers of global fixed-income active managers and the rapid adoption of the Lehman Global Aggregate Index (launched on January 1, 1999) as a performance benchmark, Lehman is introducing its Global Fixed-Income Risk Model.

The job of a risk model is to quantify the sources of risks within a portfolio, reflecting the interrelationships among different exposures.

The job of a risk model is to quantify the sources of risks within a portfolio, reflecting the *interrelationships* among different exposures. For example, a mortgage portfolio manager generally knows that his or her portfolio contains many active positions versus the benchmark. He or she may describe the portfolio as: overweight duration, short spread duration, less negatively convex than the benchmark, overweight both 15-year versus 30-year and GNMAs versus conventionals. But, how much risk is the portfolio taking? While many experienced portfolio managers have an intuitive idea what a single, active position, in isolation, means in terms of possible under- or outperformance, intuition reaches its limit when there are many simultaneous active decisions in the portfolio. Some active positions offset each other and reduce overall portfolio risk, while others can compound and increase risk. A risk model quantifies how these various

[1] *The Lehman Brothers Multi-Factor Risk Model,* L. Dynkin, J. Hyman, and W. Wu, Lehman Brothers, July 1999.

risks are interrelated and adds real value by giving the portfolio manager a complete picture of the portfolio's risk exposure.

Consider the case of a corporate bond manager who has an undesired underweight exposure to the consumer cyclical sector. The manager has the opportunity to buy more of a cyclical issuer, such as Toyota. However, while this purchase would eliminate the sector underweight, it might produce an overweight in the issuer's name within the portfolio relative to the benchmark. Does the elimination of the sector-specific systematic risk more than offset the increase in idiosyncratic risk due to the overweight in the issuer? Without a sophisticated risk model, any manager would be hard-pressed to answer such a question.

These questions become more difficult as the scope of the portfolio and benchmark increase. For a portfolio benchmarked to the U.S. Aggregate Index, how does an MBS sector overweight relate to an Agency sector underweight? Do these positions largely offset each other? If so, does this remain true if the MBS portfolio contains an overweight to GNMA premiums? The situation becomes even more complicated for a global manager using the Global Aggregate Index. What are the interrelationships for all of the various risk exposures in a global portfolio? If the manager is overweight euro cyclical corporates and decides to short yen versus the dollar, has the manager increased or decreased the tracking error risk[2] of the portfolio versus the benchmark?

Plan sponsors can also use a risk model in their investment decision-making process.

Plan sponsors can also use a risk model in their investment decision-making process. Many investment guidelines are structured by considering the allowable risks in isolation. For example, a manager must have the portfolio's duration within 0.5 years of the benchmark. Separately, the manager may only have an MBS sector overweight/underweight of at most 10% of the portfolio's market value. Some guidelines may specify a minimum percentage holding of GNMAs. However, most guidelines are silent on the permissible convexity deviation versus the benchmark. How much risk is the plan sponsor allowing the investment manager to take? A risk model can help answer such key questions.

The definition of risk varies depending on investor objectives. For a buy-and-hold investor with a long investment horizon and a stream of liabilities, the main sources of risk are the default risk of credit holdings and the reinvestment risk of interim cash flows. For a total return investor benchmarked to a market index, risk is usually defined in terms of performance relative to the benchmark.

The Lehman Brothers Multi-Factor Risk Model focuses on the second definition of risk. It was developed to help investors benchmarked to one of Lehman's Bond Indices quantify the expected monthly volatility of the return difference between the portfolio and benchmark. The 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 risk model

[2] "Tracking error risk" or "tracking error volatility" (TEV) is defined as the standard deviation of the difference between the portfolio's total return and the benchmark's total return.

has unsurpassed capabilities as we will demonstrate in this paper. And we are not done! Over time, with the accumulation of longer time series and further methodological improvements, the quality of our risk model will continue to improve.

How the Lehman Risk Model works is straightforward. The model derives historical magnitudes of different market risk factors and the relationships among them. It then measures current mismatches between portfolio and benchmark sensitivities to these risks and multiplies these mismatches by historical risk factor volatilities and correlations ("covariance matrix") to produce its key output, monthly tracking error volatility.[3] Tracking error volatility (sometimes simply referred to as "tracking error") is an important ingredient in the fixed-income manager's portfolio management process.

Tracking Error Volatility (TEV) is defined as the projected standard deviation of the monthly return differential between the portfolio and the benchmark.[4] While TEV is a measure of volatility, it can be used to make forecasts of the likely distribution of a portfolio's future returns relative to its benchmark. For example, assuming return differences are normally distributed, a portfolio with a TEV (i.e., one standard deviation) of 25 bp per month would be expected to have a return within +/- 25 bp per month of the benchmark's return, approximately 2/3rds of the time (and *under*performance of worse than -25 bp about 1/6th of the time). The Risk Model offers detailed analysis of sources of the TEV, their relative contribution to the total risk, and their interdependence.

In the new Global Risk Model , we have expanded security coverage to include the Global Investment-Grade and U.S. High-Yield markets. This new model also handles out-of-index instruments such as interest rate futures, swaps, caps and floors.

Since the early 1990s, we have developed and shared with investors a number of versions of this proprietary risk model.[5] In the new Global Risk Model (released in November 2003), 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 global investment-grade, inflation-linked, U.S. and Euro high-yield and emerging market securities. This new model also handles out-of-index instruments such as interest rate futures, swaps, caps and floors.

Consistent with past practice, our Risk Model considers all sources of performance differential between a portfolio and a benchmark. Market risk falls into two broad categories: risk resulting from the differences between the portfolio's and benchmark's sensitivities to common market risk factors (examples of such sensitivities are 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 is called *security-specific, or idiosyncratic risk*. Both are considered in our Risk Model. In addition, for securities rated Baa or lower, the Risk Model goes one step further to include default risk, which is translated into units of return volatility.

---

[3] For investors new to risk models, we offer in Appendix A a brief tutorial on the mechanics of how risk models work. Appendix B provides a review of basic risk model mathematics.

[4] More precisely, TEV measures the volatility of the uncertain part of the return difference between the portfolio and the benchmark around the expected difference in their returns.

[5] The Lehman Brothers Multi-Factor Risk Model, L. Dynkin, J. Hyman, and W. Wu, Lehman Brothers, July 1999.

Default risk is part of systematic spread risk and idiosyncratic risk. However, when a bond goes into default, multiplying the spread duration of the promised cash flows (which will not be paid in full) by the spread volatility of its peer group is an extremely imprecise measure of risk. We have found that substantially greater accuracy can be obtained for "default-risky" bonds by including a set of default risk factors that account for the difference between the bond's promised cash flow and the likely recovery rate in the event of default. We also include the effect of default correlations among issuers, which represent the systematic risk of an overall increase in default rates.

The new Global Risk Model also expands from a single currency (U.S. dollar) to all securities in the Lehman Global Aggregate Index, which covers 23 currencies (as of March 2005) and a wide spectrum of spread asset classes. This expansion beyond the U.S. dollar alone significantly increased the complexity of the model and required developing new techniques for dealing with historical time series of uneven length in different currencies. For example, historical return time series for euro-denominated assets starts in 1999, while the Lehman U.S. Credit Index returns go back to 1987. The Risk Model attempts to use the maximum-length time series in all instances.

With the globalization of our Risk Model came the need to compute risk for out-of-index instruments included in nearly every global portfolio (*e.g.,* interest rate futures, currency forwards, and interest rate swaps). The model handles a wide variety of such instruments, mostly by mapping their risk exposures on appropriate risk factors in the cash markets.

The main purpose of the Risk Model is to help a manager structure a portfolio with a desired set of risk exposures ("bets") relative to the benchmark.

The main purpose of the Risk Model is to help a manager structure a portfolio with a desired set of risk exposures (*"bets"*) relative to the benchmark. (The benchmark can either be a generic Lehman index, a custom client-specific index, or another portfolio.) The model is not intended as an ex-post analysis tool of a manager's positions, but rather as an ex-ante tool for portfolio structuring. Construction of portfolios, with a desired level of active risk, is crucial to asset managers that aim to generate a target alpha. For example, most "long-only" practitioners consider a realized information ratio (alpha divided by TEV) of 0.5 to 1.0 to be at the high end of an achievable range (of course, hedge funds strive for considerably higher results). This means that a manager with an expected alpha of 50 bp/year needs to run a risk of deviation from the benchmark of 50-100 bp/year. Should the projected TEV be much lower, achieving the target alpha is very unlikely. Active managers can use the Risk Model to ensure that the expected gain from a given exposure is sufficient to justify the risk to the portfolio from that exposure.

Risk budgeting has become an increasingly important portfolio management discipline to allocate risk optimally within a portfolio. The appropriate quantification and budgeting of active risks is a multi-dimensional task that is difficult to accomplish without the aid of tools such as a risk model. In particular, the correlations among the different active exposures make the measurement of net risk quite complex. However, TEV offers a common unit (return volatility relative to the benchmark) for diverse sources of risk ranging from FX exposure to credit sector overweights to issuer concentrations. For risk budgeting, the common unit facilitates comparing views along different market dimensions and the allocation of total risk to these views. After the active exposures have been made in the portfolio, ex-post performance attribution analysis is often performed along the same views used to reflect the ex-ante views of the manager. The objective is to find out whether these ex-ante views paid off as expected.

The Risk Model uses historical data, which, admittedly, has limitations. However, there are few alternatives to a history-based approach to the construction of a robust risk model. In this paper, we will review some of these alternatives, such as scenario analysis or path simulation, and point out the pros and cons of each. Even when the objective is to stress-test a portfolio relative to an index in an extreme scenario, historical magnitudes of market risks and the relationships among them are required to generate either extreme or historically consistent scenarios.

The Risk Model is also used to construct index replicating (proxy) portfolios by rebalancing a portfolio so that is has a very low TEV. The model uses a number of optimization algorithms to find the necessary portfolio position trades given various market constraints.

Lehman Brothers Research employs the Risk Model to help investors in many ways: to structure active or replicating portfolios, to rebalance portfolios to changing objectives with minimum turnover, to optimize risk budget allocations, and to provide objective, quantifiable advice on an expanding array of portfolio management topics.

Our presentation on the Lehman Global Risk Model is organized as follows:

Chapter 1 describes Lehman's approach to risk modeling. We discuss some of the difficulties and criticisms of our approach. We also discuss some alternative approaches. On balance, however, we argue that Lehman's approach, which utilizes Lehman's extensive database of bond-level returns, offers portfolio managers two important benefits: robust model calibration and intuitive specification of portfolio risk exposures. In other words, not only can the manger use the model with a high level of confidence, but the model also gives the manager the ability to translate the model's output into specific market actions to achieve a specific goal.

When using the Risk Model to analyze a portfolio, the manger immediately receives an extensive and objective analysis of the portfolio's risk in both absolute terms and versus the benchmark. One of the key outputs of the Risk Model is the portfolio's expected tracking error volatility (TEV) versus its benchmark. However, the Risk Model offers considerably more detailed risk analysis. This analysis is delivered in the form of the Risk Report, which is described in Chapter 2. After reviewing the Risk Report a portfolio manager would be able to answer the following questions:

i. How risky is the portfolio?
ii. What are the sources of this risk?
iii. What is the portfolio's sensitivity to risk factors?
iv. To what degree are the portfolio's risk exposures correlated?
v. What is the portfolio's security and issuer specific risk?

The specific contents of the Risk Report vary depending on the underlying portfolio and benchmark. For example, a portfolio containing only U.S. dollar assets managed against the Lehman U.S. Aggregate Index will not show risk exposures to non-U.S. currencies, euro or sterling credit risk factors, etc. Similarly, a sterling-only portfolio managed against the Sterling Aggregate Index will not show risk exposures to the U.S. dollar or euro or U.S. credit spread risk factors, etc. While the contents of the Risk Report may vary from portfolio to portfolio, the report's general format is invariant. Chapter 2 describes four Risk Reports: a U.S. dollar portfolio (versus the U.S. Aggregate Index), a euro portfolio (versus the Euro Aggregate Index), a pan-european portfolio, including euro, sterling, and Swedish krone-denominated bonds (versus the Euro Aggregate Index) and finally, a multi-currency portfolio (versus the Global Aggregate Index).

The power of the Risk Model is that gives the manager a set of optimal choices based on the manager's experience and assessment of market conditions.

As mentioned above, the Risk Model is best used by portfolio managers as an *ex-ante* trade or portfolio evaluator, not as an *ex-post* portfolio reporting system. The power of the Risk Model is that it gives the manager a set of optimal choices based on the manager's experience and assessment of market conditions. Chapter 3 illustrates (with examples) many of the portfolio applications of the Risk Model:

i. **Structuring an Efficient Active Portfolio:** A portfolio manager can use the Risk Model to structure portfolios finely tailored to reflect his or her market views.
ii. **Evaluating Portfolio Trades:** The Risk Model can be readily used to analyze the risk impact of a proposed trade.
iii. **Optimizing a Portfolio:** The Lehman Risk Model has a built-in optimizer. The optimizer allows the manager to select from an eligible list of bonds those that would help reduce his portfolio's tracking error volatility to a desired level.
iv. **Constructing Proxy Portfolios:** The Risk Model and optimizer can be combined to construct a "proxy" portfolio, containing relatively few issues, that is designed to track a broader index.
v. **Scenario Analysis:** The Risk Model can be used to help the manager specify scenarios, as well as the probabilities of the scenarios, that are internally consistent with broad market history (i.e., "maximum likelihood" scenarios).
vi. **Risk Budgeting:** A manager (and the plan sponsor) can use the Risk Model to monitor the portfolio's adherence to its risk budget allocation and to compare different types of risk on the same grounds.

Chapter 4 offers details on the structure of the Risk Model. The first step of the Risk Model is to decompose a bond's random total returns into various components. The first component is the systematic component of total return. It is the result of exposure to risk factors that affect the returns of all bonds in a given peer group (i.e., systematic risk factors). The other component of returns is the idiosyncratic return, which is driven by factors specific to the bond's issuer. Chapter 4 provides some detail on how the Risk Model handles this "return splitting."

Once returns are split into their various components, what are the risk factors that influence these returns? Specifically, what are the systematic risk factors? How do we measure a portfolio's sensitivity to these risk factors? How does the Risk Model measure idiosyncratic risk? How does the Risk Model handle default risk (including correlated defaults)? Answers to these questions depend on a bond's asset class. For example, a euro corporate bond and a U.S. corporate bond will have different systematic risk factors. The goal of Chapter 4 is to offer a brief description, by asset class, of how the Risk Model is specified.

Interested investors who have little familiarity with risk models can refer to Appendix A for a brief tutorial on how risk models are put together and how they generate an estimated tracking error volatility value. Appendix B reviews basic risk model mathematics.

Chapter 5 provides evidence on the predictive power of Lehman's multi-factor risk modeling approach to estimate a portfolio's ex-post risk. We perform various tests to examine whether the Risk Model does a good job estimating volatilities. Chapter 5 shows that the model produces good estimates of total return and tracking error volatilities, validating our risk modeling methodology.

The Lehman Global Risk Model is one of several portfolio risk measurement tools available to the manager. These other tools include scenario analysis, Value-at-Risk, Monte Carlo simulation, performance attribution, and traditional mean-variance analysis.

The Lehman Global Risk Model is one of several portfolio risk measurement tools available to the manager. As described in Chapter 6, these other tools include scenario analysis, Value-at-Risk, Monte Carlo simulation, performance attribution, and traditional mean-variance analysis. Because all tools have their particular strengths and weaknesses, these tools are often best used in a complementary fashion. For example, scenario analysis allows the manager to examine the portfolio's performance in extreme scenarios—so-called stress testing. The limitation of scenario analysis, as we will discuss, is the difficulty of defining multi-sector scenarios that are consistent with market behavior.

Another risk management tool, simulation, allows the manager to examine the performance of his portfolio (usually in absolute terms) in a set of worst case environments (*i.e.,* "tail risk"). The potential advantage of simulation is that it can model the behavior of the portfolio's performance with few restrictions on the underlying distribution of returns. Generally, simulation uses the actual shape of the distribution of historical returns to generate a distribution of potential portfolio returns. In contrast, the Risk Model uses only the mean and standard deviation of historical returns to generate the future portfolio return distribution. The limitation of simulation is the vast complexity of the exercise, especially for global portfolios. Chapter 6 discusses several other risk management tools and how they compare with the Lehman Risk Model.

We conclude with a brief discussion of future directions for the Lehman Global Risk Model. Many of these ideas and plans arise from our interactions with portfolio managers, plan sponsors, consultants, and academics. Our hope is that our new Global Risk Model will prompt many further interactions that ultimately lead to even better model accuracy and contribute to the global advancement of debt portfolio management practices. Our Modeling and Quantitative Portfolio Strategy teams welcome your questions. Your insights will spur more rapid progress in the development of future generations of risk models and expand the list of portfolio management applications.

1. MOTIVATION FOR USING THE LEHMAN BROTHERS RISK MODEL

The standard approach to risk estimation is a market structure report. However, while useful, the market structure approach has significant shortcomings that the Risk Model addresses.

In the absence of a risk model, the standard approach to risk estimation is to compare a portfolio versus its benchmark along relevant dimensions (duration buckets, credit sectors, MBS pricing tiers, etc). We call this comparison a "market structure" report. Figure 1 shows an example of such a report for a portfolio ("Aggregate-active (2)") versus a benchmark (the Lehman U.S. Aggregate index).

The manager verifies that the exposures in every significant cell reflect his views both in sign and magnitude. This is always a valid and necessary step in portfolio construction. These cells are essentially common market risk factors that the manager feels are relevant to a specific portfolio.

However, while useful, the market structure approach has significant shortcomings that the Risk Model addresses. First, even along the same axis, cells differ in risk terms. For example, does the -0.61 spread duration mismatch in ABS entail much more risk than the -0.12 mismatch in MBS? Second, some mismatches offset one another to a significant degree (*e.g.*, a market value underweight to agencies and overweight to ABS). The Risk Model takes the extra steps of determining which risk factors, or "cells," best explain the return volatility of each asset class, by quantifying their historical variances and correlations. This allows these differences in cell allocations (risk sensitivities) to be properly translated into total risk.

In both the market structure and risk model approaches, it is also common to examine issuer concentration reports. As we will show, the Risk Model concentration report not only gives a sense for the over- or under-weight in a given issuer, but quantifies the associated contribution to TEV.

Figure 1. **Simple Market Structure Report**
Portfolio Name: Aggregate_active(2), Benchmark: U.S. Aggregate Index, December 31, 2004, USD

	Total	Treasury	Agency	Credit	MBS	ABS	CMBS	Cash
Market Value								
Aggregate_active(2)	$2,900,741,606	$711,620,565	$190,349,958	$983,590,537	$687,361,815	$116,194,013	$112,838,348	$98,786,371
OA Duration								
Aggregate_active(2)	4.52	6.01	5.66	5.38	2.57	1.97	4.08	0
US Aggregate	4.34	5.35	3.79	5.74	2.86	2.58	4.59	
diff	*0.18*	*0.66*	*1.87*	*-0.36*	*-0.29*	*-0.61*	*-0.51*	
OA Spread Duration								
Aggregate_active(2)	4.64	5.93	5.68	5.34	3.23	1.97	4.08	0
US Aggregate	4.49	5.3	3.72	5.71	3.35	2.58	4.59	
diff	*0.15*	*0.63*	*1.96*	*-0.37*	*-0.12*	*-0.61*	*-0.51*	
Market Value [%]								
Aggregate_active(2)	100	24.53	6.56	33.91	23.7	4.01	3.89	3.41
US Aggregate	100	24.68	11.01	24.8	35.08	1.37	3.06	
diff	*0*	*-0.15*	*-4.45*	*9.11*	*-11.38*	*2.64*	*0.83*	*3.41*
Contribution to OASD								
Aggregate_active(2)	4.52	1.45	0.37	1.82	0.61	0.08	0.16	0
US Aggregate	4.34	1.31	0.41	1.42	1.00	0.04	0.14	0
diff	*0.18*	*0.15*	*-0.04*	*0.40*	*-0.39*	*0.04*	*0.02*	*0*

Exclusive reliance on cell comparisons can lead to an insufficient risk budget and low alpha, misplaced views, and wrong magnitudes of exposures.

We certainly do not advocate reliance on the risk model output to the exclusion of the market structure report. The Risk Model is driven by historical relationships among risk factors, which can lose predictive power temporarily (*e.g.,* during extreme market liquidity crises). Such crises are usually short-lived and are followed by the reversion to more historically typical behavior. Nevertheless, a cell-by-cell comparison between the benchmark and the portfolio constructed with the help of the Risk Model can ensure that no extreme cell exposures are taken because of over-reliance on historical correlations. On the other hand, exclusive reliance on cell comparisons can lead to an insufficient risk budget and low alpha, misplaced views, and wrong magnitudes of exposures.

A. Lehman's Approach to Risk Modeling: The Historical-Parametric Approach

Lehman derives its risk measure using variances and correlations calculated from historical returns. Such a history-based approach is often subject to criticism for instability of correlations among market risk factors and dependence of their volatilities on the interest rate cycle, etc. Another objection to this approach is the reliance on only the means and standard deviations. In reality, many returns distributions are characterized by "fat tails," where the risk of extreme events is inadequately captured by the standard deviation.

Our confidence in our approach derives from the relative stability of long-term correlations among asset returns. While correlations may deviate for a month or two from their normal long-term values, they tend to be mean-reverting.

A further objection to the historical-parametric approach is the difficulty of dealing with historical time series of unequal length. For example, there may be ten years worth of corporate bond data but only five years of ABS data. How can this approach calculate a correlation between these two sectors of the market without having to curtail the longer time series? Given the growth of new markets (*e.g.,* CMBS, inflation-linked notes, and Euro Corporates) and the relatively recent emergence of returns data for other asset classes (*e.g.,* smaller European countries), the problem of dealing with unequal time series is a limitation of the historical-parametric approach. Although Lehman has developed statistical techniques to deal with this problem in a consistent way while preserving the valuable historical information embedded in the longer historical time series, this remains a source of criticism. Our confidence in our approach derives from the relative stability of long-term correlations among asset returns. While correlations may deviate for a month or two from their normal long-term values, they tend to be mean-reverting. We feel that the value of using as much of the available time series as possible, in order to capture asset return behavior in as wide assortment of market environments as possible, greatly outweighs the difficulty of working with uneven time series.

An alternative approach to risk modeling is "forward simulation" or "scenario analysis." Instead of relying on historical variances and correlations, the manager analyzes the relative performance of the portfolio and benchmark under many possible future market environments. For securities whose returns are driven mostly by term structure risk, such as Treasuries or MBS, one can generate a set of likely or extreme yield curve scenarios. "Extreme" term structure scenarios can be derived from implied interest rate volatilities (in the option or swaption markets) rather than from history.

However, for multi-sector portfolios with allocations to credit (with default risk), such scenario simulation is a daunting task. The portfolio manager must simulate not only the term structure, but movements in credit spreads as well. Furthermore, the manager's simulations must be consistent. In other words, simulated movements in the term structure, combined with movements in credit spreads must have some foundation in reality—not only in both the absolute and relative magnitude and direction of the movements, but also the probability. This foundation can only come from historical observations.

While scenario analysis is very useful for examining possible extreme market movements, its practicality for measuring risk in normal market environments is very limited.

Reliance on "implied" volatilities and correlations for scenario analysis is not feasible as there is not enough market-based information on implied credit spread volatility and correlations of spreads with interest rates. In addition, the dimensionality of a scenario definition for credit is also extremely high; there are many credit sectors, credit ratings, and individual issuers. As many portfolio managers will attest, a complete simulation of possible scenarios for a multi-sector portfolio is a very complex and time-consuming task. While scenario analysis is very useful for examining possible extreme market movements, its practicality for measuring risk in normal market environments is very limited.

We have examined many of the concerns raised by our historical-parametric risk modeling approach. In some cases we have used them to help improve the risk model. One example is the concern over the potential instability of asset return correlations. In response, the Global Risk Model defines the spread risk factors as movements in spreads versus the local swap curve, as opposed to the treasury curve. In particular, our procedure is to divide spreads over Treasuries into swap spreads and spreads over swap rates. What do we gain with this decomposition?

First, the decomposition allows us to consider the volatility of swap rates as a separate source of risk. It is statistically and economically meaningful to single out this risk factor. The decomposition also makes it easier to identify the different sources of correlation instability. We argue that much of the instability of the correlations among spread specific risk factors when defined against the Treasury curve over the last few years is in fact embedded in swap spreads and not in the specific factors. When these two factors (*i.e.,* spreads to swaps and swap spreads) are bundled together, we get an impression of instability that may be false. Once the source of instability—namely, swap spreads—is removed, that impression is largely reduced. Therefore, the decomposition delivers a more accurate picture of the different sources of risk and the nature of their relationship. The result is that the correlations across the spread risk factors to the swap curve are, in fact, much more stable.

To illustrate this point, let's look at the correlation among changes in spreads for major U.S. indices. We begin by constructing two series of changes of OAS for each index: one with OAS defined over the Treasury curve, the other over the swap curve. We divide the sample period—January 1992 to September 2003—in two: January 1992 to July 1998 and August 1998 to September 2003. We choose this division to highlight the latter period when swap spreads were relatively volatile. Finally, we focus on four U.S. asset classes: Corporates, MBS, ABS, and Agencies.

Figure 2 presents the correlation matrices for each asset class pair. The differences in correlations between swap (SWP)-based and Treasury (TSY)-based spreads are clear once the two sub-periods are analyzed. For instance, over the first sub-period the Corporate/Agency correlations under SWP and TSY are quite different, 0.62 and 0.34, respectively. Over the second sub-period these numbers for the Agency/MBS are also quite dissimilar, 0.32 and 0.72, respectively.

Figure 2. **Correlation of Swap- and Treasury-Based Spread Changes**

1992-2003

	CRP	AGY	MBS	ABS
CRP		0.34	0.27	0.62
AGY	0.31		0.28	0.52
MBS	0.33	0.44		0.33
ABS	0.60	0.42	0.37	

TSY Spreads

SWP Spreads

1992-1998

	CRP	AGY	MBS	ABS
CRP		0.62	0.40	0.65
AGY	0.34		0.27	0.55
MBS	0.30	0.10		0.35
ABS	0.44	0.29	0.21	

1998-2003

	CRP	AGY	MBS	ABS
CRP		0.31	0.28	0.65
AGY	0.34		0.32	0.57
MBS	0.40	0.72		0.34
ABS	0.66	0.49	0.48	

Compare the correlations across the two periods for each of the two spread definitions. Figure 2 shows that swap-based spread correlations are quite stable across the two subperiods. The only exception is the Corporate/Agency pair, but this was due to the rash of significant credit shocks throughout the second period. However, correlations change significantly across periods when we look at Treasury-based spreads.

Moreover, one can see that all correlations are equal or (significantly) higher over the second period for Treasury-based spreads. This means that using the data from the first period would significantly underestimate the correlation of the factors over the second period. This seems to justify the concerns about the stability of correlations referred to above. However, the same is not true for the swap-based spreads. There is no apparent systematic bias in any particular direction for these spreads. The exception again is for the corporate class, for which the correlations are generally lower in the second period.

Overall, the evidence seems to suggest significant stability in the correlation matrix for the swap-based spread definition used in the new Global Risk Model. This result supports our historical-parametric approach to risk model design and the usefulness of the Risk Model as a tool for forward-looking risk measurement.

B. Weighting Historical Observations

How many of the available historical observations should be used when estimating the risk model's parameters? Should the risk model use all available history with equal weights or give greater weight to more recent observations?

As discussed above, use of historical data to compute the volatility and correlation parameters often runs into the problem of short or uneven time series due to the inclusion of new asset classes (*e.g.,* Euro Credit) or the lack of long stationary time series for established asset classes (*e.g.,* MBS). But, even when this is not an issue, we have to ask how many of the available historical observations should be used when estimating the risk model's parameters? Should the risk model use all available history with equal weights or give greater weight to more recent observations? While there is no obvious right or wrong answer to this question, it is useful to consider some of the arguments on both sides.

There are two strong arguments in favor of weighting historical observations unevenly. First, the risk characteristics of some asset classes evolve over time. Consequently, giving more weight to recent historical observations may be reasonable. For U.S. mortgage-backed securities (MBS), for example, prepayment efficiency has increased so dramatically over the last decade that the prepayment history of the late 80s and early 90s is no longer applicable. Whenever such evolution occurs, we should limit historical observations used in calibrating the model to only the relevant time period.

Second, during times of rapidly rising market volatility, an equal-weighted series of historical observations would underestimate the near-term risk of a portfolio. An example is the rise in issuer-specific volatility in the U.S. credit markets in 2001-2002. During such times, the risk model needs to incorporate recent experience "faster" in order to give more realistic risk projections. This can be achieved by giving greater weight to more recent observations of market behavior and lesser weight to older historical experience. However, in calm markets, this "time decay" approach to the use of historical observations could lead to underestimation of risk because of the low weight given to past market crises.

In contrast, the advantage of giving equal weight to all historical observations is that the risk model will incorporate risks that market participants may have become complacent about. For example, the spike in volatility in 1997 and 1998 followed a relatively long tranquil period in the fixed-income markets. During the tranquil period the Lehman Risk Model "overestimated" risk because it still remembered the volatility experienced in the late 1980s and early 1990s. Consequently, the volatility experienced in 1997 and 1998 was not inconsistent with the risk model's expectations.

Our recommended answer to the historical weighting question is to run the Risk Model under both assumptions and use the higher result as a conservative risk estimate.

Our recommended answer to the historical weighting question is to run the Risk Model under both assumptions and use the higher result as a conservative risk estimate.

C. Why a Multi-Factor Model and Not an Asset Volatility Model?

Why resort to factor analysis of bond returns that decomposes returns into components driven by common market variables (yield curve movement, sector spread changes, volatility changes, etc)? Why not just study historical volatilities and correlations of asset classes (or sectors) present in the portfolio and the benchmark and multiply them by portfolio over-weights or under-weights to each one? Or, alternatively, why not study historical behavior of individual issuers (issues) in the portfolio and the benchmark and derive risk estimates from over- or under-exposure of the portfolio to individual holdings?

The traditional approach to evaluating risk in a multi-sector portfolio does indeed rely on volatilities and correlations among different asset classes. The active view relative to a benchmark becomes simply the weight differential between the portfolio weight and the benchmark weight in a particular asset class. These weight differentials (active exposures) are then multiplied by a matrix of volatilities of each asset class and their correlations to get the projected tracking error.

This approach has two main shortcomings. First, the dominance of interest rates in driving the returns of all fixed income instruments creates very high correlations among asset classes. This makes it very difficult to properly measure (and optimize) the risk due to sector allocations. This issue can be partly addressed either by subdividing markets by maturity or duration, or by viewing spread asset classes in terms of excess returns, but each of these approaches brings issues of its own.

Second, the asset class representation ignores diversification risk. Assume the portfolio allocation to a given asset class is achieved by holding few securities and the benchmark allocation is well diversified. The asset volatility approach will show no risk as long as these two allocations have identical weights. Resorting to historical analysis of correlations among specific issuers (or issues) solves this problem, but creates many others. How does one evaluate the risk of a new issuer with no established market history? As a practical matter, how can one derive correlations among thousands of issuer (or issue) return time series from the limited set of available observations?

Risk factor decomposition of security returns provides a viable solution for both of these problems. First, our model selects a fairly small number of common risk factors for each market sector, which leads to a manageable number of correlations to be estimated from history. Then, we conduct historical calibration at the individual security level, leaving us with the part of bond returns unexplained by changes in all common market risk factors combined. We use these residuals to quantify security-specific risk by category of issuer (or issue) and compute the diversification risk in a portfolio.

D. The Lehman Brothers Advantage

Lehman's particular risk model implementation offers two distinct benefits to portfolio managers: accurate model calibration and intuitive specification of the exposures to the risk factors.

As discussed above, it is our belief that our historical-parametric approach to multi-factor risk modeling offers an objective and realistic tool for forward-looking risk measurement. In addition, Lehman's particular risk model implementation offers two distinct benefits to portfolio managers: accurate model calibration and intuitive specification of the exposures to the risk factors. There are several reasons we are able to deliver these benefits to users of our Risk Model.

Portfolio managers can use the Risk Model confident that the best market data available have been used to generate its parameters.

First, Lehman Brothers has been a dominant provider of fixed-income market indices to U.S. domestic and global investors for over 30 years. Over these decades, the trader-sourced pricing and analytics data in our indices have been assiduously monitored by many investors benchmarked to our indices. We, therefore, have high quality historical information at the individual security level that we use to calibrate the Lehman Global Risk Model. Portfolio managers can use the Risk Model confident that the best market data available have been used to generate its parameters.

The manager can easily translate the output from the Risk Model into specific market actions to achieve a desired goal.

Second, Lehman Brothers has had the advantage of working closely, over long periods of time, with investors who manage against Lehman indices. As a result of these relationships, Lehman is attuned to designing tools that are intuitive to portfolio managers. This is important so that the manager can easily translate the output from the Risk Model into specific market actions to achieve a desired goal. To maintain an intuitive set of risk factors, we may use a larger set of correlated factors instead of the smallest possible set of independent factors, which are often referred to as "principal components" of market movement.

To understand the importance of Lehman's modeling orientation, consider that risk measures are a product of current risk sensitivities and the historical volatilities and correlations of risk factors. For a portfolio manager, the risk sensitivity of a bond is a duration-type measure (*i.e.,* the price of the bond will change by a certain percentage amount given a specified change in interest rates). In addition, a portfolio manager usually interprets risk factors as changes in rates, spreads, or volatilities.

The same models are used to produce risk sensitivities for both portfolios and indices, which enables an "apples-to-apples" comparison.

Lehman's risk model was designed with this intuition in mind. Lehman relies on its state-of-the art modeling efforts in interest rates, prepayments, and volatilities to generate risk sensitivity measures (key-rate-durations, spread durations, and vegas) for individual bonds. The same models are used to produce risk sensitivities for both portfolios and indices, which enables an "apples-to-apples" comparison. When we fit bond returns to the risk factor model, we use these sensitivity measures, with which managers are very familiar, as the independent variables (*i.e.,* we impose risk sensitivities). The regression coefficients are then risk factors (*i.e.,* we "back out" the factor realizations), which can be readily interpreted as changes in rates, spreads, and volatilities. While Lehman's approach is contrary to the conventional approach to risk modeling, our Risk Model is much easier for a portfolio manager to use.

While Lehman's approach is contrary to the conventional approach to risk modeling, our Risk Model is much easier for a portfolio manager to use.

For example, the uncertain part of the excess return of a corporate bond (over key-rate duration-matched Treasuries) is modeled as its spread duration (risk sensitivity) times an unknown quantity (risk factor), plus an unexplained residual. Since returns are in percentage units, and spread duration is in (percentage/bp) units, the risk factor is in bp units and can easily be interpreted as the average spread change for the bond's credit sector. If the manager wishes to reduce his risk exposure to this factor, he can rely on spread duration matching to build a trade.

This is in contrast to a modeling approach that represents excess return as an average change in its known sector spread (the independent variable) times an unknown sensitivity of a particular bond to this change, which is estimated as the fitted regression coefficient. As this fitted sensitivity measure may be greater or less than the standard spread duration measure, how readily can the portfolio manager know what trade to execute to reduce his risk exposure?

The Lehman Risk Model quantifies security-specific risk by analyzing historical returns of individual securities.

And finally, the Lehman Risk Model quantifies security-specific risk by analyzing historical returns of individual securities. Diversification risk is very high on the investor's agenda, especially in credit portfolios. The idiosyncratic risk model uses the absolute value of the residual returns of individual securities unexplained by a combination of all the systematic risks.

In Chapter 4 we will present much greater detail on the structure of the Lehman Risk Model. But first, however, we now describe and discuss the output of the Risk Model and illustrate the model's many practical applications.

2. THE ANNOTATED *RISK REPORT*

We now discuss the key output of the Global Risk Model: the Risk Report. While the specific contents of the Risk Report will vary depending on the underlying portfolio and benchmark,[6] the report's general format stays the same. This chapter provides a detailed description of the Risk Report.[7]

The Risk Report is extensive. There is a summary page and many supporting pages of detail. The Risk Report is organized around the following questions:

i. How risky is the portfolio (in absolute terms and versus its benchmark)?
ii. What are the sources of this risk?
iii. What is the portfolio's sensitivity to risk factors?
iv. To what degree are the portfolio's risk exposures correlated?
v. What are the portfolio's security and issuer specific risks?

After reviewing the Risk Report, a portfolio manager would be able to identify portfolio trades that can adjust the portfolio's risk to a desired level.

After reviewing the Risk Report, a portfolio manager would not only know the answers to these questions but be able to use the Optimizer (discussed at length in Chapter 3) embedded in the Risk Model to identify portfolio trades that can adjust the portfolio's risk to a desired level.

We begin by describing the Risk Report for a U.S. Aggregate portfolio, followed by descriptions of the Risk Report for a Euro Aggregate (and sterling) portfolio and a Global Aggregate portfolio. Since the reports are very similar, for economy we provide a more detailed description of the Risk Report for a U.S. Aggregate portfolio with slightly less detail for the Euro and Global Aggregate portfolios. The purpose of separate sections is to allow users accustomed to a particular market to examine the Risk Report that they are likely to see routinely.

A. The Risk Report for a U.S. Aggregate Portfolio

Let's analyze a portfolio and discuss its Risk Report. Consider the following $2.9 billion fixed income portfolio (the same portfolio introduced in the previous chapter). The benchmark is the U.S. Aggregate Index. For this portfolio, the manager's investment style is to take modest duration bets (up to 0.5 years) and to overweight/underweight sectors (*e.g.,* underweight MBS versus Credit). The portfolio does take active corporate sector and name selection positions, but the corporate portfolio is generally well diversified. For the MBS/ABS/CMBS portfolios, the manager tries to track the respective indices using liquid names.

Using a simple market structure report, we see that as of December 31, 2004, the portfolio (containing 99 positions, including a small amount of cash) was positioned as follows versus the benchmark (Figure 3).

---

[6] The benchmark in the Risk Model may be an index, custom index, or portfolio. Consequently, the Risk Model may be used to run risk reports for one index against another; or one portfolio against another; or a portfolio versus cash.

[7] The Risk Report is available via POINT (**Po**rtfolio **In**dex **T**ool), Lehman's proprietary portfolio analytics platform.

Figure 3. **Simple Market Structure Report**
Portfolio Name: Aggregate_active(2), Benchmark: U.S. Aggregate Index, December 31, 2004, USD

	Total	Treasury	Agency	Credit	MBS	ABS	CMBS	Cash
Market Value								
Aggregate_active(2)	$2,900,741,606	$711,620,565	$190,349,958	$983,590,537	$687,361,815	$116,194,013	$112,838,348	$98,786,371
OA Duration								
Aggregate_active(2)	4.52	6.01	5.66	5.38	2.57	1.97	4.08	0
US Aggregate	4.34	5.35	3.79	5.74	2.86	2.58	4.59	
diff	*0.18*	*0.66*	*1.87*	*-0.36*	*-0.29*	*-0.61*	*-0.51*	
OA Spread Duration								
Aggregate_active(2)	4.64	5.93	5.68	5.34	3.23	1.97	4.08	0
US Aggregate	4.49	5.3	3.72	5.71	3.35	2.58	4.59	
diff	*0.15*	*0.63*	*1.96*	*-0.37*	*-0.12*	*-0.61*	*-0.51*	
Market Value [%]								
Aggregate_active(2)	100	24.53	6.56	33.91	23.7	4.01	3.89	3.41
US Aggregate	100	24.68	11.01	24.8	35.08	1.37	3.06	
diff	*0*	*-0.15*	*-4.45*	*9.11*	*-11.38*	*2.64*	*0.83*	*3.41*
Contribution to OASD								
Aggregate_active(2)	4.52	1.45	0.37	1.82	0.61	0.08	0.16	0
US Aggregate	4.34	1.31	0.41	1.42	1.00	0.04	0.14	0
diff	*0.18*	*0.15*	*-0.04*	*0.40*	*-0.39*	*0.04*	*0.02*	*0*

Overall, the portfolio is positioned as follows:

- duration overweight of 0.18 years;
- underweight MBS (both in terms of market value and contribution to spread duration);
- probably, as a result of the MBS underweight, less negatively convex than the benchmark (not shown in Figure 3);
- overweight credit (both in terms of market value and contribution to spread duration); and
- modest market value overweights to ABS and CMBS.

In terms of contribution to spread duration, the portfolio has a credit and government (Treasury and Agency) overweight of 0.40 years and 0.11 years, respectively. In addition, the portfolio has small overweights, in terms of contribution to spread duration, to both the ABS and CMBS sectors. In regard to MBS, the portfolio has a contribution to spread duration underweight of 0.39 years.

How is the portfolio positioned within each sector? The credit portion of the portfolio has a shorter duration (5.38) than the credit portion of the Aggregate. So, too, does the CMBS portion of the portfolio. There may be other significant differences between the portfolio and benchmark within each sector. For example, what are the relative exposures to the various credit quality categories on industry sectors? Since the credit portion of the portfolio probably holds many fewer names than the benchmark, the portfolio likely has a moderate amount of idiosyncratic (*i.e.,* “name”) risk relative to the benchmark.

The government portion of the portfolio has much longer duration (6.01 for Treasuries and 5.66 for Agencies) than the government sector in the Aggregate, possibly implying an overweight (underweight) at the long (short) end of the government curve. In contrast, the MBS and ABS portions of the portfolio are shorter than their respective indices in the Aggregate index.

In summary, the portfolio has many active positions versus the benchmark: duration overweight; credit/ABS/CMBS overweight; MBS underweight; convexity underweight; plus sub-sector and security-level active positions within each sub-portfolio versus its respective sector index.

What is the risk of the portfolio performing differently than its Aggregate benchmark?

What is the risk of the portfolio performing differently than its Aggregate benchmark? As a very rough approximation, assuming that Treasury interest rates have a monthly standard deviation of about 25 bp, then the 0.2 year duration overweight implies a monthly tracking error volatility of about 5 bp. How does the credit overweight interact with the duration exposure: does it increase or decrease the portfolio's tracking error arising from the duration exposure? The same question applies to the MBS underweight. Similarly, how do any sub-sector credit or MBS positions affect the overall tracking error number for the portfolio? As explained above, to understand how the various risk exposures interact, we need to know how the various risk factors are correlated. This is the job of the Global Risk Model.

As discussed in Chapter 1, when running the Risk Model, the portfolio manager must specify how much weight the model should give to historical observations when estimating the risk factor covariances. The Global Risk Model gives the manager two choices: equal-weighting or exponential time-weighting with a rate of time-decay equal to one year half-life (*i.e.,* an observation one-year old has one-half the weight as the most recent observation).[8] When invoking the Risk Model, the manager will be prompted to select a weighting scheme. For our example, we will use equal weighting for systematic and non-systematic risks and for credit default rates. The first page of the Risk Model report summarizes the manager's estimation choices (Figure 4).

[8] For details on the time-weighting estimation option, please refer to *New Estimation Options for Lehman Brothers Risk Model: Adjusting to Recent Credit Events*, A. Berd and M. Naldi, Quantitative Credit Quarterly, 2002-Q3, Lehman Brothers.

Figure 4. **Global Risk Model—U.S. Aggregate Portfolio User Defined Parameters**, December 31, 2004

Parameter	Value
Base currency	USD
Portfolio	Aggregate_active(2)
Benchmark	US Aggregate
Time-weighting of historical data in covariance matrix	
for systematic risk	No
for non-systematic risk	No
Time-weighting of credit default rates	No
(Implicit) Currency hedging for portfolio	No
(Implicit) Currency hedging for benchmark	No
Number of lines displayed in Issue-Specific and Credit Tickers Reports	100

The Risk Report is designed to answer several important questions regarding the risk of the manager's portfolio.

The Risk Report is designed to answer several important questions regarding the risk of the manager's portfolio. We begin with: How risky is the portfolio?

How risky is the portfolio?

The next page of the Global Risk Report is the *Portfolio/Benchmark Comparison Report* (presented in Figure 5). This report provides information similar to the market structure report.

The Portfolio/Benchmark Comparison Report shows the portfolio's 0.18 long duration position, as well as its less negative convex position (0.34). This implies that the portfolio's performance is less susceptible than the Aggregate index to an increase in realized volatility. The portfolio's OAS is modestly higher than the benchmark, probably due to the market value underweight to the government MBS sectors and the large overweight to credit. Other factors may be at work here, which we will try to uncover.

Figure 5. **Global Risk Model–U.S. Aggregate Portfolio**
Portfolio/Benchmark Comparison Report, December 31, 2004

Parameter	Portfolio	Benchmark	Difference
	Aggregate_active(2)	US Aggregate	
Positions	99	5836	
Issuers	38	614	
Currencies	1	1	
# positions processed	99	5831	
# positions excluded	0	5	
% MV processed	100.0	100.0	
% MV excluded	0.0	0.0	
Market Value	2900747874	8215148923	
Coupon (%)	5.66	5.24	0.42
Average Life (Yr)	6.99	6.87	0.12
Yield to Worst (%)	4.31	4.38	-0.07
ISMA Yield (%)	4.2	4.15	0.05
OAS (bps)	40	33	7
OAD (Yr)	4.51	4.33	0.18
ISMA Duration (Yr)	5.29	5.26	0.03
Duration to Maturity (Yr)	5.06	5.05	0.01
Vega	-0.04	-0.05	0.02
OA Spread Duration (Yr)	4.64	4.49	0.15
OA Convexity (Yr^2/100)	-0.15	-0.49	0.34
Total TE Volatility (bps/month)			**28.8**
Systematic Volatility (bps/month)	106.69	108.42	
Non-systematic Volatility (bps/month)	19.72	2.47	
Default Volatility (bps/month)	7.07	3.27	
Total Volatility (bps/month)	**108.73**	**108.5**	
Portfolio Beta			0.967

The report also shows that the portfolio has an overweight to spread duration. Consequently, given its overweight to Credit/ABS/CMBS and underweight to MBS, a tightening of Credit/ABS/CMBS spreads and/or a widening of MBS spreads is likely to help the portfolio outperform the benchmark.

The Comparison Report also shows systematic, default, and non-systematic volatilities for both the portfolio and the benchmark.

The Comparison Report also shows an estimated total tracking error volatility (TEV) in terms of bp/month. As of December 31, 2003, the portfolio had an estimated TEV of approximately 29 bp/month—quite a bit larger than our back-of-the-envelope 5 bp/month calculation based solely on exposure to Treasury curve risk (*i.e.,* duration). We will examine the details of this 29 bp/month TEV number shortly.

The Comparison Report also shows systematic, default, and non-systematic volatilities for both the portfolio and the benchmark. These values report the expected variability of the portfolio due to exposure to the systematic risk factors, exposure to default risk, and exposure to non-systematic risk factors. We discuss each of these in turn.

The total return on the portfolio has an estimated systematic volatility of approximately 106.7 bp/month arising from the portfolio's exposure to the volatility of systematic risk factors (*i.e.,* risk factors that are common to many issues such as changes in Treasury key rates). In other words, the portfolio is expected to have a standard deviation of returns of approximately 106.7 bp/month around its expected return. In contrast, the benchmark has an expected systematic volatility of approximately 108.4 bp/month.

For the index, the default volatility is 3.3 bp/month (the Risk Model only models default risk for bonds rated Baa and below). In contrast, the portfolio has 7.1 bp/month of default volatility, indicating that the portfolio has a lower quality credit profile that the index. This relative exposure arises in large part from a 0.72% position in FirstEnergy Corp 5.5%s of 11/06, rated Ba1, and a 1.26% position in AT&T 9.75% of 11/31 also rated Ba1. The possibility of default adds to total return volatility even if there are no changes to the systematic and non-systematic (*i.e.,* non-default) risk factors. As explained in Chapter 4, given a default probability, a recovery value assumption, correlation of defaults with other issuers rated Baa or lower (if there were any) in the portfolio, and a market value weight of the bond in the overall portfolio, the expected volatility to portfolio returns due to the possibility of defaults can be estimated.

Finally, non-systematic, or idiosyncratic, volatility arises from (non-default) issuer-specific risks. For a portfolio, non-systematic volatility is generally decreasing as the number of issuers increases. For the index, with a large number of issuers, non-systematic volatility is relatively low at 2.5 bp/month. For our portfolio with 99 issues, non-systematic volatility is higher at 19.7 bp/month. We will discover the source of the portfolio's relatively high non-systematic volatility later in our discussion of the Risk Report.

For the Global Risk Model, the three components of portfolio volatility are assumed to be independent of each other.[9] Consequently, total portfolio volatility equals:

[9] For a discussion of this aspect of the Risk Model, please refer to *The New Lehman Brothers High-Yield Risk Model*, Ganlin Chang, Lehman Brothers, November 2003, p. 12 (footnote 10).

$$\text{Total Volatility} = \sqrt{\{(\text{sys. vol.})^2 + (\text{default vol.})^2 + (\text{idio. vol.})^2\}}$$

$$= 108.7 \text{ bp/month}$$

The portfolio beta, 0.97, is the expected change in the portfolio's value in basis points, given a one basis point change in the value of the benchmark arising from the benchmark's systematic risk exposures. For example, if a change in systematic risk factors produces a 10 bp increase in the benchmark's total return, then the same change in risk factors would be expected to produce a 9.7 bp increase in the portfolio's return.

The systematic, default, and non-systematic volatilities are calculated separately for the portfolio and benchmark. The TEV, on the other hand, represents the volatility of the return difference between the portfolio and the benchmark around the expected difference in their returns. While both the benchmark and portfolio have total volatilities of approximately 110 bp/month, the tracking error volatility between the two is only 29 bp/month. Obviously, returns on the benchmark and portfolio are highly correlated, and the small difference between the two is driven by their relative exposures to risk factors. This raises the next important question: What are the sources of risk?

What are the sources of risk?

The Tracking Error Report shows the sources of risk in a portfolio relative to its benchmark.

What are the sources of risk in this portfolio relative to its benchmark? The Tracking Error Report in Figure 6 shows how the overall tracking error number (28.8 bp/month) can be broken down by relative exposures to broad categories of risk factors (systematic, default, and non-systematic). For example, the report shows that relative exposures of the portfolio and benchmark to the seven yield curve risk factors (*i.e.,* six key rate factors and a convexity factor) account, in isolation, for 7.3 bp/month of overall tracking error. Recall that the portfolio is 0.18 years longer in duration than the benchmark. As we will see

Figure 6. **Global Risk Model—U.S. Aggregate Portfolio Tracking Error Report**, December 31, 2004

Global Risk Factor	Isolated TEV (bps)	Cumulative TEV (bps)	Difference in cumulative (bps)	Percentage of tracking error variance (%)	Systematic beta
Global					
Yield Curve	7.27	7.27	7.27	6.66	1.03
Swap Spreads	1.12	7.17	-0.1	-0.03	1.02
Volatility	1.48	7.63	0.45	-0.12	0.66
Investment-Grade Spreads	5.96	9.46	1.83	9.6	1.12
Treasury Spreads	0.27	7.67	0.04	0.04	1.08
Credit and Agency Spreads	5.52	9.22	1.55	9.38	1.29
MBS/Securitized	2.53	9.39	0.17	-0.14	0.66
CMBS/ABS	0.35	9.46	0.07	0.33	1.27
High Yield Spreads	13.83	18.68	9.23	30.26	
Emerging Markets Spread	4.94	21.08	2.4	7.23	3.91
Systematic risk	21.08	21.08	0.0	53.6	0.97
Idiosyncratic risk	19.09	28.44	7.36	43.94	
Credit default risk	4.51	28.8	0.36	2.46	
Total risk		**28.8**	**0.0**	**100.0**	
Portfolio volatility (bps/month)					108.73
Benchmark volatility (bps/month)					108.5

shortly, the various key rate factors have an average volatility of approximately 26.3 bp/month. As a rough approximation, we should expect about 0.18×26.3 bp/month ≈ 4.7 bp/month of tracking error due to relative exposures to the yield curve risk factors. The difference between 7.3 bp/month and 4.7 bp/month is largely explained by convexity. Recall, the portfolio is 0.34 years^2 less negatively convex than the benchmarks. This implies that the duration difference alone will underestimate the return difference between the portfolio and benchmark due solely to changes in the yield curve.

The report then shows how much tracking error is due to the relative exposure to swap spreads. As discussed in Chapter 4, an asset's spread return is split into a component due to changes in par swap spreads and a component due to changes in sector spreads to swaps and other risk factors particular to the asset's peer group. Considering changes in swap spreads by themselves (*i.e.,* ignoring their correlation with changes in other risk factors), we see that relative exposure to the six par swap rates produces only 1.1 bp/month of tracking error. This value is shown in the column "Isolated TEV." Why so low? As we will see in the next report, compared with the benchmark, the portfolio has only a modest overweight in exposure to swap spreads. Secondly, par swap spreads are not very volatile (about 7.6 bp/month, on average). Consequently, the portfolio's exposure to par swap spreads relative to the benchmark, in isolation, produces little tracking error.

Since changes in swap spreads have low correlation with changes in Treasury rates (*e.g.,* the correlation of changes in the 10-year swap spread with changes in the 10-year Treasury key rate is 0.08), the portfolio's modest long exposure to changes in swap spreads (shown in Figure 7) helps offset the portfolio's long exposure to changes in Treasury yields. In addition, since changes in swap spreads have low volatility, the long swap spread exposure adds little to the overall tracking error, which is shown in the "Cumulative TEV" column. The combined relative exposures to Treasury rates and swap spreads produce a TEV of 7.17 bp/month, which is slightly lower than the isolated exposure to Treasury rates alone (7.27 bp/month).

The Tracking Error Report continues in this fashion: It lists the next group of risk factors and reports the TEV resulting from active exposures to those factors in isolation ("Isolated TEV") and then in combination with all preceding groups of risk factors ("Cumulative TEV"). Note that the Cumulative TEV does not increase by the isolated TEV amount due to less than perfect correlations among the risk factors. In fact, as we just saw, it may even decrease from inclusion of a risk category with low correlation to the preceding risk categories.

The pattern of the Cumulative TEV as you move down the column depends on the ordering of the risk factors. The particular order used in the Risk Report reflects the relative importance of the risk factors for a typical fixed-income portfolio. While a different ordering will still produce the same overall TEV, the levels and changes in the Cumulative (but not in the Isolated) TEV may vary.

For the U.S. dollar market, there are six volatility factors which are grouped under "Volatility" in the Tracking Error Report. There is a single volatility factor for each of the following sectors: Treasury, Agency, Investment-Grade Credit, and High Yield. In addition, there are two volatility factors for the MBS sector: a long (expiry) volatility factor and a short (expiry) volatility factor. The exposure of a portfolio or benchmark to changes in a volatility risk factor is measured by its volatility duration, which is related to the portfolio's vega. From the Portfolio/Benchmark Comparison Report, we know our portfolio has slightly less vega exposure than the index (probably due to the portfolio's MBS underweight). The combination of small relative volatility exposure and level of volatility of changes in implied volatility itself produce a low isolated TEV (1.5 bp/month).

The Investment-Grade Spread factors include all risk factors pertaining to the spread sectors (*e.g.,* Agency, Credit, MBS, ABS, and CMBS) and also some risk factors pertaining to the Treasury market beyond exposure to changes in key rates and convexity (such as spread slope and liquidity). Exposure to these spread factors is measured by a bond's option adjusted spread duration (OASD). As we see in the Portfolio/Benchmark Comparison Report, the portfolio has longer OASD than the benchmark by 0.15 years, implying that the portfolio will underperform if spreads generally widen. Overall, due to the relative spread exposure, the portfolio has an isolated TEV from spread risk factors of 6.0 bp/month—the third largest source of isolated systematic TEV in the portfolio. However, since spread changes have low (or negative) correlation with changes in yield curve risk factors, the cumulative TEV increases only 1.9 bp/month, from 7.6 bp/month to 9.5 bp/month.

The Tracking Error Report then breaks out the Investment-Grade Spread risk into four investment-grade market segments: Treasury, Credit & Agency, MBS (including any structured MBS), and CMBS/ABS. As shown in Figure 6, the exposure to credit and agency spread risk factors produces an isolated TEV of 5.5 bp/month, whereas the relative exposure to the MBS spread risk factors produces an isolated TEV of 2.5 bp/month. This may surprise investors. Recall, at the outset, that the portfolio had a Credit & Agency overweight (4.7% in market value and 0.36 years in contribution to spread duration), compared with an MBS underweight (11.4% in market value and -0.39 years in contribution to spread duration). The MBS active position seems larger than the Credit & Agency position, so why is the isolated TEV for Credit & Agency so much larger than for MBS? As we will see in the full Factor Exposure Report (Figure 7), the spread factors for Credit & Agency are generally more volatile.

Next in the Tracking Error Report is TEV due to exposure to high-yield spread factors. (Chapter 4 provides more details on the high-yield risk model.) The Aggregate (Statistics) Index, by definition,[10] contains no exposure to high-yield risk factors. The portfolio, however, has two high-yield bonds with a combined portfolio market value weight of 1.98% and a contribution to spread duration of 0.15 years. This exposure, given the relatively high volatility of high-yield spread risk factors, produces an isolated TEV of 13.8 bp/month.

Finally, the portfolio and benchmark have exposure to bonds from issuers in emerging countries. In particular, our portfolio has both a PEMEX and an UMS issue. As of December 2004, Mexico was rated Baa3, and so Mexican issuers were part of the EMG index. In addition, investment-grade dollar issuers (such as PEMEX and UMS)

[10] If the benchmark was the Aggregate (Returns Universe) Index, then there may be exposure to high-yield risk factors, as downgraded bonds are not removed from the index until the end of the month.

belonged to the Aggregate Index. Consequently, both the portfolio and benchmark have exposure to EMG risk factors (discussed in Chapter 4). On a net basis, the relative EMG exposures produces 4.9 bp/month of tracking error volatility.

Overall, our portfolio has an estimated systematic TEV of 21.1 bp/month versus the Aggregate Index. There are two other components to total TEV: Non-systematic (*i.e.,* idiosyncratic) TEV and credit default TEV. Idiosyncratic TEV measures the risk due to concentrations in a particular bond or issuer. For a given bond, the portion of its normal (i.e., non-default related) return not explained by the systematic risk factors is defined as its idiosyncratic return. For a well-diversified portfolio or index, idiosyncratic risk is typically small, as the exposure to this type of risk is spread across many small exposures to independent sources of issuer-specific risk. While the level of a portfolio's idiosyncratic risk generally declines with the number of issues, a single large position in a particularly risky asset can create significant non-systematic risk. As discussed earlier, the level of idiosyncratic volatility in the portfolio and index was 19.7 bp/month and 2.5 bp/month, respectively.

Idiosyncratic TEV is driven by the relative exposures to specific bonds and issuers.

Idiosyncratic TEV is driven by the relative exposures to specific bonds and issuers. For example, if the portfolio and benchmark each have a 0.5% market value exposure to the Ford 7.5s of 8/26, then the contribution of this issue to the portfolio's idiosyncratic TEV is zero. However, if the portfolio has a 0.5% market value weight to this issue, while the benchmark has only a 0.1% weight, then the net exposure to the issue is 0.4%, which would contribute to the portfolio's idiosyncratic TEV. The calculation of the portfolio idiosyncratic TEV begins once all the issue-level positions have been netted.

Idiosyncratic tracking error variance (*i.e.,* the square of idiosyncratic TEV) is the weighted sum of the individual issuer-level idiosyncratic tracking error variances (*i.e.,* issuer-level idiosyncratic risks are assumed to be independent). However, in the Global Risk Model, to arrive at issuer-level idiosyncratic tracking error variance, net issue-level exposures of opposite sign for a given issuer do not fully offset each other. The degree of this offset is an increasing function of the issuer's spread level. In other words, the degree of issue-level offset is larger for high spread issuers compared with low spread issuers.[11] While this relationship has been supported empirically, the underlying intuition is that higher spread issuers are more susceptible to event risk, which would produce similar spread changes for all of the issuer's bonds.

For example, suppose a portfolio and benchmark each have a 0.5% exposure to Ford. However, the Ford exposure of the portfolio is *only* to the Ford 7.5s of 8/26, whereas suppose the exposure of the benchmark is *only* to the Ford 7.125s of 11/25. Both Ford issues are very similar (*e.g.,* similar exposures to the key rate, swap spread and corporate risk factors). They also have similar idiosyncratic risk (267 bp/month for the 7.5s and 273 bp/month for the 7.125s). However, because the spread level for Ford is (currently) relatively high (about +250 to Treasuries), the Risk Model offsets a significant amount of the idiosyncratic risk when calculating the portfolio idiosyncratic TEV. In this example, the portfolio idiosyncratic TEV arising from the Ford exposure would be only 0.55 bp/month.

[11] For more details, please refer to *Are Credit Markets Globally Integrated?* Albert Desclée and Jeremy Rosten, Lehman Brothers, March 2003.

Contrast this result with an issuer with lower spreads. Suppose a portfolio and benchmark each have a 0.5% exposure to Wells Fargo. However, the WFC exposure of the portfolio is *only* to the WFC 4.95s of 10/13, whereas suppose the exposure of the benchmark is *only* to the WFC 4.625s of 4/14. The two WFC issues are very similar (*e.g.,* similar exposures to the key rate, swap spread and corporate risk factors). They also have similar idiosyncratic risk (107 bp/month for the 4.95s and 112 bp/month for the 4.625s). However, because the spread level for WFC is (currently) relatively low (about +65 to Treasuries), the Risk Model offsets less of the idiosyncratic risk when calculating WFC's contribution to portfolio idiosyncratic TEV. In this example, the portfolio idiosyncratic TEV arising from the WFC exposure is 0.58 bp/month, which, despite the shorter spread duration and lower idiosyncratic risk for the WFC issues compared with the F issues, is larger than the 0.55 bp/month of idiosyncratic TEV arising from the Ford issues.

One can think of idiosyncratic risk as having two components: issuer-specific risk and issue-specific (or, bond-specific) risk.

In short, one can think of idiosyncratic risk as having two components: issuer-specific risk and issue-specific (or, bond-specific) risk. As the creditworthiness of an entity decreases (and its spread widens), so the former dominates the latter. For highly-rated issues (*e.g.,* Aaa-rated supranationals), the issue-specific risk, typically associated with liquidity risk, will outweigh any fundamental credit concerns.

Generally, a portfolio will have greater weights in a smaller set of issues, while the benchmark will have smaller weights to many more bonds. As a result, the most dominant active weights will usually be driven by the portfolio weights, and a portfolio's idiosyncratic TEV will generally be close to the portfolio's idiosyncratic volatility. For our portfolio, the idiosyncratic TEV is 19.1 bp/month, close to the portfolio's idiosyncratic volatility of 19.7 bp/month.

By assumption, idiosyncratic risk is independent of systematic risk. As a result, the cumulative TEV is simply:

$$\text{Cumulative TEV} = \sqrt{\{(\text{isolated Systematic TEV})^2 + (\text{isolated Idiosyncratic TEV})^2\}}$$

For our manager's portfolio, we have

$$\text{Cumulative TEV} = \sqrt{\{21.08^2 + 19.09^2\}} = 28.44 \text{ bp/month}$$[12]

The credit default TEV arises from exposure to the default risk of high-yield bonds.

Finally, the credit default TEV arises from exposure to the default risk of bonds rated Baa or lower. (The tracking error due to defaults of higher-rated bonds is not modeled explicitly. Due to its extreme rarity and sparseness of data, default risk for such bonds is captured in the idiosyncratic risk term.) TEV arising from default risk is 4.5 bp/month. Again, in our model, the default TEV is assumed to be independent of both the idiosyncratic TEV and systematic TEV. Consequently, total TEV is defined as

$$\begin{aligned}\text{Total TEV} &= \sqrt{\{(\text{isolated Systematic TEV})^2} \\ &\quad \overline{+ (\text{isolated Idiosyncratic TEV})^2 + (\text{default TEV})^2\}} \\ &= 28.8 \text{ bp/month}\end{aligned}$$

[12] Assuming zero autocorrelation of the monthly tracking errors, an annual tracking error volatility number can be calculated by multiplying the monthly tracking error volatility number by √12. In this example, √12 × 15.1 bp/month = 52.3 bp/year.

The Tracking Error Report shows the isolated TEVs for the various risk factor groups. However, due to correlations among the risk factors, the isolated TEV does not necessarily represent the contribution of the set of risk factors to the portfolio's overall TEV. To gain a sense of the relative importance of the various factor groups, the Risk Model calculates the tracking error variance (i.e., TEV^2) produced by each set of risk factors (taking into account the risk factors' own volatility and correlations to all other risk factors) and expresses it as a percentage of the portfolio's total TEV^2. For the portfolio, we see that idiosyncratic risk and exposure to high-yield spreads account for almost two-thirds of the total tracking error variance.

The Risk Report has now answered: How risky is the portfolio? and What are the sources of this risk? Next, the portfolio manager will want to know more detail regarding the sources of risk. For example, the portfolio has 5.5 bp of isolated TEV due to exposure to credit spreads. Which sectors of the credit market are responsible for this risk in the portfolio? For this level of information, we need to identify the individual risk factors the net exposure of the bonds in the portfolio to these risk factors (relative to the benchmarks), and the volatilities and correlations of the risk factors.

What is the portfolio's sensitivity to risk factors, and how are they correlated?

The Factor Exposure Report lists all of the relevant risk factors, the portfolio and benchmark's exposure to each risk factor, the net exposure to the risk factor, and the volatility of the risk factor.

The "Factor Exposure Report—Full Details" (Figure 7) gives a detailed breakdown of TEV. This report lists all of the relevant risk factors, the portfolio and benchmark's exposure to each risk factor, the net exposure to the risk factor, and the volatility of the risk factor.

For example, the portfolio has a 10-year key rate duration of 1.67 years, whereas the index has a 10-year KRD of 1.24 years. The net exposure is 0.43, as shown. The volatility of the 10-year par Treasury rate risk factor is reported as 27.4 bp/month. Consequently, if the 10-year par Treasury rate moved up by one standard deviation (*i.e.,* 27.4 bp), and if all other risk factors were unchanged, then the portfolio will underperform the benchmark by 11.9 bp (= 0.43×27.4 bp). This value is shown in the column labeled "TE impact of an isolated 1 std. dev up change."

Based on historical data, a one standard deviation move in the 10-year par Treasury rate is usually associated with movement in other risk factors. Based on this historical factor correlation, if the 10-year par Treasury rate move by one standard deviation and all other risk factors moved, in turn, according to the historical factor correlation matrix, then what would be the effect on the portfolio's return versus the index? This value is shown in the next column "TE impact of a correlated one standard deviation up change." As Figure 7 shows, a 27.4 bp increase in the 10-year par Treasury rate produces portfolio outperformance of 3.8 bp, not underperformance of 11.9 bp. This is because, for example, some of our largest contributions to risk are due to short positions to other key rates and to long positions in credit whose spreads are negatively correlated with rates and would typically be expected to tighten if rates increased.

Note that the "isolated impact" reflects only the exposure to the specific factor. Thus, since this portfolio is overweight the 10-year and underweight the 5-year, we find that the effect

Figure 7. **Global Risk Model–U.S. Aggregate Portfolio Factor Exposure Report–Full Details**, December 31, 2004

Factor name	Sensitivity/Exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change (bps)	TE impact of a correlated 1 std. dev. up change (bps)	Marginal contribution to TEV (bps)	Percentage of tracking error variance (%)
CURRENCY									
USD Currency	MW%	100.0	100.0	-0.0	0.0	-0.0		0.0	-0.0
KEY RATES AND CONVEXITY									
USD 6M key rate	KRD (Yr)	0.151	0.145	0.0060	24.01	-0.14	8.3	-6.922	-0.14
USD 2Y key rate	KRD (Yr)	0.377	0.655	-0.278	29.53	8.2	8.73	-8.949	8.63
USD 5Y key rate	KRD (Yr)	0.967	1.151	-0.184	30.82	5.68	6.7	-7.167	4.59
USD 10Y key rate	KRD (Yr)	1.671	1.239	0.432	27.43	-11.86	3.78	-3.603	-5.41
USD 20Y key rate	KRD (Yr)	0.971	0.8	0.172	23.47	-4.03	1.91	-1.554	-0.93
USD 30Y key rate	KRD (Yr)	0.381	0.349	0.032	22.44	-0.73	1.47	-1.144	-0.13
USD Convexity	OAC (Yr^2/100)	-0.155	-0.493	0.338	4.75	1.61	0.2	0.033	0.04
SWAP SPREADS									
USD 6M swap spread	SSKRD (Yr)	0.17	0.15	0.021	11.38	-0.23	0.49	-0.195	-0.01
USD 2Y swap spread	SSKRD (Yr)	0.412	0.527	-0.115	5.76	0.66	0.93	-0.186	0.07
USD 5Y swap spread	SSKRD (Yr)	0.907	0.918	-0.011	5.78	0.06	1.21	-0.243	0.01
USD 10Y swap spread	SSKRD (Yr)	0.79	0.88	-0.09	6.78	0.61	1.41	-0.331	0.1
USD 20Y swap spread	SSKRD (Yr)	0.525	0.434	0.091	7.95	-0.72	1.15	-0.318	-0.1
USD 30Y swap spread	SSKRD (Yr)	0.382	0.269	0.112	7.76	-0.87	0.96	-0.258	-0.1
TREASURY SPREAD & VOL.									
USD Treasury Volatility	Volatility Duration	0.0	0.0	-0.0	112.81	0.01	-2.26	8.842	-0.0
USD Treasury spread	OASD (Yr)	1.455	1.309	0.146	1.4	-0.2	-0.56	0.027	0.01
USD Treasury Spread Slope	OASD*(TTM-AvgTTM) (Yr^2)	10.983	8.447	2.536	0.04	-0.11	2.62	-0.0040	-0.04
USD Treasury Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.0070	-0.0070	0.014	14.46	-0.21	-2.59	1.3	0.06
AGENCY SPREAD & VOL.									
USD Agency Volatility	Volatility Duration	0.0	0.0010	-0.0010	117.57	0.13	-2.36	9.633	-0.04
USD Agency Farm	OASD (Yr)	0.0	0.0040	-0.0040	5.28	0.02	-2.23	0.41	-0.01
USD Agency FHLB	OASD (Yr)	0.152	0.068	0.084	5.28	-0.44	-1.71	0.314	0.09
USD Agency FHLMC	OASD (Yr)	0.014	0.131	-0.117	5.3	0.62	-0.83	0.153	-0.06
USD Agency FNMA	OASD (Yr)	0.159	0.17	-0.011	4.02	0.05	-2.24	0.313	-0.01
USD Other Agencies	OASD (Yr)	0.048	0.036	0.012	4.83	-0.06	-1.48	0.249	0.01
USD Agency Libor Spread Slope	OASD*(TTM-AvgTTM) (Yr^2)	1.155	2.076	-0.92	0.34	0.31	0.6	-0.0070	0.02
USD Agency liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.049	0.0090	0.04	18.37	-0.73	-2.89	1.846	0.25
CREDIT IG SPREAD & VOL.									
USD Corporate volatility	Volatility Duration	0.0	0.0010	-0.0010	101.24	0.08	-1.89	6.661	-0.02
USD Banking AAA/AA	OASD (Yr)	0.017	0.029	-0.012	8.38	0.1	-9.68	2.816	-0.12
USD Banking A	OASD (Yr)	0.344	0.212	0.133	9.22	-1.22	-12.75	4.083	1.88
USD Banking BAA	OASD (Yr)	0.0	0.016	-0.016	19.58	0.31	-10.73	7.297	-0.41
USD Basic Industry AAA/AA	OASD (Yr)	0.0	0.0090	-0.0090	6.48	0.06	-7.88	1.774	-0.05
USD Basic Industry A	OASD (Yr)	0.0	0.039	-0.039	7.44	0.29	-10.76	2.778	-0.37
USD Basic Industry BAA	OASD (Yr)	0.03	0.066	-0.037	9.84	0.36	-12.28	4.194	-0.54
USD Cyclical AAA/AA	OASD (Yr)	0.0	0.01	-0.01	6.37	0.07	-8.9	1.968	-0.07
USD Cyclical A	OASD (Yr)	0.0	0.018	-0.018	9.88	0.17	-11.63	3.99	-0.25
USD Cyclical BAA	OASD (Yr)	0.238	0.128	0.11	21.58	-2.36	-12.66	9.492	3.61
USD Communication AAA/AA	OASD (Yr)	0.0	0.0	-0.0	8.56	0.0	-10.16	3.018	-0.0
USD Communication A	OASD (Yr)	0.276	0.083	0.193	9.37	-1.81	-12.38	4.026	2.69
USD Communication BAA	OASD (Yr)	0.21	0.116	0.094	15.93	-1.5	-13.12	7.256	2.37
USD Energy AAA/AA	OASD (Yr)	0.0	0.0060	-0.0060	7.34	0.05	-7.84	1.999	-0.04
USD Energy A	OASD (Yr)	0.0	0.024	-0.024	7.67	0.19	-10.8	2.875	-0.24
USD Energy BAA	OASD (Yr)	0.0	0.076	-0.076	10.12	0.77	-12.1	4.251	-1.13
USD Financial AAA/AA	OASD (Yr)	0.087	0.039	0.048	7.57	-0.37	-11.84	3.113	0.52
USD Financial A	OASD (Yr)	0.048	0.064	-0.016	10.28	0.17	-12.82	4.576	-0.26
USD Financial BAA	OASD (Yr)	0.0	0.039	-0.039	12.92	0.5	-10.24	4.592	-0.62
USD Non-Cyclical AAA/AA	OASD (Yr)	0.0	0.022	-0.022	6.75	0.15	-9.24	2.166	-0.17
USD Non-Cyclical A	OASD (Yr)	0.0	0.05	-0.05	6.93	0.34	-9.87	2.376	-0.41

Figure 7. **Global Risk Model–U.S. Aggregate Portfolio**
Factor Exposure Report–Full Details, December 31, 2004 *(continued)*

Factor name	Sensitivity/Exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change (bps)	TE impact of a correlated 1 std. dev. up change (bps)	Marginal contribution to TEV (bps)	Percentage of tracking error variance (%)
USD Non-Cyclical BAA	OASD (Yr)	0.042	0.054	-0.012	9.05	0.11	-10.85	3.412	-0.14
USD Non-Corporate AAA/AA	OASD (Yr)	0.046	0.118	-0.073	5.52	0.4	-6.26	1.199	-0.3
USD Non-Corporate A	OASD (Yr)	0.0	0.032	-0.032	7.99	0.26	-10.93	3.033	-0.34
USD Non-Corporate BAA	OASD (Yr)	0.0	0.011	-0.011	16.98	0.19	-10.29	6.07	-0.23
USD Utility AAA/AA	OASD (Yr)	0.0	0.0	-0.0	8.18	0.0	-8.71	2.473	-0.0
USD Utility A	OASD (Yr)	0.01	0.026	-0.017	8.15	0.13	-11.03	3.121	-0.18
USD Utility BAA	OASD (Yr)	0.143	0.081	0.062	14.72	-0.91	-11.71	5.984	1.28
USD Corporate Spread Slope	OASD*(TTM-AvgTTM) (Yr^2)	13.337	10.964	2.373	0.22	-0.53	2.49	-0.019	-0.16
USD Corporate Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.402	0.222	0.18	7.48	-1.35	-13.71	3.563	2.23
USD Foreign Corporates AAA/AA	OASD (Yr)	0.033	0.067	-0.034	3.46	0.12	0.41	-0.05	0.01
USD Foreign Corporates A	OASD (Yr)	0.0	0.095	-0.095	4.23	0.4	5.06	-0.743	0.25
USD Foreign Corporates BAA	OASD (Yr)	0.0	0.103	-0.103	5.82	0.6	3.78	-0.763	0.27
CREDIT HY SPREAD & VOL.									
High-yield Communication	OASD (Yr)	0.134	0.0	0.134	102.01	-13.68	-18.05	63.922	29.77
High-yield Utility	OASD (Yr)	0.013	0.0	0.013	76.51	-0.98	-13.71	36.413	1.62
High-yield Spread Slope	OASD*(TTM-AvgTTM) (Yr^2)	2.539	0.0	2.539	0.53	-1.34	12.22	-0.224	-1.98
High-yield Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.064	0.0	0.064	7.98	-0.51	-13.72	3.804	0.85
EMERGING MARKETS SPREAD									
Global EMG Investment Grade	OASD (Yr)	0.173	0.045	0.128	38.27	-4.88	-12.11	16.093	7.13
Global EMG Non-Distressed Slope	OASD*(TTM-AvgTTM) (Yr^2)	1.054	0.414	0.639	1.46	-0.93	6.74	-0.342	-0.76
Global EMG Non-Distressed Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.066	0.02	0.046	14.47	-0.67	-10.61	5.332	0.85
MBS SPREAD & VOL.									
USD MBS Short Volatility	Volatility Duration	0.011	0.013	-0.0020	112.41	0.22	0.14	-0.552	0.0
USD MBS Long/Derivative Volatility	Volatility Duration	0.02	0.033	-0.014	84.45	1.17	-0.44	1.304	-0.06
USD MBS New Discount	OASD (Yr)	0.019	0.05	-0.031	8.3	0.26	-0.28	0.082	-0.01
USD MBS New Current	OASD (Yr)	0.336	0.568	-0.232	6.84	1.59	0.9	-0.213	0.17
USD MBS New Premium	OASD (Yr)	0.297	0.388	-0.092	8.88	0.81	-0.28	0.086	-0.03
USD MBS Seasoned Current	OASD (Yr)	0.0020	0.012	-0.011	10.78	0.11	1.9	-0.711	0.03
USD MBS Seasoned Premium	OASD (Yr)	0.113	0.158	-0.045	10.41	0.47	-2.95	1.067	-0.17
USD MBS GNMA 30Y	OASD (Yr)	0.12	0.136	-0.016	3.94	0.06	-2.32	0.318	-0.02
USD MBS Conv 15Y	OASD (Yr)	0.199	0.273	-0.073	3.91	0.29	-1.79	0.243	-0.06
USD MBS GNMA 15Y	OASD (Yr)	0.0	0.0080	-0.0080	5.85	0.04	-1.75	0.356	-0.01
USD MBS Conv Balloon	OASD (Yr)	0.0	0.015	-0.015	8.25	0.13	-3.2	0.918	-0.05
CMBS SPREAD									
USD CMBS AAA	OASD (Yr)	0.141	0.129	0.012	5.79	-0.07	-6.85	1.377	0.06
USD CMBS AA	OASD (Yr)	0.018	0.0060	0.012	6.68	-0.08	-5.26	1.221	0.05
USD CMBS A	OASD (Yr)	0.0	0.0040	-0.0040	7.77	0.03	-5.59	1.508	-0.02
USD CMBS BAA	OASD (Yr)	0.0	0.0010	-0.0010	10.75	0.01	-5.27	1.97	-0.01
USD CMBS Principal Payment Window	OASD*WIN (Yr)	0.073	0.049	0.024	2.12	-0.05	1.33	-0.098	-0.01
USD CMBS Average Life Slope	OASD*(AL-AvgAL) (Yr^2)	0.121	0.247	-0.126	0.66	0.08	3.02	-0.069	0.03
USD CMBS Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	0.0020	0.0020	-0.0	5.79	0.0	-2.25	0.452	-0.0
USD CMBS Age	OASD*(AGE-AvgAGE) (Yr^2)	0.21	0.054	0.156	0.6	-0.09	4.42	-0.092	-0.05
USD CMBS Price Current Pay AAA	OASD*(Price-AvgPrice) (Yr*$)	0.041	-0.016	0.057	0.81	-0.05	-3.34	0.094	0.02
USD CMBS Price Non-Current Pay AAA	OASD*(Price-AvgPrice) (Yr*$)	0.368	0.197	0.17	0.41	-0.07	-2.8	0.04	0.02
USD CMBS Price Non-AAA	OASD*(Price-AvgPrice) (Yr*$)	0.134	0.022	0.112	0.29	-0.03	-3.51	0.035	0.01
ABS SPREAD									
USD ABS Auto	OASD (Yr)	0.0050	0.0060	-0.0010	7.83	0.01	-8.84	2.404	-0.01
USD ABS Card	OASD (Yr)	0.021	0.014	0.0070	5.56	-0.04	-7.71	1.489	0.04
USD ABS Home Equity Loans	OASD (Yr)	0.01	0.0070	0.0030	10.79	-0.04	-5.81	2.179	0.03
USD ABS Manufactured Housing	OASD (Yr)	0.0	0.0030	-0.0030	25.36	0.06	-3.37	2.968	-0.03
USD ABS Utilities	OASD (Yr)	0.043	0.0070	0.036	5.31	-0.19	-6.49	1.196	0.15
USD ABS non-AAA	OASD (Yr)	0.0	0.0050	-0.0050	6.74	0.03	1.35	-0.317	0.01
USD ABS Average Life Slope	OASD*(AL-AvgAL) (Yr^2)	0.016	0.043	-0.027	1.11	0.03	2.64	-0.101	0.01
USD ABS Liquidity	OASD*(OAS-AvgOAS) (Yr*%)	-0.0	0.0030	-0.0030	9.15	0.02	-1.78	0.566	-0.01
USD ABS Price	OASD*(Price-AvgPrice) (Yr*$)	0.0040	-0.0040	0.0070	0.71	-0.01	0.05	-0.0010	-0.0
USD ABS Auto WALA	OASD*(WALA-AvgWALA) (Yr^2)	0.0020	0.0	0.0010	5.81	-0.01	-5.95	1.2	0.01
USD ABS Home Equity Loans WALA	OASD*(WALA-AvgWALA) (Yr^2)	0.017	0.0	0.016	2.41	-0.04	-5.57	0.466	0.03
USD ABS Manufactured Housing WALA	OASD*(WALA-AvgWALA) (Yr^2)	0.0	-0.0020	0.0020	2.64	-0.0	0.16	-0.014	-0.0

of an upward move in rates is negative at the 10-year point but is positive at the 5-year point. By contrast, the "correlated impact" column considers the full set of portfolio exposures; the overall long duration credit exposures, coupled with the high correlations among different points on the curve and negative correlation with credit spreads, makes the effect of a rate rise positive all along the curve, even at the 10-year point.

The column labeled "Marginal contribution to TEV" measures how a small increase in exposure to the risk factor will affect the portfolio's systematic TEV. In other words, the Marginal Contribution to TEV equals the partial derivative of TEV with respect to the risk factor. For example, Figure 7 shows that the marginal contribution to TEV for the 10-year key rate risk factor is -3.6. This means that if the portfolio's exposure to the 10-year key rate point were to increase by 1.0, holding all other risk exposures unchanged, then the portfolio's TEV would decrease by 3.6 bp/month.[13] This change in TEV incorporates all of the correlations of the 10-year key rate risk factor with all other risk factors. Generally, a positive value for the "marginal contribution to TEV" indicates that the portfolio has a positive view (*i.e.,* an overweight) on the risk factor, whereas a negative value indicates a negative view (*i.e.,* an underweight). However, as our portfolio shows, this is not always the case. Consider the marginal contribution to TEV for the 10-year key rate risk factor. Although it is negative (*i.e.,* = -3.6), the portfolio has a positive exposure to this risk factor (= +0.43). An increase in exposure to the 10-year key rate risk factor will decrease the portfolio's overall TEV, but only if we were to disregard the correlations with all other risk factors. Recall that the portfolio is overall long duration and credit versus the benchmark. Given that the key rate risk factors are highly correlated and rates and credit are negatively correlated, an increase in exposure to the 10-year key rate factor will cause the portfolio's overall TEV to decrease despite the overweight exposure to the risk factor. This is because the effect of moving the net exposure to the 10-year key rate factor further away from zero is more than offset by the gain of the increased 10-year key rate exposure as an offset to some of the long credit exposures.

There are two key differences between the original U.S. Risk Model and the new Global Risk Model:

• The Global Risk Model introduces changes in swap spreads as risk factors.
• The two models differ in their treatment of idiosyncratic risk.

As described earlier, the last column, "Percentage of tracking error variance," measures how much the portfolio's current net exposure to a given risk factor contributes to the overall systematic TEV^2, taking into account the risk factor's own volatility as well as the correlations to all other risk factors. In Figure 7, the portfolio's net exposure to the 2-year key rate risk factor (= -0.28) accounts for 8.6% of the portfolio's $(TEV)^2$. This value incorporates the contribution of the portfolio's net exposure to the 2-year key rate risk factor as well as the portfolio's net exposures to all other risk factors that are correlated with the 2-year key rate risk factor. In contrast, the portfolio's net exposure to the 10-year key rate factor (= 0.43) accounts for -5.4% of the portfolio's $(TEV)^2$. In other words, the current exposure reduces the portfolio's $(TEV)^2$. The sum of all the percentage of tracking error variance measures (across all risk factors) sums to 100%, and the values are independent of the order in which they are displayed.[14]

[13] This calculation assumes that the increase in exposure to the risk factor is accomplished by changing cash so that net exposures to all other risk factors are unchanged.

[14] This is not the case for tracking error volatility.

While the Factor Exposure gives details on the systematic risk factor exposures, it does not identify the sources of idiosyncratic risk. We now turn to identifying the sources of idiosyncratic risk in the portfolio.

What are the portfolio's security and issuer-specific risks?

The Portfolio Issue-Specific Risk Report reflects the credit preferences of the manager.

The next report is the Portfolio Issue-Specific Risk Report (Figure 8), which measures each issue's weight in the portfolio, net market value issue weight (versus the benchmark), net market value issuer weight, marginal systematic TEV, systematic TEV, idiosyncratic TEV, and issuer idiosyncratic TEV. The issues are sorted in descending order of each issue's percentage market value weight in the portfolio.

For example, the portfolio contains a 3.4% market value holding in 30-year FNMA 6% MBS. The marginal systematic TEVof this position answers the following question: If I were to increase my position in this issue by a little bit, what would be the effect on the portfolio's overall TEVgiven the other positions in the portfolio? In other words, this value is the partial derivative of the portfolio's TEVwith respect to the net market value of the position. Portfolio managers can use this value to gauge where they can make small changes in their portfolio to reduce systematic TEV. In this particluar case, since the portfolio has a large underweight to MBS, increasing the holding of FNA060QG at the margin would reduce the portfolio's systematic TEV.

Figure 8. **Global Risk Model—U.S. Aggregate Portfolio**
Portfolio Issue-Specific Risk Report, December 31, 2004

Identifier	Ticker	Description	Currency	Coupon (%)	Maturity	Current OAS (bps)	MV issue weight (%)	MV issue net weight (%)	MV issuer net weight (%)	Marginal systematic TEV (bps)	Systematic TEV (bps)	Idiosyncratic TEV (bps)	Issuer idiosyncratic TEV (bps)
912828AS	US/T	US TREASURY NOTES	USD	1.62	1/31/2005	-47.3	7.3	7.3	7.3	-0.0077	0.14	0.01	0.01
912810DY	US/T	US TREASURY BONDS	USD	8.75	5/15/2017	0.8	5.82	5.6	5.6	-0.3978	12.38	0.45	0.45
FNA060QG	FNMA	FNMA Conventional Long T. 30yr	USD	6.0		11.3	3.41	3.41	1.17	-0.1623	1.87	0.47	0.15
FNA054QG	FNMA	FNMA Conventional Long T. 30yr	USD	5.5		18.0	2.98	2.98	-1.83	-0.2379	2.59	0.35	0.23
FNA050QG	FNMA	FNMA Conventional Long T. 30yr	USD	5.0		20.3	2.85	2.85	-0.2	-0.3184	3.6	0.44	0.07
912810DX	US/T	US TREASURY BONDS	USD	7.5	11/15/2016	-0.4	2.67	2.41	2.41	-0.4017	5.36	0.19	0.19
FNA064QG	FNMA	FNMA Conventional Long T. 30yr	USD	6.5		31.6	2.45	2.45	1.39	-0.1021	0.99	0.39	0.21
912810DV	US/T	US TREASURY BONDS	USD	9.25	2/15/2016	-0.4	2.29	2.21	2.21	-0.3917	4.5	0.16	0.16
912810EH	US/T	US TREASURY BONDS	USD	7.88	2/15/2021	0.6	2.28	2.13	2.13	-0.3651	5.36	0.2	0.2
FNC054QG	FNMA	FNMA Conventional Interm. 15yr	USD	5.5		14.3	1.93	1.93	1.37	-0.1725	0.98	0.28	0.2
FNC050QG	FNMA	FNMA Conventional Interm. 15yr	USD	5.0		17.2	1.92	1.92	1.92	-0.2528	1.56	0.24	0.24
345397SM	F	FORD MOTOR CREDIT-GLOBAL	USD	7.38	10/28/2009	193.0	1.88	1.81	2.1	0.2669	2.46	2.0	3.78
912810EM	US/T	US TREASURY BONDS	USD	7.25	8/15/2022	0.2	1.7	1.57	1.57	-0.3422	4.14	0.16	0.16
FNC044QG	FNMA	FNMA Conventional Interm. 15yr	USD	4.5		23.5	1.68	1.68	0.23	-0.3077	1.77	0.26	0.08
92344GAK	VZ	VERIZON GLOBAL FUNDING CORP-GL	USD	6.75	12/1/2005	35.0	1.43	1.43	1.99	-0.0546	0.33	0.19	1.53
36962GA4	GE	GENERAL ELECTRIC CAPITAL-GLOBA	USD	2.85	1/30/2006	27.7	1.39	1.37	1.79	-0.0771	0.36	0.11	0.5
500769AN	KFW	KREDIT FUER WIEDERAUFBAU-GLOBA	USD	2.38	9/25/2006	11.7	1.37	1.33	1.1	-0.1829	0.64	0.18	0.17
001957BD	T	AT&T CORP - GLOBAL	USD	9.75	11/15/2031	306.7	1.26	1.26	1.26	8.6374	12.51	17.49	17.49
31359MHK	FNMA	FEDERAL NATL MTG ASSN-GLOBAL	USD	5.5	3/15/2011	38.4	1.23	1.17	1.17	-0.4425	1.81	0.28	0.28

An issue's Systematic TEV measures the consequences of the portfolio's net exposure to the issue (*i.e.,* net of the benchmark's exposure) with respect to all of the systematic risk factors. This value is calculated by first subtracting the benchmark's percentage holding from the portfolio's holding to produce the issue's net factor loading, which is then applied to the systematic risk factor variance-covariance matrix to arrive at this issue's overall systematic TEV. This TEV value treats the portfolio's net exposure to this issue in isolation of all other portfolio issues.

An issue's Idiosyncratic TEV measures the level of idiosyncratic TEV produced by the portfolio's net exposure to the issue without regard to other issues held in the portfolio. The idiosyncratic TEV produced by the portfolio's 1.88% holding in the Ford 7.375s of 10/09 is 2.0 bp/month. This value is calculated by multiplying the 1.81% net exposure of the portfolio to this issue (subtracting the issue's 0.07% weight in the Aggregate Index) by the idiosyncratic risk of the issue's sector (26.8 bp/month for Baa3) and by the issue's OASD (= 4.12).

The Credit Tickers Report presents a list of the top 100 credit issuers (in terms of idiosyncratic risk) in the portfolio (net of the benchmark).

An issuer's Idiosyncratic TEV is presented in the Credit Tickers Report (Figure 9). The Credit Tickers Report presents a list of the top 100 credit issuers (in terms of idiosyncratic risk) in the portfolio, as well as the portfolio's issuer-level net market value exposure and the net contribution to OASD versus the benchmark. In addition, the

Figure 9. **Global Risk Model—U.S. Aggregate Portfolio Credit Tickers Report**, December 31, 2004

Ticker	Name	Sector	Rating	Currency	# issues in portfolio	Portfolio weight (%)	Benchmark weight (%)	Net weight (%)	Net contribution to OASD (Yr)	Systematic TEV (bps)	Idiosyncratic TEV (bps)
T	AT&T CORP - GLOBAL	WIRELINES	BA1	USD	1	1.26	0.0	1.26	0.134	12.51	17.49
F	FORD CAPITAL B.V.	TRANSPORTATION_SERVICES	BAA3 BAA2	USD	2	2.77	0.67	2.1	0.142	4.57	3.78
MEX	UNITED MEX STATES-GLOBAL	SOVEREIGNS	BAA3	USD	1	1.22	0.48	0.74	0.077	3.26	2.99
FON	SPRINT CAPITAL CORP	WIRELESS	BAA3	USD	1	0.95	0.2	0.75	0.1	2.63	2.34
PEMEX	PEMEX FINANCE LTD	FOREIGN_AGENCIES	BAA1 AAA BAA3	USD	1	1.2	0.16	1.04	0.056	2.52	2.18
IBM	INTL BUSINESS MACHINES	TECHNOLOGY	A1	USD	1	1.1	0.13	0.96	0.143	3.35	2.17
CMCSA	COMCAST CABLE COMMUNICATION	MEDIA_CABLE	BAA3	USD	1	0.96	0.25	0.71	0.08	2.14	1.91
TXU	ONCOR ELECTRIC DELIVERY	ELECTRIC	BAA2 BAA3	USD	1	0.8	0.06	0.74	0.078	2.08	1.8
VZ	GTE CORP	WIRELINES	A3 A1 A2 BAA2 BAA1	USD	2	2.29	0.3	1.99	0.103	2.34	1.53
NI	COLUMBIA ENERGY GROUP	ELECTRIC	BAA2 BAA3	USD	2	1.44	0.04	1.41	0.058	1.57	1.29
GS	GOLDMAN SACHS GROUP-GLOBAL	BROKERAGE	A1 A3	USD	1	0.73	0.36	0.37	0.072	1.71	1.17
C	COMMERCIAL CREDIT	BANKING	AA3 A1 A2	USD	2	2.12	0.5	1.62	0.073	1.88	1.14
FE	CLEVELAND ELECTRIC ILLUM	ELECTRIC	BAA3 BAA1 BA1	USD	1	0.72	0.01	0.7	0.012	0.86	1.0
WFC	WELLS FARGO + CO-GLOBAL	NON_CAPTIVE_CONSUMER	AA3 A1 A2	USD	1	1.17	0.24	0.93	0.053	1.49	0.86
GM	GENERAL MOTORS ACPT CORP	AUTOMOTIVE	BAA3	USD	2	1.78	0.62	1.16	0.028	0.89	0.76
LEH	LEHMAN BROTHERS HOLDINGS INC	BROKERAGE	A2	USD	1	1.04	0.2	0.84	0.047	1.34	0.74
KFT	NABISCO	FOOD_AND_BEVERAGE	A3 BAA1	USD	1	0.74	0.12	0.61	0.036	1.01	0.67
WMI	WMX TECHNOLOGIES	ENVIRONMENTAL	BAA3	USD	1	0.77	0.06	0.7	0.025	0.74	0.54
GE	GENERAL ELECTRIC CAPITAL SVCS	MULTIPLE	AAA A3	USD	2	2.51	0.72	1.79	0.048	1.27	0.5
TWX	TIME WARNER INC	MEDIA_CABLE	BAA1	USD	0	0.0	0.26	-0.26	-0.022	0.6	0.49
JPM	BANK ONE NA ILLINOIS-GLOBAL	BANKING	AA3 A2 A3 A1	USD	1	0.99	0.53	0.47	0.011	0.39	0.36
DCX	CHRYSLER	AUTOMOTIVE	BAA2	USD	0	0.0	0.26	-0.26	-0.014	0.4	0.3

report shows the Systematic TEV of the net exposure in isolation. The Idiosyncratic TEV presents the idiosyncratic risk of the net position. It is fair to argue that the order of this report should reflect the credit preferences of the portfolio manager.

The Risk Model assumes that an issuer's idiosyncratic risk is independent of all other risk factors in the risk model. This name-specific risk is determined by the idiosyncratic risk (*i.e.,* risk not explained by all of the systematic risk factors) of the issuer's quality & sector bucket. For example, as of December 31, 2003, Ford Capital belongs to the Baa3/Automotive bucket, so Ford Capital's idiosyncratic volatility equals the unexplained variation of all bonds belonging to the Baa3/Automotive bucket. For our portfolio, there are two Ford Capital issues with a combined market value issuer weight of 2.77% versus a benchmark issuer weight of 0.67%. The portfolio's net exposure to Ford produces an idiosyncratic TEV of 3.8 bp/month.

The biggest source of idiosyncratic risk in our portfolio is the 1.26% holding in the AT&T Corp. bond—a bond with a Ba1 rating belonging to the volatile wirelines sector (idiosyncratic sector volatility = 130.4 bp/month), and with a very long spread duration (10.65). This single issue produces 17.5 bp/month of idiosyncratic TEV and is the dominant source of idiosyncratic (and total) risk for the portfolio.

As explained earlier, the issuer's idiosyncratic risk in the portfolio is calculated by examining the weights and spread durations of the various bonds of the issuer in the portfolio versus those in the benchmark. The idiosyncratic risk model incorporates the less than perfect correlation in the idiosyncratic returns between two issues of the same issuer. So, for example, if the portfolio had the same market value weight and spread duration in Ford Capital as did the benchmark, but the portfolio had different issue weights than the benchmark, the portfolio would still have some idiosyncratic TEV arising from the issuer.

B. Risk Reports for a Euro Aggregate (and Sterling) Portfolio

We now turn to examine the Risk Report for a Euro portfolio whose benchmark is the Euro Aggregate Index. Many details of the report were discussed above for a U.S. dollar portfolio. However, for the benefit of investors who may have skipped directly

Figure 10. **Portfolio Issues Report—Euro Portfolio,** May 19, 2004

Identifier	Position Amount	Description	Coupon	Maturity Date	Yield	OAD	Classification—Broad	Index Rating
EUR	211.3	CASH—European Monetary Unit						
GR0124018525	4000	GREECE (REPUBLIC OF)	5.250	5/18/12	4.26	6.63	TREASURY	A1
XS0161488498	500	DEUTSCHE TELEKOM AG	7.500	1/24/33	6.09	12.97	COMMUNICATIONS	BAA2
XS0162513211	500	RWE AG	5.750	2/14/33	5.69	14.07	ELECTRIC	A1
FR0000485724	1000	CREDIT FONCIER DE FRANCE	5.375	3/02/13	4.33	7.06	MORTGAGES	AAA
XS0154444870	1000	FEDERAL HOME LN MTG CORP	4.750	1/15/13	4.45	7.04	FOREIGN_AGENCIES	AAA+
XS0159496867	1000	HSBC HOLDING PLC	5.375	12/20/12	4.68	6.83	BANKING	A2
DE0003611885	1000	EUROHYPO AG	4.500	1/21/13	4.34	7.12	PFANDBRIEFE_JUMBO	AAA
XS0167864544	1000	CARREFOUR SA	4.375	6/15/11	4.39	5.86	CONSUMER_NON_CYC	A1
FGBMU4:UDE	3000	Euro-BOBL			0.00	4.55	FUTURES	
FGBSU4:UDE	3000	Euro-SCHATZ			0.00	2.19	FUTURES	
FGBLU4:UDE	-5000	Euro-BUND			0.00	7.75	FUTURES	

to this section, we review the Risk Report for a Euro Aggregate portfolio. Some additional details, however, are available in the previous section.

Consider a small portfolio of euro-denominated securities benchmarked against the Euro Aggregate Index. What is the risk that the portfolio's return will deviate from the benchmark's return? The portfolio is presented in Figure 10. It includes positions in eight cash bonds, as well as long and short positions in various futures contracts. This portfolio intentionally holds only a handful of positions to illustrate the workings of the Risk Model.

As discussed for a U.S. Aggregate portfolio, before running the risk model the first step is to express preferences in terms of risk parameters. For example: should all historical data contribute equally to risk estimation or should we give more weight to recent history? Since this euro portfolio example refers to a single currency investment-grade portfolio, other user-defined parameters related to default risk (applicable to U.S. High-Yield securities) and currency-hedging (applicable to multi-currency portfolios) do not apply.

Unlike our U.S. Aggregate example, here we have chosen to use the time-weighted calibrations for systematic, non-systematic, and default risk, giving greater weight to more recent history. The first page of the Risk Report, shown in Figure 11, is a reminder of the user-defined parameters, along with portfolio and benchmark names and the base currency of the analysis.

The second page of the report, presented in Figure 12, is labeled "Portfolio/Benchmark Comparison." This report presents portfolio and index profiles and displays summary statistics regarding duration, spread, etc., as well as the estimated tracking error which will be detailed in subsequent reports. These summary statistics profile the portfolio and benchmark.

In Figure 12, we see that the portfolio is slightly longer in duration than the Euro Aggregate Index and that the expected tracking error volatility provided by the model is 33.9bp/month. In addition, the report shows the estimated absolute total return volatility for both the portfolio and index, 120.0 bp/month and 106.9 bp/month, respectively.

Thanks to the use of futures contracts, the portfolio duration is close to the duration of the index, although most bonds by themselves have much longer durations. The non-

Figure 11. **Global Risk Model—Euro Portfolio User-Defined Parameters**, May 19, 2004

Parameter	Value
Base currency	USD
Portfolio	Aggregate_active(2)
Benchmark	US Aggregate
Time-weighting of historical data in covariance matrix	
for systematic risk	No
for non-systematic risk	No
Time-weighting of credit default rates	No
(Implicit) Currency hedging for portfolio	No
(Implicit) Currency hedging for benchmark	No
Number of lines displayed in Issue-Specific and Credit Tickers Reports	100

Figure 12. **Global Risk Model—Euro Portfolio Portfolio/Benchmark Comparison Report**, May 19, 2004

Parameter	Portfolio	Benchmark	Difference
	EUR-EX1	Euro Aggregate	
Positions	12	2375	
Issuers	9	493	
Currencies	1	1	
# positions processed	12	2373	
# positions excluded	0	2	
% MV processed	100.0	100.0	
% MV excluded	0.0	0.0	
Market Value	10811	5042074597	
Coupon (%)	5.2	4.93	0.27
Average Life (Yr)	9.14	6.82	2.32
Yield to Worst (%)	4.43	3.73	0.71
ISMA Yield (%)	4.48	3.76	0.72
OAS (bps)	29	16	14
OAD (Yr)	5.39	5.23	0.16
ISMA Duration (Yr)	5.07	5.04	0.03
Duration to Maturity (Yr)	5.24	5.15	0.09
Vega	0.0	-0.0	0.0
OA Spread Duration (Yr)	5.33	5.2	0.13
OA Convexity (Yr^2/100)	0.51	0.51	0.0
Total TE Volatility (bps/month)			**33.94**
Systematic Volatility (bps/month)	116.96	106.9	
Non-systematic Volatility (bps/month)	26.53	1.33	
Default Volatility (bps/month)	4.86	1.48	
Total Volatility (bps/month)	**120.03**	**106.92**	
Portfolio Beta			1.08

systematic volatility is significant in the portfolio (26.5 bp/month, reflecting the portfolio's lack of issuer diversification) while it is very small for the broadly diversified index.

Next, the Tracking Error Summary Report (Figure 13) provides a summary of the portfolio's relative risk and the sources of this risk. Again, our sample portfolio exhibits an expected tracking error volatility of 33.9 bp/month.

The leftmost column of numbers in the Tracking Error Report provides estimates of isolated tracking errors associated with individual groups of risk factors. This assumes that the portfolio has exactly the same factor exposure as the benchmark to all systematic risk factors, with the exception of that particular sub-group. Figure 13 shows that all systematic risk expsoures account for 21.1 bp/month of isolated tracking error volatility (TEV). Figure 13 also shows that the largest source of risk in our sample portfolio is idiosyncratic risk, accounting for 26.3 bp/month of isolated TEV. Credit default risk accounts for only 4.2 bp/month of TEV. Individual sources of risk can be combined, taking correlation into account, as displayed in the second column of numbers entitled "Cumulative TEV." As you move down the list, the difference in cumulative TEV can sometimes be negative, if a particular risk is negatively correlated with other risk factors, as are MBS/Securitized spreads in our example.

The final column shows the portfolio return's beta with respect to the benchmark. We report both a portfolio "partial" beta for returns driven by changes in various groups of systematic risk factors (*e.g.,* 3.0 for investment grade spreads) as well as an "overall" beta due to a change in all systematic risk factors (*e.g.,* 1.08). Specifically, the beta coefficient

Figure 13. **Global Risk Model—Euro Portfolio Tracking Error Report**, May 19, 2004

Global Risk Factor	Isolated TEV (bps)	Cumulative TEV (bps)	Difference in cumulative (bps)	Percentage of tracking error variance (%)	Systematic beta
Global					
Yield Curve	12.04	12.04	12.04	8.84	1.09
Swap Spreads	11.24	16.12	4.09	9.14	2.05
Volatility	0.0	16.12	0.0	0.0	0.0
Investment-Grade Spreads	17.09	21.11	4.98	20.62	3.01
Treasury Spreads	2.96	16.42	0.3	0.62	0.77
Credit and Agency Spreads	17.06	21.33	4.9	20.33	4.81
MBS/Securitized	1.36	21.11	-0.22	-0.33	2.6
Emerging Markets Spread	0.21	21.06	-0.04	-0.08	0.0
Systematic risk	21.06	21.06	0.0	38.52	1.08
Idiosyncratic risk	26.28	33.68	12.62	59.96	
Credit default risk	4.18	33.94	0.26	1.52	
Total risk		**33.94**	**0.0**	**100.0**	
Portfolio volatility (bps/month)					120.03
Benchmark volatility (bps/month)					106.92

indicates how the portfolio return is expected to respond to a change in the benchmark return driven by changes in the systematic risk factors. For example, the beta value of 3.0 for investment grade spreads can be interpreted as follows. Suppose a change in the systematic investment grade risk factors (with all other risk factors unchanged) causes the benchmark return to increase by 1%. With a beta value of 3.0, the portfolio return is expected to increase by 3.0%. Typically, the "overall" beta is dominated by any long or short duration bets relative to the benchmark.

The Risk Model decomposes total portfolio risk into three components: systematic, idiosyncratic, and credit default risks. Systematic risk is explained by allocation of sensitivity across risk factors and can usually be associated with macro allocation decisions within a portfolio. Idiosyncratic (or, non-systematic) risk reflects the portfolio's concentration in a limited set of issuers and securities as a result of security selection decisions. Lastly, credit default risk reflects our portfolio's relative exposure to bonds rated Baa and lower and the default correlation structure of the bonds among themselves. In our example, the systematic risk (21.1 bp/month) is largely driven by the overweight to credit spreads (see the percentage of tracking error variance), while the idiosyncratic risk (26.3 bp/month) largely reflects the portfolio's concentration in a few credit issuers. Credit default risk is low (4.2 bp/month) due to the portfolio's and benchmarks's low exposure to bonds rated Baa and lower. To arrive at the total portfolio risk, the Risk Model combines the three sources of risk by taking the square root of the sum of their squares.

The Factor Exposure Report (Figure 14) presents details of the portfolio's systematic risks. The report covers all systematic factors relevant to the portfolio's analysis: currency, yield curve, swap spreads, volatility, credit, emerging market, and collateralized spreads. The first column of this report lists the factor's name and the second column describes how the portfolio's sensitivity to the factor is measured (*e.g.,* key rate durations for changes in Treasury key rates). The next three columns display the portfolio's exposure, the benchmark's exposure, and the net exposure to each factor. The net exposure column is the one that will map to our covariance matrix of systematic factors to provide the systematic tracking error estimate. The "factor volatility" column reports the factor's current estimated volatility (updated every month). As described earlier, factor volatilities also depend on the manager's choice regarding the time-weighting of historical data for the estimation.

Figure 14. **Global Risk Model—Euro Portfolio Factor Exposure Report,** May 19, 2004

Factor name	Sensitivity/Exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change (bps)	TE impact of a correlated 1 std. dev. up change (bps)	Marginal contribution to TEV (bps)	Percentage of tracking error variance (%)
CURRENCY									
EUR Currency	MW%	100.0	100.0	0.0	0.0	0.0		0.0	0.0
KEY RATES AND CONVEXITY									
EUR 6M key rate	KRD (Yr)	0.013	0.069	-0.056	15.3	0.86	-4.25	1.918	-0.32
EUR 2Y key rate	KRD (Yr)	0.648	0.676	-0.028	25.88	0.71	-6.61	5.039	-0.41
EUR 5Y key rate	KRD (Yr)	2.959	1.699	1.26	25.63	-32.29	-7.7	5.814	21.59
EUR 10Y key rate	KRD (Yr)	0.461	1.526	-1.065	20.66	22.0	-6.71	4.081	-12.81
EUR 20Y key rate	KRD (Yr)	0.273	0.705	-0.433	15.95	6.9	-5.86	2.753	-3.51
EUR 30Y key rate	KRD (Yr)	1.033	0.555	0.478	16.85	-8.05	-6.14	3.048	4.29
EUR Convexity	OAC (Yr^2/100)	0.513	0.51	0.0030	1.95	0.01	-1.44	-0.083	-0.0
SWAP SPREADS									
EUR 2Y swap spread	SSKRD (Yr)	0.044	0.568	-0.525	2.68	1.4	-2.83	0.223	-0.34
EUR 5Y swap spread	SSKRD (Yr)	2.2	1.283	0.916	3.32	-3.04	-8.17	0.8	2.16
EUR 10Y swap spread	SSKRD (Yr)	3.99	1.375	2.615	2.77	-7.23	-8.91	0.727	5.6
EUR 30Y swap spread	SSKRD (Yr)	1.136	0.542	0.594	4.91	-2.91	-6.81	0.986	1.72
VOLATILITY (NON-USD)									
EUR Volatility	Volatility Duration	0.0	0.0	-0.0	68.64	0.0	0.45	-0.915	0.0
TREASURY SPREAD & VOL.									
DE treasury spread	OASD (Yr)	0.0	0.757	-0.757	0.51	0.39	5.22	-0.079	0.18
FR treasury spread	OASD (Yr)	0.0	0.674	-0.674	0.53	0.36	5.63	-0.089	0.18
IT treasury spread	OASD (Yr)	0.0	0.865	-0.865	1.46	1.26	5.56	-0.239	0.61
ES treasury spread	OASD (Yr)	0.0	0.283	-0.283	1.53	0.43	4.64	-0.21	0.17
NL treasury spread	OASD (Yr)	0.0	0.181	-0.181	2.79	0.51	3.91	-0.322	0.17
BE treasury spread	OASD (Yr)	0.0	0.234	-0.234	1.98	0.46	4.06	-0.236	0.16
GR treasury spread	OASD (Yr)	2.654	0.148	2.506	1.37	-3.45	0.91	-0.037	-0.27
EUR Small AAA treasury spread	OASD (Yr)	0.0	0.207	-0.207	1.52	0.31	4.61	-0.207	0.13
EUR Small AA/A/BAA treasury spread	OASD (Yr)	0.0	0.052	-0.052	1.8	0.09	7.59	-0.402	0.06
Pan-Euro Govt Liqudity	OASD*(OAS-AvgOAS) (Yr*%)	0.068	0.04	0.027	5.65	-0.16	-1.15	0.191	0.02
Pan-Euro Govt Slope	OASD*(Life-AvgLife) (Yr^2)	6.739	17.71	-10.97	0.14	1.58	-5.67	0.024	-0.78
AGENCY SPREAD & VOL.									
Pan-Euro Agency/Local Govt. AAA	OASD (Yr)	0.0	0.213	-0.213	1.33	0.28	5.59	-0.219	0.14
Pan-Euro Agency/Local Govt. AA/A/BAA	OASD (Yr)	0.0	0.155	-0.155	1.51	0.23	4.34	-0.193	0.09
CREDIT IG SPREAD & VOL.									
Euro Banking AAA/AA	OASD (Yr)	0.0	0.132	-0.132	1.29	0.17	-3.35	0.127	-0.05
Euro Banking A/BAA	OASD (Yr)	0.687	0.166	0.521	3.62	-1.89	-6.51	0.695	1.07
Euro Financial AAA/AA	OASD (Yr)	0.0	0.025	-0.025	2.11	0.05	-6.14	0.381	-0.03
Euro Financial A/BAA	OASD (Yr)	0.0	0.048	-0.048	6.55	0.32	-7.7	1.485	-0.21
Euro Industrial AAA/AA	OASD (Yr)	0.0	0.032	-0.032	2.28	0.07	-1.85	0.124	-0.01
Euro Basic Industrial A	OASD (Yr)	0.0	0.034	-0.034	3.59	0.12	-3.55	0.375	-0.04
Euro Basic Industrial BAA	OASD (Yr)	0.0	0.024	-0.024	8.32	0.2	-2.71	0.665	-0.05
Euro Consumer Cyclical A	OASD (Yr)	0.0	0.023	-0.023	4.76	0.11	-2.89	0.405	-0.03
Euro Consumer Cyclical BAA	OASD (Yr)	0.0	0.041	-0.041	7.5	0.31	-2.72	0.601	-0.07
Euro Consumer Non-cyclical A	OASD (Yr)	0.573	0.014	0.559	3.36	-1.88	-0.68	0.067	0.11
Euro Consumer Non-cyclical BAA	OASD (Yr)	0.0	0.018	-0.018	6.61	0.12	-5.98	1.164	-0.06
Euro Communication A	OASD (Yr)	0.0	0.017	-0.017	6.47	0.11	-1.21	0.23	-0.01
Euro Communication BAA	OASD (Yr)	0.713	0.078	0.634	14.04	-8.91	-7.3	3.021	5.65
Euro Utility AAA/AA	OASD (Yr)	0.0	0.012	-0.012	2.19	0.03	-1.41	0.091	-0.0
Euro Utility A	OASD (Yr)	0.653	0.049	0.604	5.09	-3.07	-7.34	1.099	1.96
Euro Utility BAA	OASD (Yr)	0.0	0.02	-0.02	6.34	0.12	-5.99	1.119	-0.06
Euro Non-corporate AAA	OASD (Yr)	0.686	0.108	0.577	1.21	-0.7	-1.62	0.058	0.1
Euro Non-corporate AA	OASD (Yr)	0.0	0.011	-0.011	1.46	0.02	-4.12	0.177	-0.01
Euro Non-corporate A	OASD (Yr)	0.0	0.015	-0.015	1.81	0.03	-3.27	0.174	-0.01

The fourth column from the right ("TE impact of an isolated 1 std dev up change") shows a rough measure of the portfolio's sensitivity to a shock in a given risk factor. This value calculates the effect of a one standard deviation upward movement in the factor, taken in isolation, on the relative performance of the portfolio. In our example, the *net* (*i.e.,* portfolio minus benchmark) exposure to the 5-year key rate is 1.26 years of duration, while the volatility of that key rate is 25.6 bp/month. The product of these two, with a sign adjustment, is -32.3 bp. This value is the expected underperformance of our portfolio with respect to its benchmark given a one standard deviation upward move in the euro 5-year key rate, holding all other risk factors constant.

It is unrealistic to assume that the 5-year key rate, or any other risk factor for that matter, could move significantly while all other risk factors remain unchanged. We know from observation that all systematic factors are correlated. The next column performs the same simple scenario analysis, but now taking factor covariances into account. For example, based on factor correlations, an upward change in the 5-year key rate will produce changes in other risk factors. Therefore, the effect on tracking error is not limited just to the change in the 5-year key rate risk factor because the change in the other risk factors induced by the change in the 5-year key rate will also affect tracking error. For our portfolio, an upward change in the 5-year key rate is typically associated with similar changes across the yield curve. Here, the portfolio's underweight to the 10-year key rate partially offsets the overweight to the 5-year rate. Consequently, the net effect on portfolio relative return of a one standard deviation increase in the 5-year key rate is -7.7 bp, substantially less than the -32.3 bp estimated in the isolated shock scenario.

The second column from the right in Figure 14 shows marginal contribution to tracking error volatility. A positive number indicates that a marginal increase in exposure will increase risk while a negative number indicates a potential risk reduction. These marginal contributions can be used to infer implicit allocation bets in a portfolio. So, a negative marginal contribution to risk is consistent with a bearish view, while a positive marginal contribution implies a bullish view, with the relative magnitude of the view being proportional to the marginal contributions. The variance decomposition in the right-hand side column of the Factor Report highlights the main sources of tracking error, taking correlation effects into account. One should be aware that percentage and, in particular, marginal contribution to risk can be very sensitive to relatively small changes in portfolio composition.

Regarding euro government bonds, the model includes country spread factors for treasury bonds issued by euro-members.

Regarding euro government bonds, the model includes country spread factors for treasury bonds issued by euro-members. However, their effect on portfolio risk will typically be dwarfed by any credit spread exposure in the portfolio. In our example portfolio, we have a substantial position in a Greek government bond. This bond maps to the Greek treasury spread factor that represents the systematic spread risk of Greek government bonds with respect to the euro swap curve. Including country specific factors in the euro treasury market allows for a precise measurement and attribution of risk for pure government bond portfolios and reflects the variations in investor perception of the different euro sovereign issuers.

Figure 14 reveals that the portfolio contains some long duration corporate bonds. They map to the systematic factors that correspond to their industry and quality and will also contribute to a high loading to the euro credit slope factor, which captures the risk of change in slope of the term structure of credit spreads. As our credit bonds have a generally higher spread than other bonds from similar sectors in the the index, the exposure to the euro credit liquidity factors is significant. This factor, which we label "liquidity," represents the risk that relatively higher spread bonds may—everything else unchanged—perform differently than lower spread bonds.

Having described in some detail the systematic risk embedded in the portfolio, we now move to an analysis of the issuer and issue-specific tracking error. The Credit Ticker Report in Figure 15 consolidates exposure across all individual positions associated with a particular issuer ticker for the portfolio and the benchmark. It reports the net market weight and contribution to spread duration at the issuer level. The far right column of the report displays the idiosyncratic risk associated with each ticker (the report is sorted on this value). High issuer-specific idiosyncratic risks are typically associated with a bullish view on the issuer if the net spread duration exposure is positive, or a bearish view if the spread duration exposure is negative.

For our sample portfolio, the largest issuer specific idiosyncratic risk is Deutsche Telekom, with an isolated idiosyncratic tracking error volatility of 16.0 bp/month. This large number, unrealistic for an actual investment-grade portfolio, is explained by our large concentrated position in a 30-year DT bond which belongs to a sector that has, historically, witnessed substantial idiosyncratic spread behavior.

This report also reflects the different treatment of idiosyncratic risk that may exist within a particular subset of the market. For example, Credit Foncier and EuroHypo are both collateralized bonds found in our example portfolio. Both of them map to our

Figure 15. **Global Risk Model–Euro Portfolio**
Credit Ticker Concentration Report, May 19, 2004

Ticker	Name	Sector	Rating	Currency	# issues in portfolio	Portfolio weight (%)	Benchmark weight (%)	Net weight (%)	Net contribution to OASD (Yr)	Systematic TEV (bps)	Idiosyncratic TEV (bps)
DT	DEUTSCHE TELEKOM AG	WIRELINES	BAA2	EUR	1	5.54	0.49	5.06	0.694	15.23	15.95
HSBC	HOUSEHOLD FINANCE CORP	BANKING	A2 A3 A1	EUR	1	9.86	0.27	9.59	0.674	14.64	5.15
RWE	RWE AG	ELECTRIC	A1	EUR	1	4.68	0.2	4.48	0.64	12.79	3.78
CARR	CARREFOUR SA	SUPERMARKETS	A1	EUR	1	9.59	0.09	9.5	0.569	12.78	3.54
FHLMC	FEDERAL HOME LN MTG CORP	FOREIGN_AGENCIES	AAA+	EUR	1	9.56	0.56	9.0	0.658	14.35	1.79
CFF.COL	CREDIT FONCIER DE FRANCE	MORTGAGES	AAA	EUR	1	10.02	0.44	9.58	0.696	15.25	1.64
EURHYP.COL	DEUTSCHE HYPO FRANKFURT	MULTIPLE	AAA AA1	EUR	1	9.46	1.25	8.21	0.643	14.08	0.64
FRTEL	FRANCE TELECOM	WIRELINES	BAA2	EUR	0	0.0	0.4	-0.4	-0.021	0.46	0.44
TITIM	OLIVETTI INTERNATIONAL BV	WIRELINES	BAA1 BAA2	EUR	0	0.0	0.42	-0.42	-0.02	0.46	0.44
GM	GENERAL MOTORS ACCEPT CORP	AUTOMOTIVE	BAA2	EUR	0	0.0	0.41	-0.41	-0.014	0.28	0.39
KFW	KREDIT FUER WIEDERAUFBAU	OTHER_AGENCY	AAA	EUR	0	0.0	1.57	-1.57	-0.066	1.48	0.21
VIEFP	VEOLIA ENVIRONNEMENT	UTILITY_OTHER	BAA2	EUR	0	0.0	0.13	-0.13	-0.0080	0.16	0.17
INTNED	ING BANK	BANKING	AA3 A1 A3	EUR	0	0.0	0.41	-0.41	-0.021	0.46	0.16
F	FORD MOTOR CREDIT	AUTOMOTIVE	BAA3 A3	EUR	0	0.0	0.22	-0.22	-0.0060	0.12	0.16
MEX	UNITED MEXICAN STATES	SOVEREIGNS	BAA3	EUR	0	0.0	0.1	-0.1	-0.0040	0.13	0.14
ALZ	ALLIANZ FINANCE BV	LIFE	AA3 A2 A3	EUR	0	0.0	0.2	-0.2	-0.011	0.23	0.14
DCX	DAIMLERCHRYSLER NORTH AMER	AUTOMOTIVE	BAA2	EUR	0	0.0	0.21	-0.21	-0.0050	0.12	0.14
POLAND	POLAND (REPUBLIC OF)	SOVEREIGNS	BAA1	EUR	0	0.0	0.14	-0.14	-0.0090	0.19	0.11
MUNRE	MUNICH RE FINANCE BV	P&C	A3	EUR	0	0.0	0.07	-0.07	-0.0050	0.1	0.1
EIB	EUROPEAN INVESTMENT BANK	SUPRANATIONALS	AAA	EUR	0	0.0	1.32	-1.32	-0.055	1.25	0.1
REPSM	REPSOL SA	INTEGRATED	BAA2	EUR	0	0.0	0.06	-0.06	-0.0030	0.07	0.1
BATSLN	BRITISH AMERICAN TOBACCO	TOBACCO	BAA1	EUR	0	0.0	0.1	-0.1	-0.0050	0.1	0.1
CROATI	CROATIA (REPUBLIC OF)	SOVEREIGNS	BAA3	EUR	0	0.0	0.05	-0.05	-0.0030	0.07	0.09
ASSGEN	ASSICURAZIONI GENERALI SPA	LIFE	AA3 A1 A2	EUR	0	0.0	0.11	-0.11	-0.0070	0.15	0.08
AXASA	AXA SA	LIFE	A2 BAA1	EUR	0	0.0	0.05	-0.05	-0.0030	0.06	0.08

single systematic factor for the euro collateralized market, which is sufficient given the absence of prepayment risk. However, because they belong to different subsets of the euro collateralized market, they are assigned different idiosyncratic volatilities. When estimating idiosyncratic risk, we separate the highly regulated and homogeneous German Pfandbriefe market from other mortgage collateralized bonds. The right-hand side column of the Figure 16 (the Portfolio Issue-Specific Risk Report) shows that although our two collateralized positions have similar sizes, maturities, and net duration contributions, they display fairly different contributions to issuer-specific risk (1.64 bp/month for Credit Foncier compared to 0.64 bp/month for EuroHypo).

The ticker level analysis covers all issuers either in the portfolio or the index, so it also quantifies the risk of underweighting individual issuers. This is illustrated at the bottom of Figure 16, where we see that *excluding* France Telecom from our portfolio generates an idiosyncratic risk for our portfolio of 0.4 bp/month due to this relatively volatile issuer having a significant weight (0.4%) in the benchmark.

Further details at the individual position level can be found in the Issue-Specific Risk Report (Figure 16). In this report, we have the details of idiosyncratic risks for every position in the portfolio, including futures contracts. Although widely used for interest rate management purposes, futures contracts can display their own idiosyncratic behavior due to the possibility of a change in the underlying cheapest-to-deliver bond.

We have also constructed a component of the Global Risk Model that is tailored specifically to the sterling market.

So far in this section, we have analyzed a single-currency euro-denominated portfolio. However, we also have a component of the Global Risk Model that is tailored specifically to the sterling market, with its own set of risk factors. In fact, the same analysis we used for the euro portfolio could have been performed for a sterling-only portfolio, with the same level of detail in risk attribution. To demonstrate this, we slightly expand our portfolio example to include bonds denominated in sterling. In Figure 17, we present the revised portfolio composition, which now includes some non-core positions such as an HSBC sterling bond, which is partially offset by a short position in a gilt futures contract. For good measure, we also include a Spintab bond, which is a Swedish mortgage bond denominated in Swedish krone.

Keeping the same benchmark, the Euro Aggregate index, we can now analyze the effect of these inclusions on the portfolio risk profile. Figure 18 presents the new tracking error (46.5 bp/month). Note that the sterling currency exposure has become a significant

Figure 16. **Global Risk Model–Euro Portfolio**
Portfolio Issue-Specific Risk Report (Excerpts), May 19, 2004

Identifier	Ticker	Description	Currency	Coupon (%)	Maturity	Current OAS (bps)	MV issue weight (%)	MV issue net weight (%)	MV issuer net weight (%)	Marginal systematic TEV (bps)	Systematic TEV (bps)	Idiosyncratic TEV (bps)	Issuer idiosyncratic TEV (bps)
GR0124018525	GGB	GREECE (REPUBLIC OF)	EUR	5.25	5/18/2012	15.0	39.33	39.16	39.16	0.6068	58.71	9.58	9.58
FR0000485724	CFF	CREDIT FONCIER DE FRANCE	EUR	5.38	3/2/2013	12.3	10.02	9.99	9.58	0.643	15.7	1.66	1.64
XS0159496867	HSBC	HSBC HOLDING PLC	EUR	5.38	12/20/2012	48.8	9.86	9.84	9.59	0.7059	14.88	5.28	5.15
XS0167864544	CARR	CARREFOUR SA	EUR	4.38	6/15/2011	39.8	9.59	9.57	9.5	0.5946	12.85	3.55	3.54
XS0154444870	FHLMC	FEDERAL HOME LN MTG CORP	EUR	4.75	1/15/2013	24.4	9.56	9.48	9.0	0.6595	14.82	1.81	1.79
DE0003611885	EURHYP	EUROHYPO AG	EUR	4.5	1/21/2013	12.9	9.46	9.4	8.21	0.6508	14.92	0.65	0.64
XS0161488498	DT	DEUTSCHE TELEKOM AG	EUR	7.5	1/24/2033	116.1	5.54	5.53	5.06	2.0053	15.55	16.28	15.95
XS0162513211	RWE	RWE AG	EUR	5.75	2/14/2033	72.9	4.68	4.66	4.48	1.6659	12.99	3.83	3.78
FGBLU4:UDE		Euro-BUND	EUR			0.0	-0.0	-0.0	-0.0	N/A	87.9	15.72	15.72
FGBMU4:UDE		Euro-BOBL	EUR			0.0	0.0	0.0	0.0	N/A	36.53	5.48	5.48
FGBSU4:UDE		Euro-SCHATZ	EUR			0.0	0.0	0.0	0.0	N/A	16.41	2.45	2.45

Figure 17. **Global Risk Model—Euro Portfolio**
Portfolio Issues Report—Pan-European Portfolio, May 19, 2004

Identifier	Position Amount	Description	Coupon	Maturity Date	Yield	OAD	Classification—Broad	Index Rating	Crcy
EUR	211.3	CASH - European Monetary Unit							EUR
GR0124018525	4000	GREECE (REPUBLIC OF)	5.250	5/18/12	4.26	6.63	TREASURY	A1	EUR
XS0161488498	500	DEUTSCHE TELEKOM AG	7.500	1/24/33	6.09	12.97	COMMUNICATIONS	BAA2	EUR
XS0162513211	500	RWE AG	5.750	2/14/33	5.69	14.07	ELECTRIC	A1	EUR
FR0000485724	1000	CREDIT FONCIER DE FRANCE	5.375	3/02/13	4.33	7.06	MORTGAGES	AAA	EUR
XS0145507124	1000	HOUSEHOLD FINANCE CORP	7.000	3/27/12	5.89	6.12	FINANCE_COMPANIES	A2	EUR
XS0154444870	1000	FEDERAL HOME LN MTG CORP	4.750	1/15/13	4.45	7.04	FOREIGN_AGENCIES	AAA+	EUR
XS0159496867	1000	HSBC HOLDING PLC	5.375	12/20/12	4.68	6.83	BANKING	A2	EUR
DE0003611885	1000	EUROHYPO AG	4.500	1/21/13	4.34	7.12	PFANDBRIEFE_JUMBO	AAA	EUR
XS0167864544	1000	CARREFOUR SA	4.375	6/15/11	4.39	5.86	CONSUMER_NON_CYC	A1	EUR
FGBMU4:UDE	3000	Euro-BOBL			0.00	4.55	FUTURES		EUR
FGBSU4:UDE	3000	Euro-SCHATZ			0.00	2.19	FUTURES		EUR
FGBLU4:UDE	-5000	Euro-BUND			0.00	7.75	FUTURES		EUR
SE0000630204	1000	SPINTAB AB	5.750	6/15/05	2.736	1	MORTGAGES	AA3	SEK
XS0145507124	1000	HOUSEHOLD FINANCE CORP	7.000	3/27/12	5.894	6.12	FINANCE_COMPANIES	A2	GBP
RU4:LIF	-1000	Long Gilt			0	7.38	FUTURES		GBP

Figure 18. **Global Risk Model—Euro Portfolio**
Tracking Error Report—Pan-European Portfolio, May 19, 2004

Global Risk Factor	Isolated TEV (bps)	Cumulative TEV (bps)	Difference in cumulative (bps)	Percentage of tracking error variance (%)	Systematic beta
Global					
Currency	27.44	27.44	27.44	33.53	
Yield Curve	10.8	30.88	3.44	8.2	0.92
Swap Spreads	9.8	32.95	2.07	4.87	1.86
Volatility	0.0	32.95	-0.0	-0.0	-0.0
Investment-Grade Spreads	16.94	34.85	1.9	9.56	3.01
Treasury Spreads	2.66	33.35	0.4	0.71	0.66
Credit and Agency Spreads	16.82	34.7	1.35	8.58	4.91
MBS/Securitized	1.05	34.85	0.15	0.27	2.24
Emerging Markets Spread	0.21	34.8	-0.05	-0.07	0.0
Systematic risk	34.8	34.8	0.0	56.08	0.86
Idiosyncratic risk	30.6	46.34	11.54	43.35	
Credit default risk	3.51	46.47	0.13	0.57	
Total risk		**46.47**	**0.0**	**100.0**	
Portfolio volatility (bps/month)					101.83
Benchmark volatility (bps/month)					106.92
European Bloc (EUR + CHF + DKK + NOK + SEK)					
Yield Curve	9.44	9.44	9.44		
Swap Spreads	8.19	12.72	3.28		
Volatility	0.0	12.72	-0.0		
Investment-Grade Spreads	14.09	18.52	5.81		
Treasury Spreads	2.66	13.48	0.76		
Credit and Agency Spreads	14.11	18.42	4.93		
Securitized	1.05	18.52	0.11		
Emerging Markets Spread	0.21	18.44	-0.08		
Cumulative	18.44	18.44	0.0		

Figure 19. **Global Risk Model—Euro Portfolio**
Factor Exposure Report—Pan-European Portfolio (Excerpts), May 19, 2004

Factor name	Sensitivity/Exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change (bps)	TE impact of a correlated 1 std. dev. up change (bps)	Marginal contribution to TEV (bps)	Percentage of tracking error variance (%)
CURRENCY									
EUR Currency	MW%	85.34	100.0	-14.66	0.0	-0.0		0.0	-0.0
GBP Currency	MW%	13.72	0.0	13.72	2.02	27.67	26.24	1.138	33.61
SEK Currency	MW%	0.94	0.0	0.94	1.08	1.02	-1.69	-0.039	-0.08
KEY RATES AND CONVEXITY									
EUR 6M key rate	KRD (Yr)	0.011	0.069	-0.058	15.3	0.89	9.31	-3.063	0.38
EUR 2Y key rate	KRD (Yr)	0.553	0.676	-0.123	25.88	3.17	12.97	-7.225	1.91
EUR 5Y key rate	KRD (Yr)	2.525	1.699	0.826	25.63	-21.17	15.27	-8.419	-14.97
EUR 10Y key rate	KRD (Yr)	0.393	1.526	-1.133	20.66	23.4	16.73	-7.437	18.13
EUR 20Y key rate	KRD (Yr)	0.233	0.705	-0.473	15.95	7.54	16.46	-5.651	5.75
EUR 30Y key rate	KRD (Yr)	0.881	0.555	0.326	16.85	-5.5	15.72	-5.701	-4.0
EUR Convexity	OAC (Yr^2/100)	0.438	0.51	-0.072	1.95	-0.14	-6.36	-0.267	0.04
GBP 6M key rate	KRD (Yr)	-0.0010	0.0	-0.0010	16.65	0.01	11.83	-4.239	0.01
GBP 2Y key rate	KRD (Yr)	-0.0020	0.0	-0.0020	26.89	0.05	16.15	-9.349	0.03
GBP 5Y key rate	KRD (Yr)	0.195	0.0	0.195	25.16	-4.92	17.62	-9.54	-4.01
GBP 10Y key rate	KRD (Yr)	-0.274	0.0	-0.274	21.62	5.93	18.29	-8.508	5.02
GBP Convexity	OAC (Yr^2/100)	-0.016	0.0	-0.016	2.19	-0.03	-3.73	-0.176	0.01
SEK 6M key rate	KRD (Yr)	0.0060	0.0	0.0060	16.25	-0.09	8.19	-2.862	-0.04
SEK 2Y key rate	KRD (Yr)	0.0040	0.0	0.0040	27.82	-0.1	10.99	-6.579	-0.05
SWAP SPREADS									
EUR 2Y swap spread	SSKRD (Yr)	0.037	0.568	-0.531	2.68	1.42	-3.31	0.191	-0.22
EUR 5Y swap spread	SSKRD (Yr)	1.877	1.283	0.594	3.32	-1.97	-7.97	0.57	0.73
EUR 10Y swap spread	SSKRD (Yr)	3.405	1.375	2.03	2.77	-5.62	-8.45	0.503	2.2

Figure 20. **Global Risk Model—Euro Portfolio**
Credit Ticker Concentration Report—Pan-European Portfolio (Excerpts), May 19, 2004

Ticker	Name	Sector	Rating	Currency	# issues in portfolio	Portfolio weight (%)	Benchmark weight (%)	Net weight (%)	Net contribution to OASD (Yr)	Systematic TEV (bps)	Idiosyncratic TEV (bps)
HSBC	HOUSEHOLD FINANCE CORP	NON_CAPTIVE_CONSUMER	A2 A3 A1	EUR GBP	2	20.96	0.27	20.69	1.363	31.9	21.14
DT	DEUTSCHE TELEKOM AG	WIRELINES	BAA2	EUR	1	4.73	0.49	4.24	0.589	12.95	13.56
RWE	RWE AG	ELECTRIC	A1	EUR	1	3.99	0.2	3.79	0.545	10.88	3.22
CARR	CARREFOUR SA	SUPERMARKETS	A1	EUR	1	8.18	0.09	8.09	0.485	10.89	3.02
FHLMC	FEDERAL HOME LN MTG CORP	FOREIGN_AGENCIES	AAA+	EUR	1	8.16	0.56	7.6	0.558	12.16	1.52
CFF.COL	CREDIT FONCIER DE FRANCE	MORTGAGES	AAA	EUR	1	8.55	0.44	8.11	0.59	12.94	1.39
EURHYP.COL	DEUTSCHE HYPO FRANKFURT	MULTIPLE	AAA AA1	EUR	1	8.07	1.25	6.82	0.542	11.88	0.54
FRTEL	FRANCE TELECOM	WIRELINES	BAA2	EUR	0	0.0	0.4	-0.4	-0.021	0.46	0.44
TITIM	OLIVETTI INTERNATIONAL BV	WIRELINES	BAA1 BAA2	EUR	0	0.0	0.42	-0.42	-0.02	0.46	0.44
GM	GENERAL MOTORS ACCEPT CORP	AUTOMOTIVE	BAA2	EUR	0	0.0	0.41	-0.41	-0.014	0.28	0.39
KFW	KREDIT FUER WIEDERAUFBAU	OTHER_AGENCY	AAA	EUR	0	0.0	1.57	-1.57	-0.066	1.48	0.21
VIEFP	VEOLIA ENVIRONNEMENT	UTILITY_OTHER	BAA2	EUR	0	0.0	0.13	-0.13	-0.0080	0.16	0.17
INTNED	ING BANK	BANKING	AA3 A1 A3	EUR	0	0.0	0.41	-0.41	-0.021	0.46	0.16
F	FORD MOTOR CREDIT	AUTOMOTIVE	BAA3 A3	EUR	0	0.0	0.22	-0.22	-0.0060	0.12	0.16
MEX	UNITED MEXICAN STATES	SOVEREIGNS	BAA3	EUR	0	0.0	0.1	-0.1	-0.0040	0.13	0.14
ALZ	ALLIANZ FINANCE BV	LIFE	AA3 A2 A3	EUR	0	0.0	0.2	-0.2	-0.011	0.23	0.14
DCX	DAIMLERCHRYSLER NORTH AMER	AUTOMOTIVE	BAA2	EUR	0	0.0	0.21	-0.21	-0.0050	0.12	0.14
POLAND	POLAND (REPUBLIC OF)	SOVEREIGNS	BAA1	EUR	0	0.0	0.14	-0.14	-0.0090	0.19	0.11
MUNRE	MUNICH RE FINANCE BV	P&C	A3	EUR	0	0.0	0.07	-0.07	-0.0050	0.1	0.1
EIB	EUROPEAN INVESTMENT BANK	SUPRANATIONALS	AAA	EUR	0	0.0	1.32	-1.32	-0.055	1.25	0.1
REPSM	REPSOL SA	INTEGRATED	BAA2	EUR	0	0.0	0.06	-0.06	-0.0030	0.07	0.1
BATSLN	BRITISH AMERICAN TOBACCO	TOBACCO	BAA1	EUR	0	0.0	0.1	-0.1	-0.0050	0.1	0.1
CROATI	CROATIA (REPUBLIC OF)	SOVEREIGNS	BAA3	EUR	0	0.0	0.05	-0.05	-0.0030	0.07	0.09
ASSGEN	ASSICURAZIONI GENERALI SPA	LIFE	AA3 A1 A2	EUR	0	0.0	0.11	-0.11	-0.0070	0.15	0.08
AXASA	AXA SA	LIFE	A2 BAA1	EUR	0	0.0	0.05	-0.05	-0.0030	0.06	0.08

source of risk, accounting for 33% of the tracking error variance. The bottom panel of the figure shows the contribution of the sterling portion of the portfolio to the portfolio's risk.

As the portfolio is now invested in a broader variety of market sectors, the factor exposure report is expanded to display all relevant sources of systematic tracking error. Figure 19 provides some excerpts from this report to show currency factors as well as relevant yield curve factors for GBP and SEK-denominated bonds. As our GBP investment is a credit bond, it also maps to GBP swap spreads and corporate spread factors.

The issuer-specific risk report is also adjusted to reflect the new portfolio composition, as shown in Figure 20. Although issued by different entities within the HSBC group, the two bonds that share that ticker are assumed to have strong commonality in idiosyncratic spread performance. Their idiosyncratic spread behavior is consolidated assuming an imperfect correlation that itself is a function of the spread level of the issuer (this issue is discussed further in Chapter 4). Now, the top contributor to idiosyncratic risk is HSBC, closely followed by Deutsche Telekom. Note, however, that the difference in idiosyncratic risk contribution between these two issuers is modest, although HSBC's exposure, in terms of net contribution to spread duration, is more than twice as large as Deutsche Telekom's.

C. The Risk Report for a Global Aggregate Portfolio

The Global Risk Model is capable of handling "core-plus" portfolios that are benchmarked against a single currency index, but which may have multi-currency exposure.

So far, we have described the Risk Report for a U.S. dollar portfolio and for a euro (and pan-euro) portfolio. As its name implies, the new Global Risk Model was designed particularly to handle *global* portfolios (*i.e.,* portfolios that include assets from more than one currency market). Therefore, it is also capable of handling "core-plus" portfolios that are benchmarked against a single currency index but which may have multi-currency exposure. The Risk Report for a global portfolio is very similar to a risk report for a dollar, euro, or sterling portfolio except for the larger number of relevant risk factors. Although the Risk Report has been described in detail in the previous two sections, for the benefit of investors who may have jumped directly to this section, we will quickly review the Risk Report generated by a global portfolio.

As investors are well aware, the Global Risk Model is based upon a covariance matrix of systematic, non-systematic and default risk factors derived from historical data. How should the historical risk factor data be used to estimate this matrix? Give equal weight to the data (*i.e.,* unweighted) or give less weight to older observations and more weight to more recent observations (*i.e.,* exponential weighting)?[15] The Risk Model allows the manager to choose the weighting scheme (a separate choice can be made for systematic, idiosyncratic, and default risk).

If exponential weighting is chosen over equal weighting, the manager implicitly expects recent historical correlations to persist, unlikely to revert to earlier periods.

Whatever choice the manager makes implies a view. If exponential weighting is chosen over equal weighting, the manager implicitly expects recent historical correlations to persist, unlikely to revert to earlier periods. In the absence of a view, the manager might consider running one set of reports with unweighted risk factors and another with weighted risk factors and evaluate the difference in the estimated TEVs.

[15] As discussed above, for exponential time-weighting, we use a one year half life. Another way to think about this weighting scheme is that data from the past twelve months has the same combined weight in the covariance estimation as the combined weight of all data prior to twelve months ago.

A further choice is provided for currency hedging schemes: "(Implicit) Currency hedging for the benchmark" or "No implicit currency hedging."

A further choice is provided for currency hedging schemes. The treatment of the benchmark is straightforward: select "(Implicit) Currency hedging for the benchmark" to measure risk against the fully hedged index; turn this feature off to use the unhedged index. For the portfolio, the two choices represent two different ways of using the Risk Model: one in which all currency hedging transactions (FX forwards, etc.) are explicitly recorded in the portfolio, and another in which no such transactions are included, but we assume, as a shortcut that all investments are hedged back to base currency using an overlay. Using "(Implicit) Currency hedging for the portfolio" specifies this shortcut mode. When implicit hedging is selected for both the currency and the benchmark the TEV calculation will show no currency risk at all.[16]

Selecting "No implicit currency hedging" turns off this shortcut assumption of perfect hedging and requires the full details of any hedging instrument transactions to be entered into the portfolio. This is clearly appropriate when using an unhedged benchmark, but can be very useful when using a hedged benchmark as well. In many portfolios, foreign exchange forwards can be used to add some currency risk to the position by incomplete hedging of some positions. In other portfolios, the FX exposure may be managed separately from the bond market exposure by using an FX overlay. In either of these cases, the ability to precisely specify the portfolio's exposures is required for a proper calculation of risk. The manager's choices are reported in the Risk Report's User-Defined Parameters screen (Figure 21)

How risky is the portfolio?

The Portfolio/Benchmark Comparison Report (Figure 22) provides details of the number of positions in the portfolio and the benchmark, as well as average portfolio and benchmark data. For a multi-currency portfolio, many of these statistics will not be particularly useful since these represent averages of duration sensitivities and yield curves in different markets, some of which are not correlated with each other. The report also provides summary risk data expressed (with the exception of beta) as volatility in bp/month. All volatility numbers, including tracking errors, may be annualized by multiplying the monthly numbers by $\sqrt{12}$.[17]

[16] This calculation neglects the small amount of residual currency return typically observed even in hedged portfolios due to imperfect hedging. Assuming no intentional currency exposures are taken on, the risk stemming from imperfect hedging should be small relative to other risks in most portfolios.

[17] Scaling a monthly number to an annual number by multiplying by $\sqrt{12}$ assumes zero autocorrelation of the monthly tracking errors.

Figure 21. **Global Risk Model—Global Aggregate Portfolio Entering User-Defined Parameters**, June 30, 2004

Parameter	Value
Base currency	EUR
Portfolio	EURP-EX1
Benchmark	Euro Aggregate
Time-weighting of historical data in covariance matrix	
for systematic risk	Yes
for non-systematic risk	Yes
Time-weighting of credit default rates	Yes
(Implicit) Currency hedging for portfolio	No
(Implicit) Currency hedging for benchmark	No
Number of lines displayed in Issue-Specific and Credit Tickers Reports	100

The single best measure of portfolio risk relative to its benchmark is tracking error volatility (TEV). This statistic measures the volatility (standard deviation) of the return difference between the portfolio and the benchmark around the expected return difference. That is, TEV measures not the likely return differential, but rather the uncertainty of that differential.

Nevertheless, it is possible to estimate the probabilities of a given return difference. For example, if we assume returns are normally distributed,[18] then we can state that 16% of the time, portfolio return will be more than one TEV below the benchmark return.[19] For our portfolio, 16% of the time, the portfolio is likely to underperform (with respect to the expected level of outperformance) by more than 26.0 bp over one month, or 26.0 bp $\times \sqrt{12} = 90.1$ bp over one year.

Total Volatility measures the absolute risk of the portfolio and benchmark separately. The Portfolio/Benchmark Report also displays separately systematic (market) volatility, non-systematic (issue or issuer-specific) volatility, and default volatility (which applies only to securities rated Baa and lower). From the report, it is apparent that the portfolio has comparable risk to the benchmark, as far as all these measures of risk are concerned.

[18] Technically, this analysis also assumes that the portfolio and the benchmark have the same mean return over the coming month. The discrepancies arising from this assumption are typically minor in practice.

[19] Relaxation of the assumption of normality can be made by using, for example, Student's "t" distribution.

Figure 22. **Global Risk Model—Global Aggregate Portfolio Entering User-Defined Parameters**, June 30, 2004

Parameter	Portfolio	Benchmark	Difference
	GRMRV_BP	Global Agg	
Positions	90	9247	
Issuers	68	1221	
Currencies	9	13	
# positions processed	90	9243	
# positions excluded	0	4	
% MV processed	100.0	100.0	
% MV excluded	0.0	0.0	
Market Value	68354878	19806996765	
Coupon	5.3	4.51	0.79
Average Life	5.88	7.11	-1.23
Yield to Worst	3.54	3.67	-0.13
ISMA Yield	3.34	3.43	-0.09
OAS			
OAD	4.22	5.19	-0.96
ISMA Duration	4.16	5.24	-1.08
Duration to Maturity	4.2	5.3	-1.1
Vega	-0.02	-0.02	0.0
OA Spread Duration	4.21	5.17	-0.96
OA Convexity	0.22	0.25	-0.03
Total TE Volatility (bp/month)			**26.0**
Systematic Volatility (bp/month)	173.78	175.72	
Default Volatility (bp/month)	5.95	0.0	
Non-systematic Volatility (bp/month)	5.78	1.18	
Total Volatility (bp/month)	**173.98**	**175.72**	
Portfolio Beta			0.979

Portfolio Beta measures the sensitivity of the portfolio with respect to the benchmark. In our portfolio, a 1% benchmark return would be expected to be accompanied by a 0.979% portfolio return. Note this is a function both of the slightly lower volatility of the portfolio, as well as its similarity to the benchmark. A portfolio could have a greater volatility than its benchmark, but if it has low correlation with the benchmark, then it could have a beta well below one.

What are the sources of risk?

We know that total portfolio risk relative to the benchmark, as expressed by TEV, is 26.0 bp, but what are the sources of that risk? The Tracking Error Report (Figure 23) provides the answers. This report identifies the sources of TEV in two ways. First, it groups together risk factors from around the world. So, for example, all the currency risk factors are grouped globally and reported as a separate "currency" risk factor. Second, below the "global" version of the report are risk factor exposures within each of the major currency regions of the world (i.e., Dollar Bloc, Pan Euro Bloc, Sterling, and Yen). This version of the report is not shown in Figure 23.

In the "Isolated TEV" column, we note that 24.66 bp of TEV comes from systematic risk, 5.73 bp from idiosyncratic risk, and 5.91 bp from default risk. Since our model assumes that these factors are independent, we compute total TEV as:

$$\text{Total risk} = \sqrt{(\text{Systematic risk}^2 + \text{Idiosyncratic risk}^2 + \text{Default risk}^2)}$$

Figure 23. **Global Risk Model—Global Aggregate Portfolio Portfolio/Benchmark Comparison**, June 30, 2004

Global Risk Factor	Isolated TEV	Cumulative TEV	Difference in cumulative	Percentage of tracking error variance	Systematic beta
Global					
Currency	16.04	16.04	16.04	34.54	1.05
Yield Curve	18.19	23.32	7.28	49.12	0.83
Swap Spreads	1.97	23.37	0.05	0.5	0.84
Volatility	0.38	23.33	-0.04	-0.17	0.8
Investment-Grade Spreads	3.1	23.38	0.04	0.37	0.84
Treasury Spreads	1.48	23.39	0.06	0.35	1.36
Credit and Agency Spreads	2.14	23.37	-0.02	-0.12	0.84
MBS/Securitized	1.53	23.37	0.0	0.1	0.7
CMBS/ABS	0.29	23.38	0.0	0.05	1.25
High Yield Spreads	3.78	24.66	1.29	5.63	
Systematic risk	24.66	24.66	0.0	89.99	0.98
Idiosyncratic risk	5.73	25.32	0.66	4.85	
Credit default risk	5.91	26.0	0.68	5.16	
Total risk (bp/month)		**26.0**	**-0.0**	**100.0**	
Portfolio volatility (bp/month)					173.98
Benchmark volatility (bp/month)					175.72

Looking at sources of systematic risk, we note that currency risk (16.04 bp) and yield curve risk (18.19 bp) are the principal sources of TEV. These risk exposures, which represent mismatches between portfolio and benchmark exposures, are correlated. We can observe the degree to which exposures are correlated in the "Cumulative TEV" and "Difference in Cumulative" column. While yield curve risk, on a standalone basis, is 18.19 bp, it contributes only 7.28 bp/month to total portfolio risk, given its correlation just with the portfolio's currency exposure. Since yield curve risk is likely to be correlated with other exposures (*e.g.*, credit risk), it would be very useful to know how much it contributes to total tracking volatility given all other exposures (not just currency risk).

Figure 24. **Global Risk Model—Global Aggregate Portfolio Tracking Error Report**, June 30, 2004

Factor name	Sensitivity/ exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change	TE impact of a correlated 1 std. dev. up change	Marginal contribution to TEV	Percentage of tracking error variance
CURRENCY									
USD Currency	MV%	36.79	40.65	-3.86	0.0	-0.0		0.0	-0.0
CAD Currency	MV%	2.57	1.7	0.87	1.54	1.35	5.85	0.348	1.17
EUR Currency	MV%	35.46	31.63	3.84	2.9	11.14	9.19	1.026	15.15
GBP Currency	MV%	3.96	4.53	-0.57	2.81	-1.6	5.83	0.63	-1.38
DKK Currency	MV%	0.7	0.65	0.05	2.95	0.15	8.83	1.002	0.19
SEK Currency	MV%	0.38	0.51	-0.12	3.28	-0.41	8.46	1.066	-0.51
NOK Currency	MV%	2.0	0.11	1.89	3.0	5.68	9.28	1.07	7.79
JPY Currency	MV%	15.86	18.52	-2.66	3.33	-8.86	-4.92	-0.631	6.45
AUD Currency	MV%	2.27	0.43	1.85	2.7	4.99	6.78	0.705	5.0
NZD Currency	MV%	0.0	0.07	-0.07	2.58	-0.18	6.68	0.663	-0.18
KRW Currency	MV%	0.0	0.98	-0.98	3.12	-3.06	-2.5	-0.299	1.13
SGD Currency	MV%	0.0	0.13	-0.13	1.56	-0.21	4.22	0.253	-0.13
THB Currency	MV%	0.0	0.1	-0.1	3.54	-0.34	2.93	0.399	-0.15
KEY RATES AND CONVEXITY									
USD 6M key rate	KRD (Yr)	0.041	0.047	-0.0060	23.98	0.14	9.12	-8.408	0.19
USD 2Y key rate	KRD (Yr)	0.169	0.268	-0.099	29.48	2.93	13.71	-15.552	5.95
USD 5Y key rate	KRD (Yr)	0.373	0.51	-0.138	30.9	4.25	14.87	-17.671	9.35
USD 10Y key rate	KRD (Yr)	0.368	0.591	-0.223	27.59	6.16	15.62	-16.583	14.24
USD 20Y key rate	KRD (Yr)	0.191	0.37	-0.178	23.66	4.22	15.5	-14.103	9.67
USD 30Y key rate	KRD (Yr)	0.133	0.151	-0.018	22.63	0.42	15.37	-13.384	0.95
USD Convexity	OAC (Yr^2/100)	-0.112	-0.077	-0.035	4.19	-0.15	3.53	0.568	-0.08
CAD 6M key rate	KRD (Yr)	0.011	0.0010	0.01	37.89	-0.38	8.24	-12.012	-0.46
CAD 2Y key rate	KRD (Yr)	0.0050	0.0090	-0.0040	39.36	0.16	9.46	-14.323	0.22
CAD 5Y key rate	KRD (Yr)	0.0010	0.022	-0.021	34.42	0.73	9.7	-12.843	1.05
CAD 10Y key rate	KRD (Yr)	0.046	0.035	0.011	28.23	-0.3	9.32	-10.118	-0.41
CAD 30Y key rate	KRD (Yr)	0.033	0.045	-0.011	23.72	0.27	8.63	-7.87	0.34
EUR 6M key rate	KRD (Yr)	0.029	0.023	0.0060	16.76	-0.1	3.0	-1.933	-0.05
EUR 2Y key rate	KRD (Yr)	0.367	0.212	0.155	23.84	-3.7	6.94	-6.363	-3.8
EUR 5Y key rate	KRD (Yr)	0.554	0.529	0.025	24.44	-0.61	10.96	-10.301	-0.99
EUR 10Y key rate	KRD (Yr)	0.234	0.484	-0.25	22.85	5.72	11.85	-10.416	10.02
EUR 20Y key rate	KRD (Yr)	0.213	0.224	-0.011	18.61	0.2	9.54	-6.828	0.29
EUR 30Y key rate	KRD (Yr)	0.466	0.175	0.291	18.3	-5.33	9.26	-6.521	-7.3
EUR Convexity	OAC (Yr^2/100)	0.212	0.165	0.047	1.95	0.09	1.23	0.092	0.02

The "Percentage of tracking error variance" answers that question. 49.12% of risk relative to benchmark comes from yield curve risk, taking into account its correlation with all other portfolio exposures. While currency risk represents 16.04 bp/month of TEV on a stand-alone basis, or almost the same amount as yield curve risk, it contributes significantly less as a percentage of total TE variance, due to its correlation with other risk factors.[20]

The algebraic sign of the "Percentage of tracking error variance" number indicates whether that particular exposure contributes to total portfolio risk or whether it acts as a hedge, offsetting risk coming from other risk exposures. For example, the exposure to credit and agency spreads is responsible, on an isolated basis, for 2.14 bp of TEV. However, this exposure is sufficiently negatively correlated with other portfolio exposures to reduce overall variance (*i.e.,* its percentage of tracking error variance is -0.12%).

What is the portfolio's sensitivity to risk factors?

The Tracking Error Report summarizes a portfolio's risk exposures to various groups of risk factors such as total currency risk and total yield curve risk. The Factor Exposure Report (Figure 24 presents an excerpt) shows the sources of that risk. The report groups together risk factors to allow the user to view, for example, all sources of currency risk or all sources of yield curve risk together. The isolated risk contributed by any given risk factor depends upon the relative portfolio exposure (or sensitivity) to that factor and the volatility of that factor. For example, the currency risk section shows portfolio and benchmark exposures to all currencies in the portfolio and benchmark. The relative exposure is measured by the market value percentage overweight (X% overweight in currency Y), and the volatility of that exchange rate in base currency terms (bp per month).[21]

[20] Here, the variance of tracking error is used as a measure of risk and not the volatility (standard deviation), as this allows a linear decomposition of risk.

[21] To be precise, it is the volatility of the return of the given currency against the base currency that constitutes the FX factor in the Risk Model. So, if the portfolio has Yen currency exposure and the base currency of the portfolio is U.S. dollars, the volatility will be that of the monthly return of the yen against the dollar. Similarly, if the base currency is euros, the volatility will be that of yen/euro.

Figure 25. **Global Risk Model—Global Aggregate Portfolio Factor Exposure Report (Excerpt)**, June 30, 2004

Factor name	Sensitivity/ exposure	Portfolio exposure	Benchmark exposure	Net exposure	Factor volatility	TE impact of an isolated 1 std. dev. up change	TE impact of a correlated 1 std. dev. up change	Marginal contribution to TEV	Percentage of tracking error variance
CREDIT IG SPREAD & VOL.									
USD Corporate volatility	Volatility Duration	-0.0	0.06	-0.06	0.82	0.05	-8.65	0.273	-0.06
USD Banking AAA/AA	OASD (Yr)	0.0	0.019	-0.019	8.54	0.16	-6.04	1.985	-0.15
USD Banking A	OASD (Yr)	0.034	0.084	-0.05	9.41	0.47	-7.02	2.54	-0.49
USD Banking BBB	OASD (Yr)	0.0	0.011	-0.011	20.09	0.21	-4.68	3.615	-0.15
USD Communication AAA/AA	OASD (Yr)	0.0	0.0010	-0.0010	8.65	0.01	-5.73	1.907	-0.01
USD Communication A	OASD (Yr)	0.0	0.03	-0.03	9.52	0.28	-6.52	2.388	-0.27
USD Communication BBB	OASD (Yr)	0.087	0.047	0.04	16.39	-0.65	-6.25	3.941	0.6
High-yield Cyclical	OASD (Yr)	0.029	0.0	0.029	39.64	-1.16	-11.0	16.768	1.88
High-yield Communication	OASD (Yr)	0.017	0.0	0.017	101.21	-1.7	-6.37	24.793	1.6
High-yield Non-Cyclical	OASD (Yr)	0.021	0.0	0.021	29.87	-0.63	-11.46	13.167	1.06
High-yield Technology	OASD (Yr)	0.0050	0.0	0.0050	83.45	-0.38	-6.91	22.193	0.39

Note that the full list of factor exposures (not shown in Figure 24) includes sensitivities to investment grade and high-yield credit spread factors, as well as to collateralized spread factors. The factors, and exposures to those factors, are different for the various categories of risk factors. Additionally, while the Global Risk Model comprises almost 300 risk factors, if neither the portfolio nor the benchmark has exposure to those risk factors, those factors will not be visible in the Factor Exposure Report.

We derive all factors and exposures in the same way. The historical return due to each risk factor is computed as the product of the factor volatility and the relative portfolio exposure to that factor. For example, the historical factor volatility of euro 10-year key rate is 22.85 bp per month, and the portfolio has a net key-rate duration underweight to this key rate of -0.25 years. Therefore, the risk due to the portfolio's exposure to that factor is computed as 22.85 bp × -0.25 = 5.72 bp/month. In other words, a one standard deviation increase in the of 10-year euro key rate would have a 5.72 bp/month effect on portfolio tracking error (see "TE impact of an isolated 1 std. dev up change").

The risk factors are intuitive. The currency factors are all expressed in base currency terms. If, for example, our portfolio had a base currency of euros, the yen currency risk factor would be computed relative to the euro. The slope factors for government and credit sectors measure the volatility of the steepness of the off-the-run/on-the-run spread curve (for governments) and the steepness of the credit curve for the credit instruments. In governments, the OAS factors can be interpreted as measuring the volatility of liquidity risk, recognizing that higher-OAS bonds are likely to have less liquidity than lower-OAS bonds. In credit, the OAS factor reflects a flight to quality effect along with the greater volatility of higher spread securities.

Within groups of risk factors, we can assess the relative risk of different exposures. For example in Figure 24, we see that the volatility of the euro (2.9%) is less than that of the yen (3.33%). Additionally, the volatility of 10-year U.S. key rate (27.59 bp/month) is substantially greater than 10-year euro key rate (22.85 bp/month). We can also assess the relative risk between different groups of risk factors. For example, one year of KRD exposure to the U.S. 10-year key rate is equivalent, in risk terms, to 1.21 (= 1.0 × 27.59 / 22.85) years of KRD exposure to the euro 10-year key rate.

To what degree are portfolio exposures correlated?

Portfolio managers intuitively recognize that some exposures in a portfolio are correlated and others less so. For example, a portfolio's exposure to spread sectors is correlated with its yield curve exposure. But how do these correlations affect the sensitivity of the overall portfolio's behavior to changes in risk factors? Our portfolio is underweight the euro 10-year key rate, and, as we would expect, an isolated one standard deviation rise in the 10-year key rate will cause the portfolio to outperform by 5.72 bp. In practice, though, if the 10-year key rate rises, then 5-year and 30-year key rates will typically rise as well. Our portfolio is overweight in its exposure to the 5-year and 30-year key rates. Accordingly the portfolio's true sensitivity to the 10-year euro key rate should reflect the shift in the yield curve that typically accompanies a rise in the 10-year key rate, as well as the portfolio's exposure to those key rate shifts. This is precisely the measure that is given under "TE impact of a correlated 1 std. dev change." As Figure 24 shows, the tracking error impact of a correlated 1 standard deviation change in the 10-year euro key rate in 11.85 bp.

Additionally, when the U.S. 10-year key rate rises, the yield curve tends to flatten, credit spreads tighten, and the spread to European and Japanese government bonds widens. Therefore, the portfolio's overall sensitivity to a move in the U.S. 10-year key rate is much more than just its 10-year key rate duration. Its sensitivity should assume that all other risk factors move by an amount that reflects their historical relationship with the U.S. 10-year key rate.

What happens to total portfolio risk if we increase the exposure to one risk factor? "Marginal Contribution to Tracking Error (MCTE)" answers this question. For example, a 1% increase in yen exposure would lead to a 0.63 bp/month decrease in total portfolio TEV. Note that in our portfolio, we are underweight yen relative to benchmark. However, since we are underweight dollars too, the increase in yen exposure (which would reduce risk) is offset by the increased underweight in U.S. dollars that is implied by an increase in the yen weighting.

The real value of MCTE is what it implies for the relative attractiveness of a particular exposure. Figure 25 provides some detail from part of the report shown in Figure 24. When comparing risk factors whose exposures are measured in the same way[22] (*e.g.,* high-yield and investment grade credit sectors, whose exposures are measured by option-adjusted spread duration), we can infer the relative attractiveness (from the portfolio manager's viewpoint) of all credit sectors. In our portfolio, the largest MCTE in the credit spread sectors comes from the U.S. high-yield sectors. This implies that the portfolio manager has the greatest degree of confidence in high-yield (especially communications) as a source of outperformance compared to other sectors.

MCTE is also very useful for measuring the sensitivity of the portfolio to certain risk factors. How is that different from the benchmark exposures listed in the Factor Exposure reports? In our portfolio, there are some credit sectors in which we have underweighted exposure relative to benchmark (*e.g.,* BBB Banking); however, since we are overweight credit in this portfolio, a widening of BBB Banking spreads would tend to have a negative effect on portfolio performance. Accordingly, an increase in the exposure to that sector will increase TEV.

In general, the effect of a specific trade on portfolio risk and portfolio sensitivities to risk factors is almost impossible to ascertain without a risk model.

An additional example is provided by the portfolio's exposure to euro bonds. The portfolio is overweighted in its exposure to 2-year, 5-year, and 30-year key rates. However, since the portfolio is underweighted duration elsewhere, increasing duration exposure further will reduce TEV. In general, the effect of a specific trade on portfolio risk and portfolio sensitivities to risk factors is almost impossible to ascertain without a risk model.[23] We observe that portfolio sensitivities to risk factors are very different from just the duration exposures of those factors.

---

[22] Note that MCTE is defined as the impact on TEV of a marginal change in exposure to a risk factor. For example, If we compare the MCTE from 10-year U.S. key par rate to the MCTE from the yen, we must recognize that we are comparing the impact on TEV of an increase in exposure measured by duration contribution to an exposure measured by percentage allocation.

[23] For a discussion of the sensitivity of the Bund-Treasury trade on other risk factors, see "How Risky is the Bund-Treasury Trade," Global Relative Value, November 10, 2003, Lehman Brothers.

What is the portfolio's security and issuer specific risk?

We now examine issue and issuer specific risk. In Figure 26, we look at all sources of risk contributed by a given security, taking into account both systematic risk and idiosyncratic risk (excluding currency risk). If you desire to reduce risk through one or two trades, this report will show you the list of bonds that will accomplish that goal, sorted in descending order of portfolio weight.

The first bond, Spain 6% (EUR) has less systematic risk than Italy 5.75% (EUR), 9.69 bp/month versus 11.33 bp/month. Both bonds have greater systematic TEV than the France 5% (EUR). However, if the desire was to reduce systematic risk through the sale of a single bond, then this would be achieved best through the sale of France 5% (EUR) since this bond has a much higher marginal systematic TEV(0.52 bp/month).

The Credit Tickers Report (Figure 27) sorts issuers, in descending order, by idiosyncratic risk. Issuers are grouped together according to their ticker (*e.g.,* Ford and Ford Motor Credit have the same ticker). As discussed in Chapter 4, idiosyncratic risk is a function not just of the issuers, but of the specific issues held. Accordingly, idiosyncratic risk will be somewhat lower if the portfolio spreads a fixed market value across three Ford bonds[24] rather than putting this market value in a single Ford issue.

Though Nextel represents only a small holding in the portfolio in terms of net weight (0.27%) and net contribution to OASD (0.017), it is the largest contributor to idiosyncratic (issuer specific) risk, because of the risk of the credit itself. Certainly Nextel will be a source of systematic risk, since it is sensitive to a rise in spreads of B-rated

[24] The Ford bonds may be in different currencies. For a discussion of the correlation of same-issuer idiosyncratic spread changes across different currencies and their dependence on spread levels and sector, see "Are Credit Markets Globally Integrated? An Initial Assessment," Albert Desclée and Jeremy Rosten, Lehman Brothers, March 2003.

Figure 26. **Global Risk Model—Global Aggregate Portfolio Portfolio Issue-Specific Risk Report (Excerpt)**, June 30, 2004

Identifier	Ticker	Description	Currency	Coupon (%)	Maturity	Current OAS (bps)	MV issue weight (%)	MV issue net weight (%)	MV issuer net weight (%)	Marginal systematic TEV (bps)	Systematic TEV (bps)	Idiosyncratic TEV (bps)	Issuer idiosyncratic TEV (bps)
ES0000011652	SPGB	SPAIN (KINGDOM OF)	EUR	6.0	1/31/2008	1.2	3.32	3.2	3.2	0.3909	9.69	0.42	0.42
BE0000297060	BGB	BELGIUM (KINGDOM OF)	EUR	4.75	9/28/2006	-0.3	3.27	3.21	3.21	0.4566	9.57	0.17	0.17
FR0101659813	BTNS	FRANCE (REPUBLIC OF)	EUR	5.0	7/12/2005	-3.2	3.11	2.97	2.97	0.5168	8.7	0.06	0.06
IT0003256820	BTPS	ITALY (REPUBLIC OF)	EUR	5.75	2/1/2033	21.8	3.0	2.89	2.89	0.0928	11.33	1.62	1.62
IT0001086559	BTPS	ITALY (REPUBLIC OF)	EUR	6.75	2/1/2007	6.6	2.85	2.78	2.78	0.4452	8.31	0.26	0.26
US298785CH75	EIB	EUROPEAN INVESTMENT BANK	EUR	5.0	4/15/2008	10.4	2.79	2.75	3.63	0.3789	8.38	0.42	0.38
JP10220312C4	JGB	JAPAN (GOVT OF) 2YR #203	JPY	0.1	12/20/2004	1.4	2.68	2.68	2.68	-0.3286	8.92	0.02	0.02

Figure 27. **Global Risk Model—Global Aggregate Portfolio Credit Tickers Report**, June 30, 2004

Ticker	Name	Sector	Rating	Currency	# issues in portfolio	Portfolio weight	Benchmark weight	Net weight	Net contribution to OASD	Systematic TEV	Idiosyncratic TEV
CREDIT											
NXTL	NEXTEL COMMUNICATIONS	WIRELESS	B2	USD	1	0.27	0.0	0.27	0.017	1.57	2.26
QUS	QWEST SERVICES CORP	WIRELINES	CAA1	USD	1	0.2	0.0	0.2	0.0060	0.52	2.07
AWE	AT&T WIRELESS SVCS INC-GLOBAL	WIRELESS	BAA2	USD	1	1.45	0.05	1.4	0.083	2.45	1.9
NRUC	NATIONAL RURAL UTILS CFC-GLOBA	MULTIPLE	A1 A2	USD EUR	1	1.11	0.05	1.06	0.132	3.23	1.69
THC	TENET HEALTHCARE CORP	HEALTHCARE	B3	USD	1	0.34	0.0	0.34	0.021	0.68	1.48
TRWAUT	TRW AUTOMOTIVE INC	AUTOMOTIVE	B1	USD	1	0.39	0.0	0.39	0.016	0.48	1.36
NSC	NORFOLK SOUTHERN CORP	RAILROADS	BAA2	USD	1	0.68	0.03	0.65	0.074	1.82	1.17
EAUG	VIVENDI UNIVERSAL	MULTIPLE	BA1 BAA3	USD EUR	1	0.36	0.0	0.36	0.013	0.35	1.05
CAG	CONAGRA INC	FOOD_AND_BEVERAGE	BAA2 BAA1	USD	1	0.98	0.03	0.95	0.055	1.57	0.97
DT	DEUTSCHE TELEKOM INT FIN-GLOBA	MULTIPLE	BAA2	USD EUR GBP	1	0.87	0.22	0.65	0.037	2.17	0.83
NT	NORTEL NETWORKS LTD-GLOBAL	TECHNOLOGY	B3	USD	1	0.3	0.0	0.3	0.0050	0.38	0.55
TYC	TYCO INTL GROUP SA	MULTIPLE	BAA3	USD EUR GBP	1	0.47	0.05	0.42	0.025	0.73	0.52
OXY	OCCIDENTAL PETROLEUM	INDEPENDENT	BAA1	USD	1	0.83	0.02	0.82	0.031	0.91	0.49
GM	GENERAL MOTORS ACPT CORP	MULTIPLE	BAA2	USD EUR GBP JPY	0	0.0	0.4	-0.4	-0.02	0.67	0.49
OOMLN	MMO2 PLC	WIRELESS	BAA2	EUR GBP	1	0.85	0.01	0.84	0.02	2.5	0.42

industrials and default risk. But the idiosyncratic risk reported here is in addition to those sources of risk. This ranking of credits by idiosyncratic risk can be seen as an implied ordering of manager views. For example, it suggests that this manager has the highest return expectation, among credits, in Nextel.

We have now described the Risk Report for several different type of portfolios. We now turn to a discussion of the many applications of the Risk Model.

3. RISK MODEL APPLICATIONS

The utility and power of the model lies in its ability to offer optimal risk choices rather than simply monitor choices that have already been made.

The Lehman Brothers Global Risk Model is an invaluable portfolio management tool for both active and passive managers. The Risk Model is best used by a portfolio manager as an objective way to rank portfolio alternatives under consideration. In other words, the Risk Model is an *ex-ante* trade or portfolio evaluator. While a risk manager can also use it as an *ex-post* portfolio reporting system, the utility and power of the model lies in its ability to offer optimal risk choices rather than simply monitor choices that have already been made.

In this chapter, we present six important portfolio management applications of the Lehman Risk Model:

A. **Structuring an Efficient Active Portfolio:** A portfolio manager can use the Risk Model to structure a portfolio that is finely tailored to reflect his market views. A manager may have a view on credit spreads, and by using the Risk Model, he/she can make sure that the portfolio does not have any unintentional market exposures.
B. **Evaluating Portfolio Trades:** The Risk Model can be readily used to analyze the risk impact of a proposed trade. Does the trade introduce any unexpected and unwanted risk exposures?
C. **Optimizing a Portfolio:** The Lehman Risk Model has a built-in optimizer. The optimizer allows the manager to select from an eligible list of bonds those that would help reduce the portfolio's tracking error volatility to a desired level. We work through a detailed example of using the optimizer.
D. **Constructing Proxy Portfolios:** The Risk Model and optimizer can be combined to construct a "proxy" portfolio containing relatively few issues designed to track a broader index with minimum expected tracking error volatility.
E. **Scenario Analysis:** Many portfolio managers supplement their risk analysis by stress-testing their portfolios using scenario analysis. However, fully specifying scenarios is difficult. Given a hypothetical movement in the term structure, what happens to spreads in the various market sectors? To volatility? To currencies? It is unrealistic to assume that these other risk factors remain unchanged when the term structure moves. The Risk Model can be used to help the manager specify scenarios, and probabilities of the scenarios, that are internally consistent with broad market history.
F. **Risk Budgeting**: Not only can the Risk Model be used to measure risk, it can be used to control risk allocation. An increasing number of managers operate within a pre-specified "risk budget." In other words, the manager is required to take market positions so that the portfolio's expected tracking error volatility remains within the limit. A manager (and the plan sponsor) can use the Risk Model to monitor the portfolio's adherence to its risk budget and to compare different types of risk on the same footing.

A. Structuring an Efficient Active Portfolio

Consider the following everyday investment process: A portfolio manager with views on expected movements in rates, spreads, and volatilities wishes to create a portfolio that reflects his or her views. Generally, the manager will take an existing portfolio and make provisional trades until the portfolio has the desired exposures. There are, however, many possible ways to structure a portfolio to reflect a particular view. Some trades may introduce some unintentional exposures to other risk factors. Perhaps, buying the long credit bonds has introduced an undesired exposure to credit spreads.

Or, perhaps a lightening of the MBS portfolio has left the portfolio underweighted to the premium MBS sector. Since a given bond has exposure to many different risk factors, transactions within a portfolio can easily produce some unintended risk exposures. This is particularly true for portfolios benchmarked against broad-based indices such as the U.S. Aggregate or the Global Aggregate.

By running the portfolio, with provisional trades, through the Risk Model, the manager can quickly identify any unexpected active exposures.

By running the portfolio, with provisional trades, through the Risk Model, the manager can quickly identify any unexpected active exposures. As a simple example, consider a manager who has decided to be long duration in anticipation of a decline in long Treasury yields. By examining the Factor Exposure Report (Chapter 2), the manager may discover that the portfolio has a large relative exposure to Baa-rated cyclicals arising from a position in long auto bonds. While the manager's overall position to cyclicals may be neutral *in market value terms*, the manager has a net portfolio exposure to changes in the spreads of Baa-rated cyclicals. This exposure is likely making the portfolio's tracking error larger than if the portfolio did not have this sector exposure. If the manager has no particular view on cyclical spreads, removing this exposure will help reduce undesired tracking error.[25]

Using the Risk Model to examine a portfolio and any proposed trades is also useful when a portfolio is managed by a group of portfolio managers.

Using the Risk Model to examine a portfolio and any proposed trades is also useful when a portfolio is managed by a group of portfolio managers. In such a setting, it is not unusual for the Chief Investment Officer or Senior Portfolio Manager to set the tone for the overall portfolio (*e.g.,* "the Fed is expected to ease and we expect rates to decline with a general recovery in spreads"). The sector portfolio managers are then free to structure their sector portfolios with this top-down view in mind. However, a problem can develop if each portfolio manager incorporates the same view in his or her own individual portfolios. For example, the MBS manager may underweight MBS overall, and current coupons and premiums in particular, if rates are expected to decline. Perhaps the MBS manager will invest cash from any dollar rolls in lower-rated spread assets. The corporate manager may overweight the long end of the corporate spread curve and increase exposure to lower-rated names. So, too, for the ABS and CMBS manager. How do all these portfolios fit together, and how do their risks interrelate? While each individual portfolio conforms to the CIO's world view, is the overall portfolio taking too much risk due to a compounding of active exposures? Perhaps there are too many proposed trades? Running the portfolio and the proposed trades through the Risk Model is a useful check for excessive or any unintentional risk exposures.

As described in Chapter 2, the Risk Report is extensive: relative exposures to all of the risk factors; estimated tracking error volatilities arising from various sets of risk factors including an overall portfolio tracking error volatility; and estimated tracking error arising from idiosyncratic risk exposures. While all of this information is helpful, the overall tracking error number usually receives the most attention. The estimated TEV is the model's estimate of the standard deviation of the total return difference between the portfolio and the benchmark.[26] This estimated TEV is based, in part, on the

[25] As discussed below, there is a feature in the Risk Model optimizer that allows a manager to freeze exposures on certain risk factors and reduce tracking error arising from exposure to all other risk factors.

[26] If return differences are assumed to be normally distributed, then a familiar confidence interval can be constructed: The return difference will be within ±1.96 × TEV of the mean return difference, 95% of the time.

historical relationship of the risk factors captured by the historical variance-covariance matrix of the realized risk factors.

All of the above presupposes that historical volatilities and correlations are a good guide to the future, and there is some evidence to support this assertion (see Chapter 1). Nonetheless, the near-term future may differ from the historical experience used to estimate the variance-covariance matrix. This possibility may cause managers to have low confidence in the estimated tracking error number. However, even a skeptic in these matters should note that when structuring and evaluating different portfolios what is important is *relative* TEV—in other words, how does the TEV of the original portfolio compare to the proposed portfolio? Managers should have much more confidence in relative tracking errors since both TEVs are calculated using the same variance-covariance matrix. If portfolio A has a tracking error of 30 bp per month, while portfolio B has a tracking error of 20 bp per month, then there is high confidence that portfolio A is 50% riskier than portfolio B. While risk factor volatilities may fluctuate over time, the correlations of risk factors are more stable. Consequently, comparing tracking errors of portfolios at a given time is a realistic ranking of their relative risks.

All of the above implies that portfolio managers can confidently leverage the power of the Risk Model to add significant value in the portfolio structuring process, helping them to implement only those views that they wish to express and with a careful eye to the risk embedded in the portfolio.

B. Evaluating Proposed Trades

Not only is the Risk Model useful to evaluate a portfolio structured around a particular market view, it can also provide useful insight when considering individual proposed trades, such as a modest duration extension, sector overweight, or a one-on-one bond swap. Does such a proposed trade produce any unexpected risk exposures?

Another important question is whether a proposed trade produces an expected return pickup that would justify any potential increase in tracking error.

Another important question is whether a proposed trade produces an expected return pickup that would justify any potential increase in tracking error. Alternatively, a proposed trade may offer both an expected return pickup, as well as a reduction in expected tracking error. As an example of how to use the Risk Model to evaluate proposed trades, consider the U.S. Aggregate portfolio discussed in Chapter 2.

Suppose the portfolio manager is considering adding to the portfolio's corporate exposure either because the manager expects tighter corporate spreads or expects unchanged spreads and would like to increase the carry on the portfolio. The manager is considering selling $37 million of the UST 7.25 of 8/22 and buying $48.3 million (which would be market value neutral) of the Sprint Capital 6.875% of 11/28. The Sprint bonds are Baa-rated and have an OAS of +124 bp. The proposed trade would be approximately 1.5% of the overall market value of the portfolio.

The portfolio manager can enter the proposed trade into the portfolio and then examine how the revised portfolio compares to the benchmark. The effect of the trade is shown below:

	Pre-Trade	Post-Trade	Benchmark
OAD	4.51	4.56	4.33
Contribution to Credit OASD	1.82	2.03	1.42
Yield	4.31%	4.34%	4.38%
OAS	40 bp	42 bp	33 bp
TEV	**28.8 bp/month**	**31.6 bp/month**	

The proposed trade would certainly have the anticipated effect on the portfolio. While the overall duration would be little changed, the contribution to credit spread duration would increase from 1.82 to 2.03, and the portfolio yield and OAS would increase from 4.31% and 40 bp, to 4.34% and 42 bp, respectively.

Is this yield pickup and increased spread exposure worth the risk? Without a risk model, the manager would have had difficulty formulating the portfolio management question so precisely.

Is this yield pickup and increased spread exposure worth the risk? Using the Risk Model we see that the portfolio's estimated tracking error volatility has increased from 28.8 bp/month to 31.6 bp/month. This 3 bp/month increase is approximately 10 bp/year. Is the 3 bp in portfolio yield worth the increase in portfolio risk? Without a risk model, the manager would have had difficulty formulating the portfolio management question so precisely.

C. Optimizing a Portfolio

The Risk Model does an excellent job of identifying and measuring the relative risk exposures of a portfolio versus its benchmark. However, suppose the manager wants to reduce the portfolio's estimated tracking error volatility. Which bonds should be sold and bought? Since a bond has exposure to many risk factors, selling a particular bond to reduce one risk exposure may introduce other active risk exposures that could partially frustrate the effort to reduce overall TEV. The large number of risk dimensions makes it difficult for a portfolio manager to move efficiently towards a desired TEV target without the aid of an optimizer.

There is an optimizer built within the Global Risk Model.

The optimizer allows the manager to bring his or her intuition and market knowledge to bear on the optimization process, both to identify bonds that can be realistically bought and sold and to select bonds for which he or she has a positive/negative outlook.

Fortunately, there is an optimizer built within the Global Risk Model. The optimizer's objective is to minimize a portfolio's estimated tracking error volatility by suggesting trades from among the existing bonds in the portfolio and a set of eligible non-portfolio bonds (the "swap pool") provided by the portfolio manager. When invoked, the optimizer uses an algorithm known as "gradient descent"[27] to suggest a list of portfolio bonds to sell.[28] This list is ranked in descending order of how much impact a sale of a portion of the bond, at the margin, will reduce tracking error volatility. The portfolio manager can then select a bond from the list, and the optimizer will then provide a list of bonds to buy from the swap pool, also ranked in order of which bond will provide the greatest reduction in TEV. Although the optimizer provides a "best" sell candidate and an associated "best" buy candidate, it is important to note that the portfolio manager is at liberty to select any bond in each list. This essential feature allows the manager to bring his or her intuition and market knowledge to bear on the optimization process, both to identify bonds that can be realistically bought and sold and to select bonds for which he or she has a positive/negative outlook.

To illustrate how the optimizer works, we will use the active U.S. Aggregate portfolio from Chapter 2. As you may recall (repeated in Figure 28), this portfolio (as of December 31,

[27] Details of the gradient descent procedure can be found in the Appendix of *The Lehman Brothers Multi-Factor Risk Model*, July 1999.

[28] Of course, the optimizer can first show the ranked list of bonds to buy.

2004) has an estimated monthly tracking error of 28.8 bp/month (or approximately 99.8 bp annually). Suppose the portfolio manager wants to move the portfolio closer to the benchmark (the U.S. Aggregate Index) and reduce TEV. The optimizer can be used to define a transaction path to lower tracking error volatility.

The optimizer is shown in Figure 29. This screen shows the portfolio name (Aggregate_active(2)); the benchmark (U.S. Aggregate); the original TEV (28.8 bp/month) and also the user settings for the risk model (un-weighted options for systematic risk, idiosyncratic risk, and credit default rates).

An important part of the optimization process is the "Swap Universe." The swap universe is the portfolio or index containing bonds that the optimizer will select from when recommending bonds to buy for the portfolio in order to reduce TEV. The Swap Universe is defined by the portfolio manager. For example, the Swap Universe could be the U.S. Aggregate Index itself. So, for each bond in the portfolio the optimizer will search through and rank all bonds in the Aggregate Index as possible buy candidates.

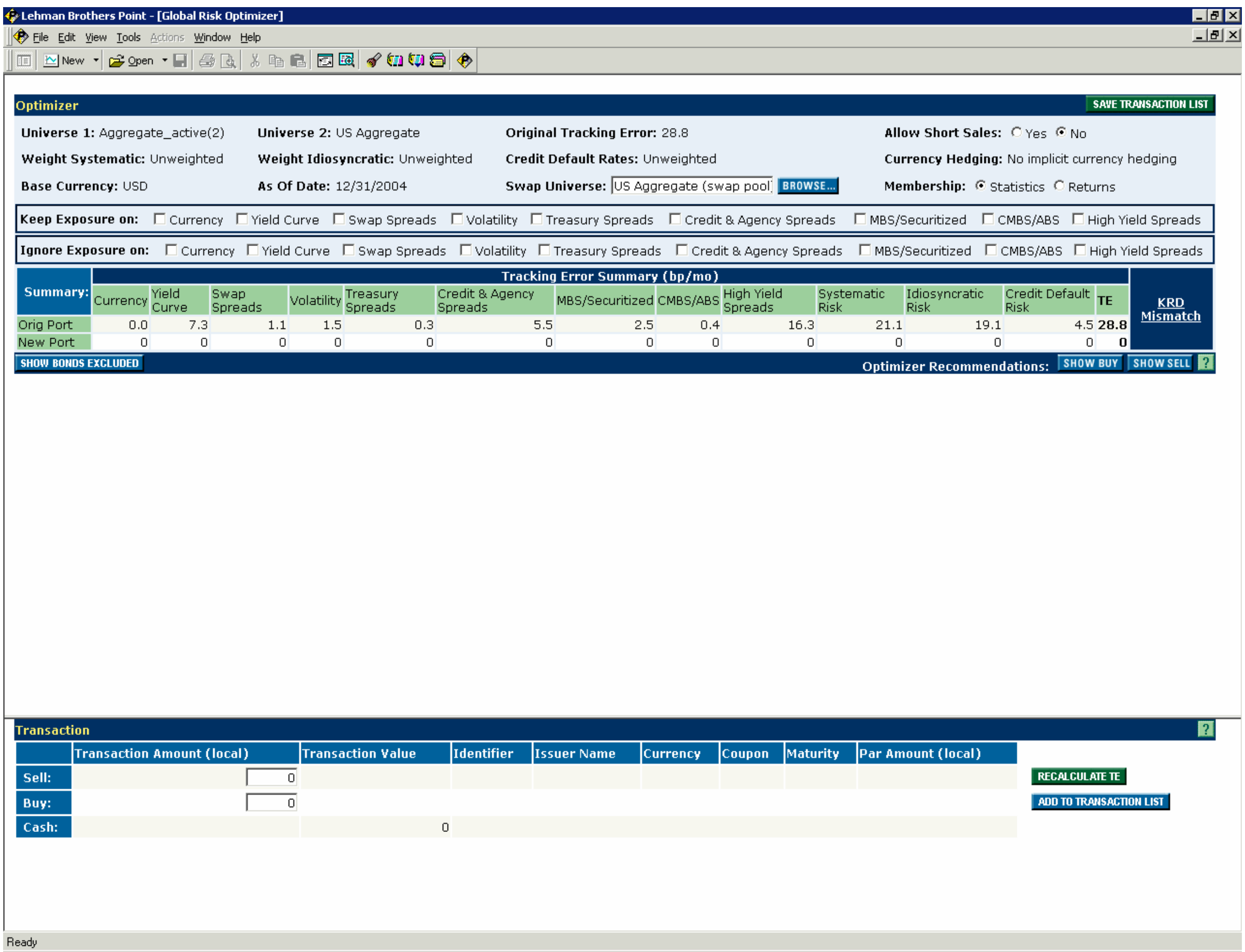
Figure 28. **Global Risk Model—U.S. Aggregate Portfolio Portfolio/Benchmark Comparison**, December 31, 2004

Parameter	Portfolio	Benchmark	Difference
	Aggregate_active(2)	US Aggregate	
Positions	99	5836	
Issuers	38	614	
Currencies	1	1	
# positions processed	99	5831	
# positions excluded	0	5	
% MV processed	100.0	100.0	
% MV excluded	0.0	0.0	
Market Value	2900747874	8215148923	
Coupon (%)	5.66	5.24	0.42
Average Life (Yr)	6.99	6.87	0.12
Yield to Worst (%)	4.31	4.38	-0.07
ISMA Yield (%)	4.2	4.15	0.05
OAS (bps)	40	33	7
OAD (Yr)	4.51	4.33	0.18
ISMA Duration (Yr)	5.29	5.26	0.03
Duration to Maturity (Yr)	5.06	5.05	0.01
Vega	-0.04	-0.05	0.02
OA Spread Duration (Yr)	4.64	4.49	0.15
OA Convexity (Yr^2/100)	-0.15	-0.49	0.34
Total TE Volatility (bps/month)			**28.8**
Systematic Volatility (bps/month)	106.69	108.42	
Non-systematic Volatility (bps/month)	19.72	2.47	
Default Volatility (bps/month)	7.07	3.27	
Total Volatility (bps/month)	**108.73**	**108.5**	
Portfolio Beta			0.967

The power of the optimizer is in the definition of the Swap Universe. Using the Aggregate Index as the swap universe is not particularly useful because many of the bonds in the index are difficult to locate. Instead, a manager can use his or her market knowledge to structure a more realistic Swap Universe. For example, the manager could construct a custom index of all outstanding Treasuries, current coupon MBS, and large new issue corporates to serve as the Swap Universe. Alternatively, a manager may create a portfolio that contains issuers or specific bonds that are on his or her analyst's "OK-to-buy list" and use this as the Swap Universe.[29]

[29] Such custom indices and portfolios can be easily created using POINT.

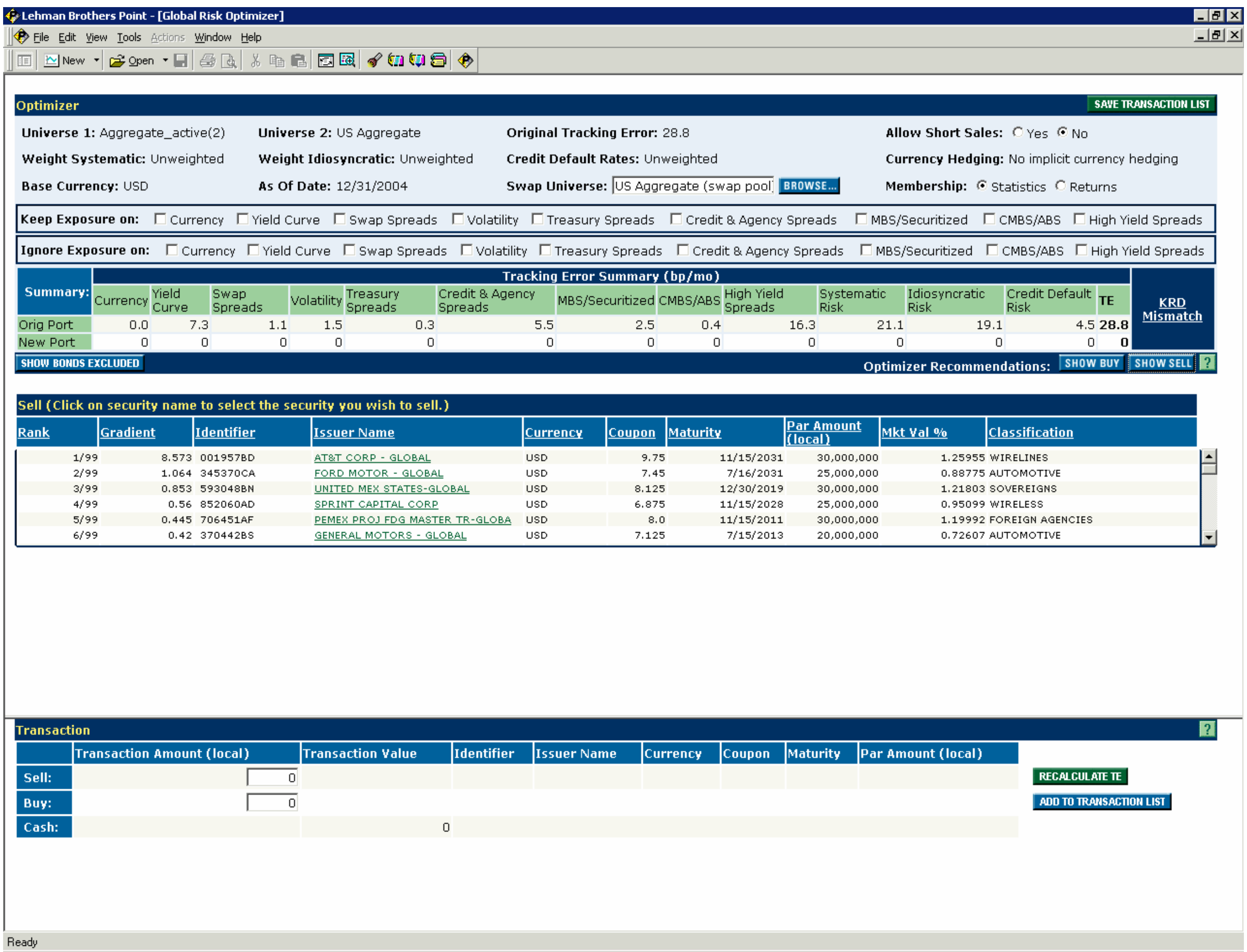
Figure 29. **Global Risk Model—U.S. Aggregate Portfolio Optimizer,** December 31, 2004



Our portfolio manager wants to reduce the portfolio's TEV. Once the Swap Universe is defined, the manager asks the optimizer to suggest bond to sell. The optimizer responds (using a "gradient descent" optimization algorithm) with a list of sell candidates. The bonds are ranked in terms of their potential to reduce portfolio TEV at the margin. As shown in Figure 30, AT&T 9.75s of 11/31 is ranked first followed by the Ford 7.45s of 7/31. The magnitude of the gradient value indicates the potential for TEV reduction.

As mentioned above, the portfolio manager can select any bond in the list as a possible sell candidate. For illustration, let us suppose the manager decides to sell some of the AT&T 9.75's of 11/31. Note that the portfolio is holding $30 million in these bonds, which comprise 1.26% of the portfolio's market value. After the manager selects this

Figure 30. **Global Risk Model—U.S. Aggregate Portfolio Optimizer—Sell Candidates,** December 31, 2004



Summary:	Tracking Error Summary (bp/mo)												
	Currency	Yield Curve	Swap Spreads	Volatility	Treasury Spreads	Credit & Agency Spreads	MBS/Securitized	CMBS/ABS	High Yield Spreads	Systematic Risk	Idiosyncratic Risk	Credit Default Risk	TE
Orig Port	0.0	7.3	1.1	1.5	0.3	5.5	2.5	0.4	16.3	21.1	19.1	4.5	28.8
New Port	0	0	0	0	0	0	0	0	0	0	0	0	0

Rank	Gradient	Identifier	Issuer Name	Currency	Coupon	Maturity	Par Amount (local)	Mkt Val %	Classification
1/99	8.573	001957BD	AT&T CORP - GLOBAL	USD	9.75	11/15/2031	30,000,000	1.25955	WIRELINES
2/99	1.064	345370CA	FORD MOTOR - GLOBAL	USD	7.45	7/16/2031	25,000,000	0.88775	AUTOMOTIVE
3/99	0.853	593048BN	UNITED MEX STATES-GLOBAL	USD	8.125	12/30/2019	30,000,000	1.21803	SOVEREIGNS
4/99	0.56	852060AD	SPRINT CAPITAL CORP	USD	6.875	11/15/2028	25,000,000	0.95099	WIRELESS
5/99	0.445	706451AF	PEMEX PROJ FDG MASTER TR-GLOBA	USD	8.0	11/15/2011	30,000,000	1.19992	FOREIGN AGENCIES
6/99	0.42	370442BS	GENERAL MOTORS - GLOBAL	USD	7.125	7/15/2013	20,000,000	0.72607	AUTOMOTIVE

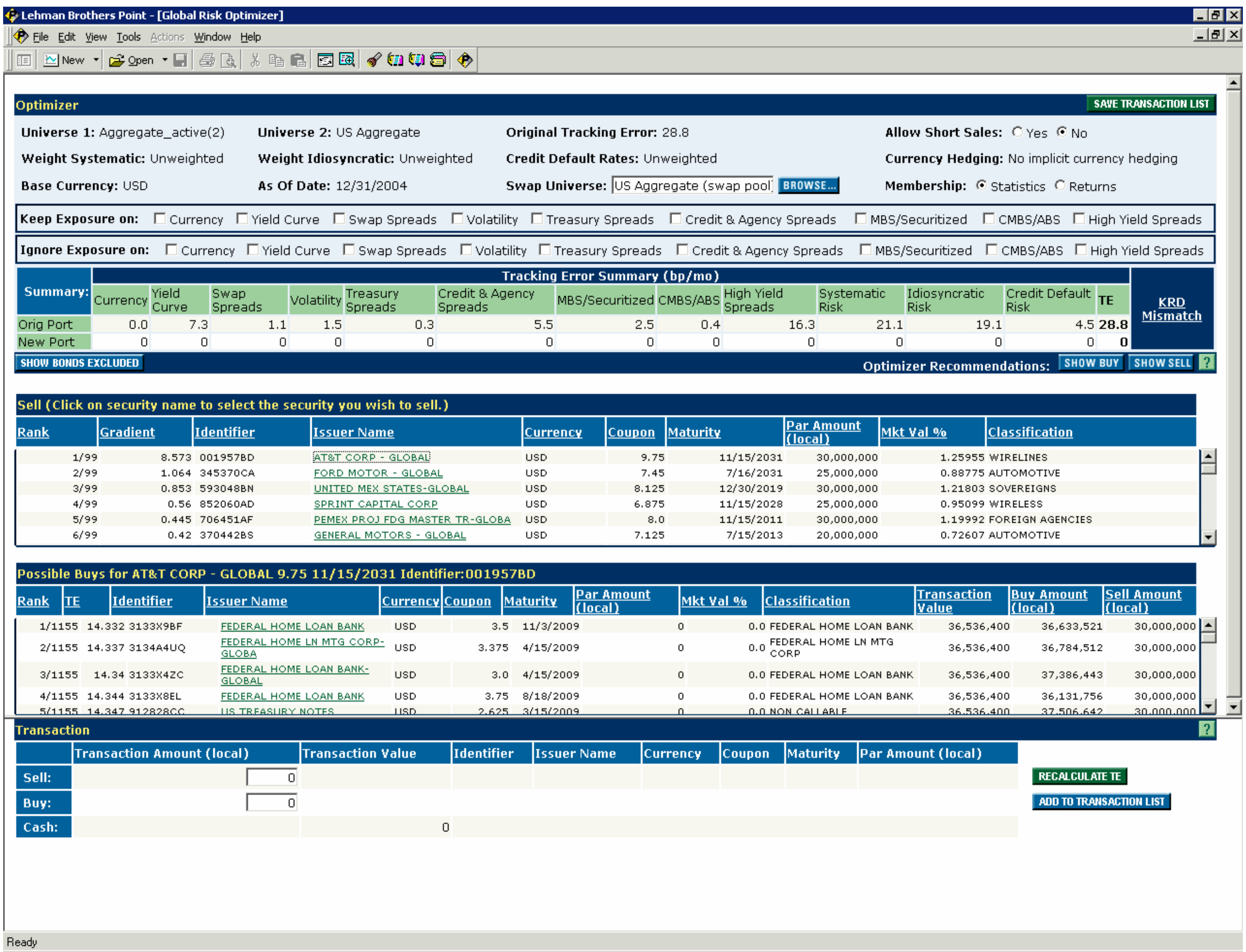
	Transaction Amount (local)	Transaction Value	Identifier	Issuer Name	Currency	Coupon	Maturity	Par Amount (local)
Sell:	0							
Buy:	0							
Cash:		0						

issue, the optimizer will return with a list of buy candidates from among the bonds in the Swap Universe.[30] The optimizer ranks all 1,155 issues in the swap universe and in the portfolio as possible buy candidates given that the AT&T bond was selected as the sell candidate. The optimizer now appears as shown in Figure 31.

The optimizer lists the "Possible Buys" for swapping with the AT&T bond. The first item is an FHLB debenture (3.5% of 11/09). In other words, by selling $30,000,000 par of

[30] In this example, the Swap Universe is the U.S. Aggregate Index filtered to include only bonds issued within the last three years and with at least $500 million outstanding—"an investable swap pool?" This example highlights the power of the Swap Universe definition.

Figure 31. **Global Risk Model—U.S. Aggregate Portfolio Optimizer—Buy Candidates,** December 31, 2004



AT&T and buying $36,633,521 of the FHLB debenture, the portfolio's estimated TEV will fall from 28.8 bp/month to 14.33 bp/month. Suppose, however, the manager feels that this FHLB issue is hard to find, or perhaps the manager has some reservations about the issuer. The manager can simply browse the buy list to look for more appetizing buy candidates.

Suppose the manager takes a liking to the FHLMC 3.375% of 4/15/2009. As shown, the optimizer is recommending the sale of $30,000,000 par of AT&T and purchase of $36,784,512 par of the Freddie Mac bond, to reduce the portfolio's estimated TEV to 14.34 bp/month.

This first trade recommendation illustrates the power of the Risk Model-optimizer combination. It is useful to ask: "Why is the optimizer recommending this trade?" Recall that the portfolio is long duration (0.18) versus the benchmark. Term structure risk, given its historical volatility, is a source of tracking error volatility. Since the optimizer is trying to reduce overall TEV, it is natural for the optimizer to focus on the duration exposure. The trade sells the AT&T bond, with a duration of 10.8, for the FHLMC debenture, with duration of 3.95, which shortens overall duration by about 0.10.

The true power of the Optimizer: it can efficiently identify trades that will help to reduce several risk exposures simultaneously.

However, this first trade accomplishes much more! Recall that the portfolio also has an overweight in spread duration (0.15), has an overweight to the corporate sector, and an underweight to the Agency and MBS sectors. Remarkably, the optimizer's first trade recommendation (i.e., buy FHLB 3.5s of 11/09) also reduces two of these three additional exposures simultaneously, as does the second ranked recommendation. This is the true power of the optimizer: it can efficiently identify trades that will help to reduce several risk exposures simultaneously.

If the manager selects the FHLMC debenture to buy (not to worry, the manager can always change his or her mind later), the Transaction portion of the optimizer records the recommended trade details (Figure 32). Note that the par amounts of both sides of the trade can still be manually adjusted by the portfolio manager (and the estimated TEV will be recalculated accordingly). When the manager selects "Add to Transaction List," the trade is saved to be imported to the portfolio once the optimizer session is concluded. However, the effect of the trade is reflected in the Summary window (center of screen—Figure 34). The Summary window shows the original portfolio (and its risk exposures) relative to the new portfolio.[31]

The manager can continue to use the optimizer in this fashion. At some point, the manager will stop when the desired TEV level is reached or the optimizer fails to find any more productive trades. The manager will then enter these transactions into the portfolio.[32]

---

[31] The manager can also see a detailed breakdown of the portfolio's key rate exposures by currency ("OAD Mismatch").

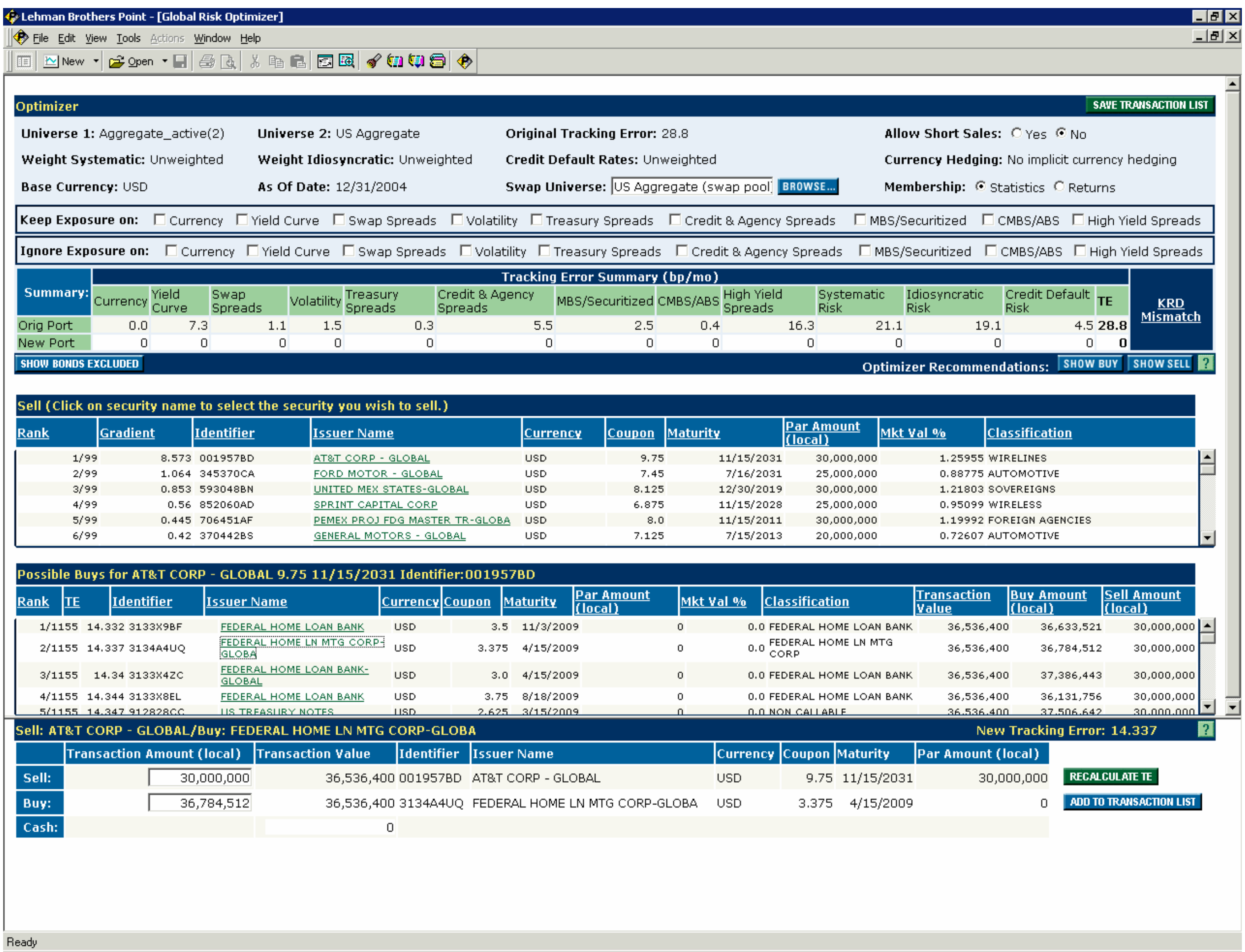
[32] POINT offers an easy way to import the desired transactions into the portfolio.

The optimization can be constrained so as not to disturb a desired portfolio exposure.

It is important to note that the optimization can be constrained so as not to disturb a desired portfolio exposure. For example, if the manager were happy with the portfolio's exposure to the MBS risk factors, then he or she could constrain the optimizer to "Keep Exposure On: MBS/Securitized," and the optimizer would recommend trades to reduce overall TEV while keeping the active portfolio exposures to the MBS risk factors unchanged.

Alternatively, the manager can elect to have the optimizer "Ignore Exposure On" certain sets of risk factors. To see how this feature is useful, recall that exposure to yield curve risk factors is a major source of portfolio TEV. Consider a manager who is currently overall duration neutral to his benchmark. However, the duration of his

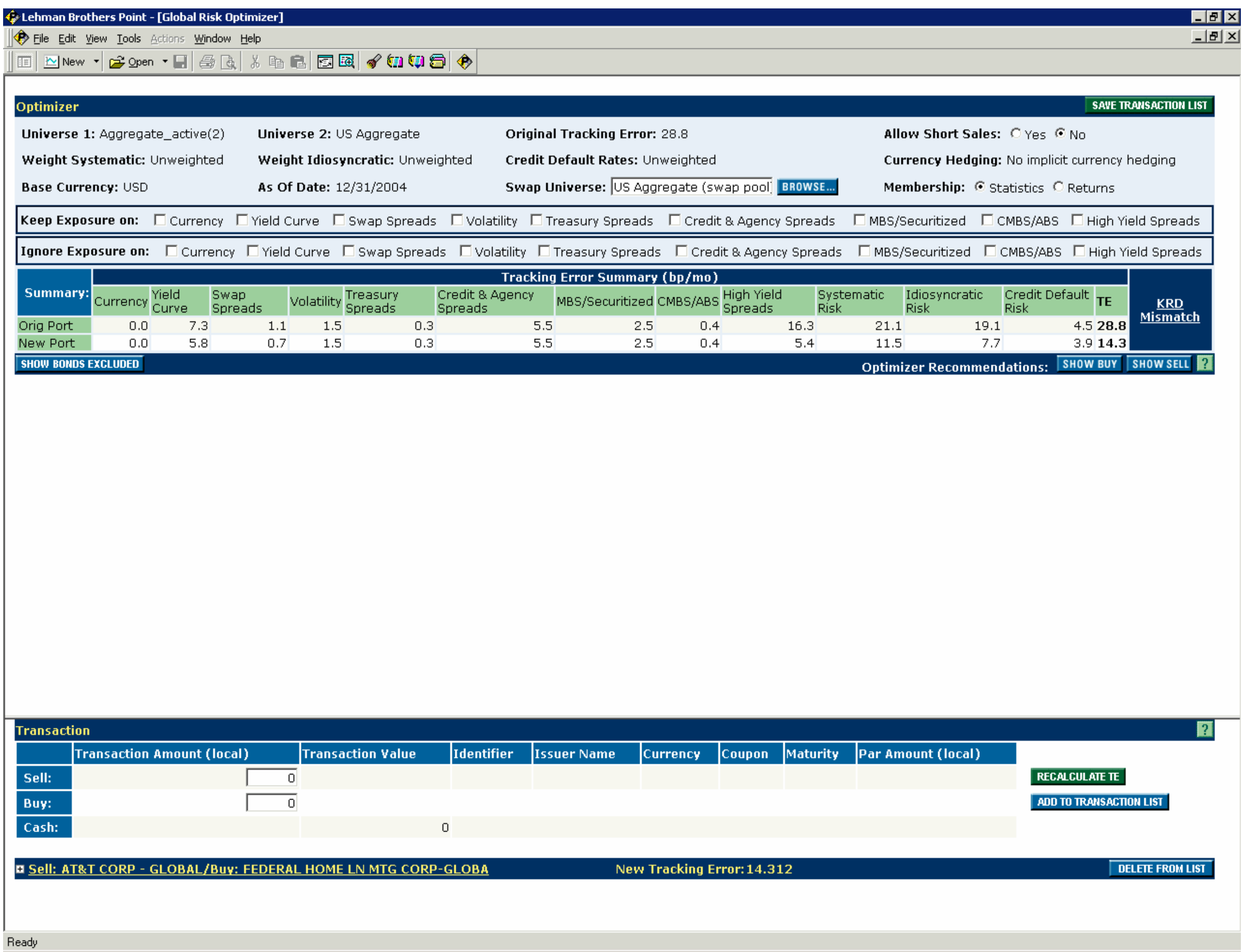
Figure 32. **Global Risk Model—U.S. Aggregate Portfolio Optimizer—Buy Candidate Selected,** December 31, 2004



credit sector holdings is much longer than that of the benchmark's credit sector. If the manager wanted to balance the credit sector mismatches, the optimizer would be reluctant to shorten the duration of the credit sector, since doing so would introduce an overall portfolio duration *bet* that will tend to increase TEV. So, the manager can tell the optimizer to "Ignore Exposure On" the yield curve, and the optimizer will suggest trades to move the portfolio's credit sector exposure closer to that of the benchmark without regard to the resulting yield curve exposure ramifications. Once the credit sectors are aligned, the manager can then remove the "Ignore" feature on the yield curve and let the optimizer suggest trades (most likely Treasury trades) to match-up yield curve exposures.

Another application of this "Ignore Exposure On" feature is the case of a credit manager whose performance is measured in excess return space. This manager assumes that any

Figure 33. **Global Risk Model—U.S. Aggregate Portfolio Optimizer—Seeing the Effect of a Trade,** December 31, 2004



yield curve exposure generated by the credit portfolio will be hedged away by the duration manager. Consequently, the credit manager can disregard yield curve exposures when structuring the credit portfolio. The important risk measure for this manager is tracking error excluding the term structure risk factors and the "Ignore Exposure On" feature allows this to be minimized.

To conclude this example, the optimizer was used to generate eight trades (Figure 34) to reduce the portfolio's TEV from 28.8 bp/month to 7.6 bp/month.

As a result of these trades, the relative duration position was reduced from 0.18 to -0.06, spread duration from 0.15 to -0.08; the overweight (contribution to OAD) in credit was changed from +0.40 to -0.08; and the underweight in MBS changed from -0.39 to -0.09. Figure 35 (after the eight transactions) can be compared with Figure 28 (before transactions) to see how the risk exposures have changed. The optimizer was able to quickly identify eight trades (in a ninety-nine bond portfolio) that cut estimated tracking error volatility by almost 75%.

As this example illustrates, the Risk Model, combined with the optimizer, is a powerful tool to adjust the risk exposures of a portfolio relative to its benchmark. The Risk Model and optimizer can also be used in several other portfolio applications, such as constructing proxy portfolios, scenario analysis, and risk budgeting. We now turn to a discussion of these other applications.

Figure 34. **Global Risk Model**
Optimizer—Transactions, December 31, 2004

Type	CUSIP	Issuer	Quantity	Price	New TEV
Sell	459200BB	INTL BUSINESS MACHINES - Global	$24,326,689	105.531	7.55
Buy	742718DB	PROCTER + GAMBLE CO	$23,908,108	105.639	
Sell	337932AA	FIRSTENERGY CORP	$20,000,000	103.187	7.85
Buy	FGB05004	FHLM Gold Guar Single F. 30yr	$20,802,807	99.463	
Sell	706451AF	PEMEX - Global	$22,065,272	115	8.23
Buy	FGB04404	FHLM Gold Guar Single F. 30yr	$26,365,380	96.724	
Sell	68233DAR	ONCOR ELECTRIC DELIVERY	$20,000,000	113.44	8.68
Buy	465410BF	ITALY (REPUBLIC OF) - Global	$23,018,634	100.397	
Sell	852060AD	SPRINT CAPITAL CORP	$25,000,000	109.465	9.1
Buy	298785CX	EUROPEAN INVESTMENT BK- Global	$28,853,264	95.429	
Sell	593048BN	UNITED MEX STATES - Global	$30,000,000	117.75	10.15
Buy	FNA04404	FNMA Conventional Long T. 30yr	$36,363,934	96.787	
Sell	345370CA	FORD MOTOR - Global	$25,000,000	99.591	12.13
Buy	3133X9BF	FEDERAL HOME LOAN BANK	$25,819,915	99.171	
Sell	001957BD	AT&T CORP - Global	$30,000,000	120.542	14.31
Buy	3134A4UQ	FHLMC - GLOBAL	$36,784,512	98.613	

Figure 35. **Global Risk Model Optimizer—Revised Portfolio Risk Exposures,** December 31, 2004

Parameter	Portfolio	Benchmark	Difference
	Aggregate_new_active(2)	US Aggregate	
Positions	101	5836	
Issuers	36	614	
Currencies	1	1	
# positions processed	101	5831	
# positions excluded	0	5	
% MV processed	100.0	100.0	
% MV excluded	0.0	0.0	
Market Value	2900828603	8215148923	
Coupon (%)	5.4	5.24	0.16
Average Life (Yr)	6.36	6.87	-0.5
Yield to Worst (%)	4.18	4.38	-0.2
ISMA Yield (%)	3.97	4.15	-0.18
OAS (bps)	29	33	-4
OAD (Yr)	4.28	4.33	-0.06
ISMA Duration (Yr)	4.93	5.26	-0.33
Duration to Maturity (Yr)	4.73	5.05	-0.32
Vega	-0.04	-0.05	0.01
OA Spread Duration (Yr)	4.4	4.49	-0.08
OA Convexity (Yr^2/100)	-0.27	-0.49	0.22
Total TE Volatility (bps/month)			**7.55**
Systematic Volatility (bps/month)	107.35	108.42	
Non-systematic Volatility (bps/month)	5.22	2.47	
Default Volatility (bps/month)	4.48	3.27	
Total Volatility (bps/month)	**107.57**	**108.5**	
Portfolio Beta			0.989

D. Constructing Proxy Portfolios

The Risk Model and optimizer can also be used to construct efficient proxy portfolios from cash.

The Risk Model and optimizer can also be used to construct efficient proxy portfolios from cash. A proxy portfolio is designed to track an index with minimum realized tracking error. A "passive" manager may construct proxy portfolios to fill a mandate for a low tracking error portfolio. An "active" manager may use a proxy portfolio to hold an influx of new cash, or when he or she is very defensive versus the benchmark, or as a core portfolio to express portfolio views.

Without the use of a risk model, a passive portfolio is typically constructed using stratified sampling. However, because stratification does not allow risk in one dimension to help offset risk in another dimension, proxy portfolios constructed in this fashion tend to contain a relatively large number of issues as it becomes necessary to populate all of the "buckets." While this may be feasible for very large passive portfolios, this is an inefficient strategy for smaller portfolios.

Given the interrelationship of risks captured in the Risk Model, a low tracking error portfolio may not necessarily have issues populating each "bucket." Instead, the risk model realizes that a bond contributes to many dimensions of a portfolio's risk. Consequently, the risk model may choose to leave a bucket empty if the exposures arising from that bucket are matched by bonds in other highly correlated buckets. As a result, a proxy portfolio constructed using the Risk Model and optimizer is typically smaller. Given the transactions costs for small lots and the difficulty of finding particular bonds to populate specific buckets for a stratified sample, a proxy portfolio constructed using the Risk Model can be executed more quickly and more cost efficiently.

Investors have successfully used the Risk Model and optimizer for many years to construct proxy portfolios.

Investors have successfully used the Risk Model and optimizer for many years to construct proxy portfolios. Typically, realized tracking errors have been somewhat less than estimated tracking errors. For example, proxy MBS and government portfolios have been built and run for many years with realized tracking errors very rarely exceeding one standard deviation (TEV = 5 bp/month). The reason for the success of such portfolios is the lack of idiosyncratic risk in these bond instruments. A distinctive feature of proxy portfolios is that they contain relatively few bonds whereas the underlying benchmark usually holds hundreds of positions. (For example, an MBS proxy portfolio may contain twelve bonds whereas the MBS Index contains almost 410 generics.) Consequently, a bond in the proxy portfolio may comprise a 5% market value weight, compared with a 0.5% weight in the index. This is a very large relative overweight, which exposes the proxy portfolio to event risk. Generally, MBS and government bond issues have very little idiosyncratic (or, event) risk, which greatly increases the probability that the proxy will closely track the benchmark.

However, this is not the case for corporate bonds or for any other asset class with a relatively large amount of idiosyncratic risk. A distinguishing characteristic of the Lehman Risk Model is that it explicitly incorporates a bond's idiosyncratic risk into the measurement of overall tracking error. To reduce idiosyncratic risk (and, hence, overall tracking error volatility) to a reasonable level, a proxy corporate portfolio must contain a fairly large number of bonds. Although the systematic component of TEV can be lowered with a relatively small number of bonds, idiosyncratic risk can only be effectively reduced by adding to the number of bonds in the proxy.

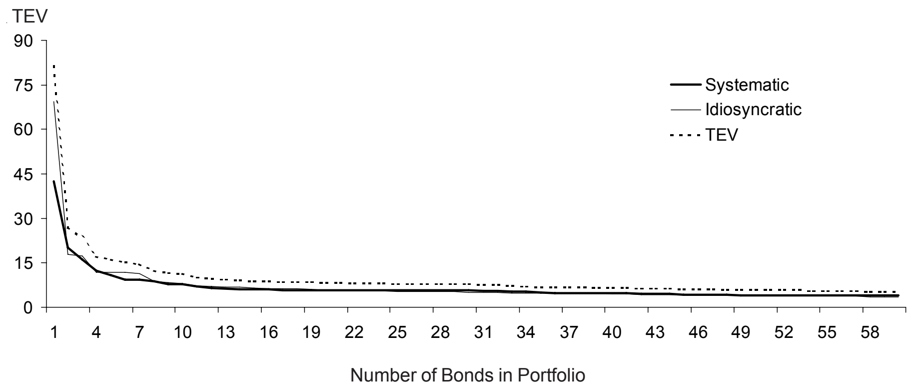
Figure 36 graphs the relationship between the number of bonds in a U.S. Aggregate proxy portfolio and the estimated TEV. The proxy portfolio begins with a single corporate bullet bond with its duration matched to the Aggregate Index (HFC 4 1/8s of 12/2008, belonging to the A-rated financial credit sector), which produces a TEV of approximately 81 bp/month. The systematic (43 bp/month) and idiosyncratic (70 bp/month) components of TEV are also shown. Note that the idiosyncratic risk is a substantial portion of overall TEV. We then let the optimizer recommend sells and buys to bring down TEV.[33] Figure 36 shows what happens to the systematic, idiosyncratic, and overall TEV as bonds are added to the proxy portfolio.

By the time the proxy portfolio contains five bonds, the overall TEV has already fallen by over 80% to 16 bp/month. The systematic TEV has declined to 11 bp/month, whereas the idiosyncratic TEV has fallen from 70 bp/month to 12 bp/month.

What did the optimizer do to bring TEV down so quickly? Before showing the answer, let us first build some intuition. The initial TEV is 81 bp/month. What are the

[33] We limit the set of bonds eligible for portfolio inclusion to issues in the U.S. Aggregate Index that were issued within the prior three years and which have at least $500 million outstanding.

Figure 36. **Global Risk Model—U.S. Aggregate Proxy Portfolio**
Proxy Portfolios—TEV as a Function of the Number of Bonds
December 31, 2004



components of TEV? Figure 37 presents the risk sector components of TEV. For the initial one bond proxy portfolio, risk from yield curve exposure is 30 bp/month. Although the bond matches the overall duration of the benchmark, there is substantial key rate duration exposure (i.e., a large overweight to 5-year Treasury key rate and large underweight to all other key rates). Risk from agency/credit spreads is relatively large at 35 bp/month. This risk arises solely from exposure to credit risk factors as the portfolio is 100% invested in credit. The third largest component of systematic risk is the 14 bp/month exposure to swap spreads. Again, the single bond portfolio is a bullet with a concentrated positive exposure to 5-year swap spreads and large underweight to all other key rate swap spreads.

Intuition tells us that the portfolio needs exposure to other parts of the Treasury curve, other swap spreads, and should reduce credit sector exposure. In fact, this is what the optimizer recommends with a single trade.

Intuition tells us that the portfolio needs exposure to other parts of the Treasury curve, other swap spreads, and should reduce credit sector exposure. In fact, this is what the optimizer recommends with a single trade:

First Trade Recommended by Optimizer
Sell: 89% portfolio position in HFC corporate bond
Buy: 89% portfolio position in FNMA 5 ½s 7/2012 callable at 7/2005.

The Fannie Mae callable debenture gives the portfolio exposure to many points along the Treasury and swap spread curve. In addition, it gives the portfolio large exposure to a different, and less volatile (factor volatility of 4.1 bp/month), part of the agency/credit sector, while substantially reducing exposure to the A-rated financial sector (factor volatility of 10.7 bp/month).

This first trade reduces overall TEV to 27 bp/month from 81 bp/month. Note what happens to the components of TEV: TEV due to yield curve exposure falls from 30 bp/month to 9 bp/month; swap spread exposure from 14 bp/month to 4 bp/month and agency/credit spread exposure from 35 bp/month to 15 bp/month. The movements in the TEV components can be seen in Figure 37.

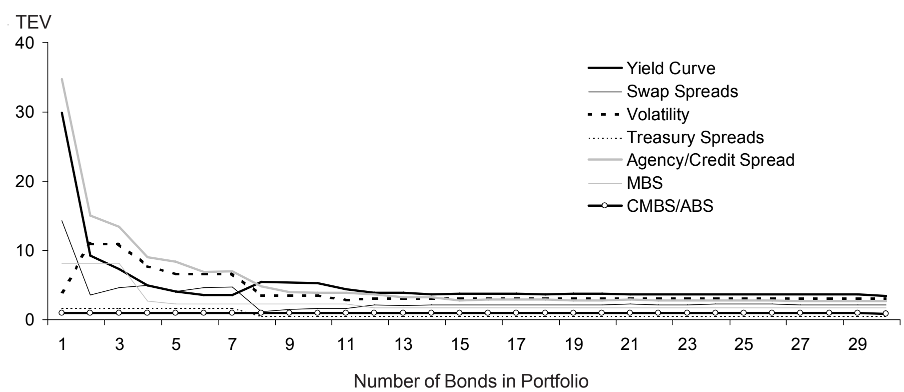
Although most of the TEV components decreased with the first trade, the observant investor will notice that the TEV due to volatility exposure increased! This is because the callable FNMA bond is much more negatively convex than both the credit bond that was sold and the benchmark. As a result, the portfolio TEV exposure due to volatility has increased from 4 bp/month to 11 bp/month. However, given the covariance of the volatility risk factor and the other systematic risk factors, the increase in exposure to volatility does not offset the reduction in overall TEV due to the reduction in the other systematic risk exposures. The optimizer will allow an increase in some risk exposures provided that the reduction in other risk exposures produces an overall TEV reduction.

Idiosyncratic risk also drops sharply with the introduction of the second bond in the portfolio. This reduction occurs for two reasons. First, for bonds that belong to different issuers, the Risk Model assumes that their idiosyncratic risks are uncorrelated. Consequently, adding bonds to the portfolio reduces idiosyncratic risk through diversification. Second, the FNMA bond has much lower idiosyncratic risk (18 bp/month) than the HFC bond whose position was reduced (70 bp/month).

Once the portfolio contains 15 bonds, the portfolio's TEV is 8.8 bp/month with systematic TEV at 6 bp/month and idiosyncratic TEV at 6.5 bp/month. Note also that the components of TEV begin to flatten out as well (Figure 38). Adding more bonds to the portfolio improves TEV, both systematic and idiosyncratic TEV, only very gradually. By the 50th bond, overall TEV is 5.8 bp/month, with systematic TEV at 4 bp/month and idiosyncratic TEV at 4.1 bp/month.[34]

[34] It is important to note that TEV measures "normal market" volatility. A portfolio containing relatively few bonds managed against the U.S. Aggregate index remains vulnerable in that the particular credit issues selected may experience unusual volatility (*i.e.,* downgrades or defaults) not fully captured by historical volatilities. Portfolio managers need to determine whether there is sufficient diversification in their credit portfolio beyond the reported TEV number. For details, please refer to *Sufficient Diversification in Credit Portfolios*, May 2002, Lehman Brothers.

Figure 37. **Global Risk Model—U.S. Aggregate Portfolio Proxy Portfolios—TEV Sector Components as a Function of the Number of Bonds,** December 31, 2004



The large spurt of idiosyncratic risk in 2001 and 2002 prompted a new feature in the Lehman risk models. Since idiosyncratic risk is "episodic," if it is averaged over long periods of time, the magnitude of idiosyncratic risk may seem small, although, over short periods, it can dominate. The Risk Model measures idiosyncratic risk historically, but the user has the choice of specifying how much weight to give to recent, as opposed to more distant, history. For example, if the manager feels that a recent period of high idiosyncratic risk is likely to persist, he or she can ask the Risk Model to give more weight to recent periods when measuring the magnitude of idiosyncratic risk. This choice will increase the TEV penalty for holding too few bond issuers and will encourage the proxy portfolio builder to add more names. However, if the manager has a forecast of low idiosyncratic risk, he or she may wish to use a level of idiosyncratic risk measured over a long historical period, which will typically be low. Generally, it is wise to err on the conservative side and run the Risk Model using both assumptions for idiosyncratic risk and take the higher of the two estimated TEVs.

While the Risk Model allows calibration of idiosyncratic risk to more closely match a manager's near-term forecast, idiosyncratic risk is still measured historically. As such, it cannot capture any new event risk that may affect a particular issuer.

E. Scenario Analysis

The tracking error number from a risk model is just one way of measuring a portfolio's risk versus its benchmark. To supplement their risk analysis, many investors also perform scenario analysis (see also Chapter 6).

Scenario analysis involves specifying various possible future market environments and measuring how the portfolio performs in each. For example, a common set of scenarios is to examine the portfolio assuming the UST yield curve shifts in a parallel fashion ±50 bp, ±100 bp, and ±200 bp over a relevant holding period horizon (say, twelve months). Both the portfolio and benchmark are re-priced at the horizon with the new UST curve, and the relative performance is calculated.

The difficulty with scenario analysis is the specification of the scenarios. Not only must portfolio managers guard against specifying scenarios that conform only to their market forecasts, but scenarios must be internally consistent.

The difficulty with scenario analysis is the specification of the scenarios. Not only must portfolio managers guard against specifying scenarios that conform only to their market forecasts, but scenarios must be internally consistent. If a manager specifies movements in the UST curve, how should the other risk factors change commensurately? Is it realistic to specify a +100 bp shift in the UST curve and hold credit spreads unchanged? In other words, for each of the UST curve scenarios what should happen to spreads? to volatility? to the slope of the UST curve? to the slope of the various spread sector curves?

The Risk Model can be used to help the portfolio manager construct realistic scenarios.

The Risk Model can be used to help the portfolio manager construct realistic scenarios. It is important that the manager construct scenarios, both "favorable" and "adverse," in a fashion that is internally consistent with realistic market behavior. For example, suppose a manager specifies a -100 bp shift in the UST curve along with a 50 bp tightening of credit spreads. The historical experience is that UST yield changes and spread changes tend to be negatively correlated. Therefore, the manager's scenario is very unlikely and probably adds very little relevant information regarding the risk of the manager's portfolio. Alternatively, the manager may assume the UST curve is unchanged but wants to examine the portfolio given a 20 bp widening of industrial sector spreads. What should the manager assume about spread movements in other sectors? Is it a realistic scenario to assume that all other sector spreads remain unchanged?

The data contained in the Risk Model can be very helpful for constructing scenarios. Many managers may want to examine how the portfolio performs assuming various UST yield curve shifts. However, such a manager may not have a view on sector spread changes or volatility changes. In this case, the manager may simply want the scenario to reflect the assumed yield curve move and the most likely concomitant move in the other risk factors. Given the manager's specified shift in some risk factor(s), the risk model can use the historical risk factor variance-covariance matrix to generate the expected shift in all other risk factors.

Using the Risk Model to construct realistic scenarios increases the value of the scenario analysis to the portfolio manager. The manager can specify a shift in some set of risk factors, and, in turn, the Risk Model will shift all the other risk factors in a way that makes the scenario most likely.

Using the Risk Model to construct realistic scenarios increases the value of the scenario analysis to the portfolio manager. The manager can specify a shift in some set of risk factors, and, in turn, the Risk Model will shift all the other risk factors in a way that makes the scenario most likely.

F. Risk Budgeting

We have described many uses of the Risk Model to measure risk. However, the Risk Model can also be used to control risk. This feature is particularly attractive to a plan sponsor or a chief investment officer who wishes to limit the ex-ante risk of an investment manager.

Most investment management agreements specify risk guidelines for the investment manager. Similarly, internal investment company policies limit the risk that an individual manager may take. However, these risk guidelines are generally written in terms of permitted portfolio deviations from a target level or benchmark. For example, some guidelines state that a portfolio's duration must remain within a value of 5 ± 0.5. Presumably, this tolerance band was specified to limit the total return volatility of the portfolio. However, when was the tolerance band established? Was it established during a period of low interest rate volatility so that a 0.5 duration deviation implied a relatively modest total return deviation? Or, was it established during a high volatility period so that the plan sponsor fully expected more extreme portfolio return deviations? Depending on when the guidelines were written, the permitted duration deviation could imply very different portfolio return deviations.

This issue becomes more complicated when the risk guidelines involve many constraints. For example, besides a duration constraint, risk guidelines may also specify permitted sector overweights (in market value terms) such as "the portfolio's weighting in the corporate sector may not deviate by more than 5 percentage points from the benchmark weight." The guidelines may also specify a permitted over- or underweight in the various quality sectors (*e.g.,* the portfolio may not contain more than 10% in bonds rated Baa or worse).

The problem with many risk guidelines is that the constraints are piecemeal. It is difficult to determine the overall level of risk permitted in the portfolio.

The problem with risk guidelines specified in such a manner is that the constraints are piecemeal. It is difficult to determine the overall level of risk permitted in the portfolio which is, presumably, what the plan sponsor is trying to articulate. As the market environment changes, the same constraints could imply very different portfolio risk levels. In addition, how do the various risk constraints interact? A duration overweight with a 10% MBS overweight could imply a different portfolio risk level than the same duration overweight with a 10% MBS underweight, although both positions would be permissible.

The underlying goal of the plan sponsor or chief investment officer is to limit the overall risk of the portfolio. In effect, the intent is to constrain the volatility of the portfolio or the tracking error of the portfolio versus a benchmark. Ideally, the guidelines should be specified in terms of tracking error limits (*i.e.,* a risk budget), and the portfolio manager should have discretion as to where to take risk provided the portfolio stays within the risk budget.

The Risk Model can enable a manager to operate within a risk budget.

The Risk Model can be used as an objective monitor of the portfolio manager's activities.

The Risk Model can enable a manager to operate within a risk budget. Rather than specify individual limits (*e.g.,* duration deviation must be within 0.5 years and Baa's must be less than 10% of the overall portfolio), the sponsor may specify that the manager may take no more than 50 bp per year of expected tracking error. The manager is then free to take active exposures anywhere in the portfolio provided, of course, that the portfolio's overall estimated tracking error remains less than 50 bp. The Risk Model can be used as an objective monitor of the portfolio manager's activities.[35]

[35] Additional applications of the Global Risk Model appear regularly in the monthly Quantitative Porfolio Strategy section in *Global Realtive Value*.

4. MODEL OVERVIEW BY ASSET CLASS

Moving from a theoretical concept of a risk model to a practical portfolio management tool requires the specification and estimation of the risk factors. So far, we have only spoken of the systematic risk factors in the abstract. What are the systematic risk factors? Where do they come from? How do we estimate their values?

This risk model construction process begins by "returns splitting."

The risk model construction process begins by decomposing bond returns into various parts. This exercise is often referred to as "return splitting." For each bond in the Lehman Index database, we break down a bond's monthly return into the following components:[36]

$$\text{TotalRet} = \text{CurrencyRet} + \text{CarryRet} + \text{YieldCurveRet} + \text{VolatilityRet} \\ + \text{SwapSpreadRet} + \text{SpreadRet}$$

First, for bonds that are in a different currency than the base currency, there is a stochastic CurrencyRet component to total returns. The Global Risk Model currently contains 22 currency risk factors covering 23 currencies.[37]

The CarryRet component is deterministic (*i.e.,* known at the beginning of each month). The CarryRet is simply the bond's monthly coupon return plus any return arising simply from the passage of time.

The four remaining return components are stochastic (*i.e.,* unknown at the beginning of the month). Each of these components of return is modeled separately and is assumed to be driven by its own set of risk factors. The YieldCurveRet component represents that portion of a bond's total return due to the movement of the currency's benchmark curve. For example, the YieldCurveRet for a U.S. dollar bond is modeled as the sum of the bond's Treasury key-rate durations multiplied by the change in the appropriate key rate.[38] (This is discussed in more detail below.) Similarly, the VolatilityRet is modeled as the sum of a bond's volatility duration multiplied by the change in the corresponding implied volatility. The SwapSpreadRet component is modeled as the sum of a bond's swap spread key rate durations multiplied by the change in the appropriate key rate swap spreads.

The YieldCurveRet, VolatilityRet, and SwapSpreadRet return component models are relatively straightforward and are similar across different asset classes within a currency market. In other words, all U.S. securities have the same YieldCurveRet model (and, hence, potential exposure to the same set of key rate risk factors). In addition, the YieldCurveRet models are also similar across currency markets. For example, the U.S. dollar and Euro models both have similar sets of six key rate risk factors—specific to their own benchmark yield curve, of course.

[36] This chapter will simply outline the return splitting process. Details are beyond the scope of this paper.

[37] The 23 currencies are: CAD, EUR, GBP, DKK, SEK, CHF, NOK, JPY, AUD, NZD, KRW, SGD, THB, SIT, PLN, HUF, SKK, ZAR, MXN, HKD, CLP, CZK and USD. One currency is the base currency for calculating FX rates and volatility. Hence, there are 22 currency risk factors.

[38] There is also a convexity factor in the YieldCurveRet model.

The last component of return is SpreadRet. This is the portion of a bond's total return that is not explained by carry, changes in the yield curve, changes in volatility, and changes in swap spreads. Treatment of this component of a bond's return depends heavily on the characteristics of the bond's asset sector. Consequently, each major asset sector of a given currency market has its own SpreadRet model and its own set of risk factors. The U.S. Credit SpreadRet model is very different structurally from the U.S. MBS SpreadRet model. The Credit SpreadRet model has changes in various credit sector spreads as the main risk factors—exactly what a credit portfolio manager's intuition would say. In contrast, the MBS SpreadRet model has changes in spreads for discount/current /premium price mortgages as the main risk factors—exactly what an MBS portfolio manager's intuition would say. This difference in model specification reflects the different drivers of spread return in the various asset sector markets.

Additionally, there may be differences in models for the same sector but in different currency markets. As a result, while the U.S. Credit SpreadRet model shares similar characteristics with the Euro Credit SpreadRet model, there are some differences. For example, the Dollar Credit SpreadRet model has nine credit sectors, while the Euro Credit SpreadRet model has seven. Differences in model specification reflect different market sector structures.

In summary, the total return for each bond is split into several components. Each component, in turn, is then modeled as a linear combination of systematic risk factors. Each month, across all bonds in the index, each component of total return is regressed on the factor loadings for each of the component's risk factors. (Note, the YieldCurveRet and Swap SpreadRet components are modeled using observed factors.) These factor loadings are calculated from the cash flows of each bond. The realized monthly value for the risk factor is the estimate produced by the regression. The residuals from each component regression (*i.e.,* the portion of returns not explained by the systematic risk factors) are aggregated and used in the model for the bond's non-systematic (*i.e.,* idiosyncratic) risk (see Section 4.E).

We now discuss the four main systematic components of a bond's returns: YieldCurveRet, SwapSpreadRet, VolatilityRet, and SpreadRet. For each of these model components we provide a brief description of the model's specification. Where significant, we highlight how the model's specification varies depending on the particular currency or sector. Much of the chapter will describe the SpreadRet models where there is a great deal of variety in the model specifications.

A. Yield Curve Return Models

Over the past decade, the local swap curve—not the treasury curve—has become the benchmark curve for many asset classes. For asset classes that continue to quote bond spreads relative to the treasury curve, an increasing number of investors also examine the spread to the swap curve. There are two main reasons for this development. First, there has been rapid growth in assets managed by investors who fund themselves at LIBOR (*i.e.,* swap rates). For this influential class of investors, their relative value decision is based, in part, on a bond's spread to the swap curve. Second, during the latter part of the 1990s, there was growing concern (now passed) regarding the scarcity of U.S. Treasury securities. As a result, U.S. investors and traders began to hedge their positions using swaps and to view swaps as a more relevant benchmark.

The Global Risk Model recognizes the swap curve as the benchmark curve for all assets.

The Global Risk Model recognizes the swap curve as the benchmark curve for all assets. In other words, movement in the swap curve is the systematic component of return that is common to all assets. However, for the four currency bloc markets (dollar, euro, sterling and yen) the Global Risk Model splits changes in the swap curve into two pieces: changes in the local treasury yield curve and changes in local swap *spreads* (which is the spread of the swap curve to the treasury curve). Consequently, every bond in these four currency markets has a component of total return due to changes in the treasury curve and a component of return due to changes in swap spreads. In the Global Risk Model, each component of a bond's return is modeled separately with its own set of risk factors: Treasury curve risk factors (changes in treasury key rates) for the YieldCurveRet model and swap spread risk factors (*i.e.,* changes in swap spreads) for the SwapSpreadRet model. We first discuss the YieldCurveRet model, then the SwapSpreadRet model (applicable to the four currency bloc market).

Movements in the local treasury or swap yield curve will clearly have a major effect on almost any fixed income security. By considering the effect of the reshaping of the yield curve during the course of a month, holding all else constant, we calculate the return of a given security due to that movement. This is the YieldCurveRet component of a bond's total return. To model this component of return, we consider the movement of a few key points on the par curve. These key-rates, along with the sensitivity of the security to them—the key rate durations (KRDs)—allow us to explain over 95% of the yield curve return. With the inclusion of a convexity term, we explain close to 100%.

For each month, we collate these key rate factors. In this way we obtain historical monthly realizations for all of our factors going back as far as January 1990. By way of illustration, below is a sample time series of the U.S. dollar 6-month key rate movements.

Month	**Movement of USD 6-Month Key Rate** (%)
Jan-90	0.151
Feb-90	-0.087
Mar-90	0.270
Apr-90	0.089
May-90	-0.381
…	…
Apr-03	0.011
May-03	-0.086
Jun-03	-0.142
Jul-03	0.121
Aug-03	0.005
Sep-03	-0.042

Risk factor time series data are then used to generate the covariance matrix. As each month of additional data becomes available, the risk factor database and covariance matrix is updated.

While structurally similar, there are some differences in the YieldCurveRet models for the various currency markets. The U.S. dollar, euro, sterling, Norwegian krone, Swedish krona, Danish krone, Canadian dollar, Swiss franc, and yen YieldCurveRet models have the key rate risk factors shown in Figure 38.

The factor loading for each key rate is the bond's key rate duration for that key rate. Note the presence of the 7-year key rate for the yen market, reflecting the importance of that point of the curve for the yen yield curve. Each of the four currency bloc models (*i.e.*, U.S. dollar, euro, sterling, and yen) also includes a convexity risk factor, which is defined as the square of the average change in all of the key rates in the relevant market.

The YieldCurveRet model for other markets (*i.e.,* Australian, New Zealand, Hungary, Korea, Poland, Slovakia, Thailand, Czech Republic, South Africa, and Singapore) is a single factor, the average change in their respective treasury market's par yield, and a bond's loading on that risk factor is the bond's modified duration.

B. Swap Spread Return Models

Having first stripped away the deterministic component of return—coupon and rolldown—and then the local treasury yield curve return as described above, we then identify the component of a bond's total return due to movement in swap spreads. This applies to the four currency bloc markets where the yield curve risk factors are treasury key rates.

The SwapSpreadRet model estimates a bond's return due to swap spread changes as the sum of the changes in several key swaps, each multiplied by the bond's appropriate swap spread key rate duration. The SwapSpreadRet model is similar to the YieldCurveRet model, except that changes in key swap spreads replace changes in treasury key rates and swap spread key rate durations replace treasury key rate durations.

While structurally similar, there are some differences in the SwapSpreadRet models for the various currency markets.

Again, while structurally similar, there are some differences in the SwapSpreadRet models for the various currency markets. The swap spread risk factors for the U.S. dollar, euro, sterling, and yen SwapSpreadRet models are shown in Figure 39.

For bonds outside of these markets (*e.g.,* Australian, New Zealand and Singapore), changes in swap spreads are not used as risk factors.

As discussed in Chapter 1, the introduction of swap spread risk factors is a notable change from the previous U.S. Risk Model. This change was driven by changes in the marketplace

Figure 38. **Global Risk Model—Systematic Risk Factors**
YieldCurveRet Models

Market	Yield Curve Risk Factors
U.S. Dollar, Euro, Sterling	6-Mo; 2-Yr; 5-Yr; 10-Yr; 20-Yr; and 30-Yr Treasury Key Rates
Yen	6-Mo; 2-Yr; 5-Yr; 7-Yr; 10-Yr; 20-Yr and 30-Yr Treasury Key Rates
Canadian Dollar	6-Mo; 2-Yr; 5-Yr; 10-Yr; and 30-Yr Swap Key Rates
SEK and NOR	6-Mo; 2-Yr; 5-Yr; and 10-Yr Swap Key Rates
CHF	6-Mo; 2-Yr; 5-Yr; 10-Yr; and 20-Yr Swap Key Rates
DKK	6-Mo; 2-Yr; 5-Yr; 10-Yr; 20-Yr and 30-Yr Swap Key Rates

Figure 39. **Global Risk Model—Systematic Risk Factors**
SwapSpreadRet Models

Market	Swap Spread Risk Factors
U.S. Dollar	6-Mo; 2-Yr; 5-Yr; 10-Yr; 20-Yr and 30-Yr Swap Spreads
Euro and Sterling	2-Yr; 5-Yr; 10-Yr; and 30-Yr Swap Spreads
Yen	6-Mo; 2-Yr; 5-Yr; 7-Yr; 10-Yr; 20-Yr and 30-Yr Swap Spreads

over the intervening period and the broadening of the risk model coverage to include markets and assets that have long used the swap curve as a pricing benchmark. Please refer to Section 5.B for a discussion of the empirical significance of swap spreads as a risk factor.

C. Volatility Return Models

After stripping away the yield curve and swap spread components of return, a portion of the total return for bonds with embedded options (*e.g.,* callable corporates and MBS) will be driven by changes in implied volatilities. The Global Risk Model has a single estimated volatility risk factor each for U.S. Agencies, U.S. Treasuries, U.S. investment-grade corporates, U.S. high-yield and two estimated volatility risk factors for MBS (a short-expiry factor and a long-expiry factor). The EUR and GBP markets, having few bonds with optionality, have as their volatility factor the observed change in the 5x5 swaption volatility.

The risk exposure to the volatility risk factor is measured by the bond's "volatility duration," which is calculated by dividing the bond's vega by its full price.[39]

D. Spread Return Models

The above risk factors—movements of key points on par curves, changes in swap spreads and some volatilities—are all "observable." In other words, we can read their values off a market data screen and maintain them in a database. The final systematic component of return—those due to spread movements—is, however, more challenging and must be modeled in a different way.

The SpreadRet component of a bond's total return refers to that portion of return remaining after all other systematic return components have been accounted for and stripped away. SpreadRet is, in turn, made up of two distinct pieces: a systematic piece, which is modeled, and a non-systematic piece, which is whatever is left unexplained. Both pieces of SpreadRet are vital in quantifying the volatility of a given security's total return and, hence, the total return volatility of a portfolio. We now discuss the systematic SpreadRet model. The estimation of idiosyncratic risk is discussed toward the end of this chapter.

To build intuition for modeling the systematic component of a bond's SpreadRet we will briefly discuss the approach for credit bonds. However, the analysis also applies to all bonds that trade with a spread: Agencies, U.S. dollar MBS, Pfandbriefes, etc.[40]

Consider a security that belongs to the U.S. Dollar A-rated/financial sector of the credit market. In any given month, this security's total return will be driven by a series of market factors. We have already discussed several of these systematic factors: currency (CurrencyRet), yield curve movements (YieldCurveRet), changes in swap spreads (SwapSpreadRet) and changes in volatility (VolatilityRet). These systematic factors

[39] For U.S. MBS, a bond's overall volatility duration is partitioned into a short-expiry and long-expiry volatility duration based on the bond's option-adjusted duration.

[40] Treasuries also have a spread component of return. Since the treasury curve is a "fitted" curve, a treasury bond could be priced at a spread to that curve. For U.S. Treasuries, there are three spread return risk factors (level, slope, and liquidity). For European Treasuries, there is a spread level risk factor—one for each of the major European countries (DE, FR, IT, ES, NL, BE, and GR). In addition, there is a treasury spread level risk factor for "small" Aaa-rated European countries and one for "small" non-Aaa-rated European countries. Canada and Japan each have a single treasury spread level risk factor.

generally account for a large part of the bond's total return. However, a significant portion of total return will remain unexplained. This remaining portion of return is usually driven by spread movements within the bond's asset sector. It seems reasonable that the return of this particular A-rated/financial bond will, to some extent, reflect spread movements in the A-rated/financial sector as a whole. This is a sector or peer group effect on total return that is common (*i.e.,* systematic) to all bonds belonging to that credit sector. The Global Risk Model treats this sector factor (*i.e.,* changes in the average spread for bonds in a sector) as a systematic risk factor. Credit bonds have exposure only to the sector risk factor of their sector.

In addition to sector risk, there are other systematic risk factors that drive SpreadRet. Bonds that belong to the same sector may have differential returns due to their relative spread level and relative maturity. For example, some A-rated/financial bonds may trade at a wider OAS compared with other A-rated/financial bonds. This wider spread level may reflect a relative lack of liquidity (*i.e.,* a liquidity premium) or perhaps there is a "sub-sector" within the A-rated/financial sector that naturally trades at a somewhat wider spread. Fluctuations in this liquidity premium or "sub-sector" premium will contribute to the SpreadRet for bonds with wider or narrower spreads than their peer group average. Consequently, the Global Risk Model treats this OAS level factor as a systematic risk factor.

A similar argument also applies for the relative maturities of bonds in a given sector. In other words, there may be a spread slope so that longer maturity bonds in a sector trade differently than shorter maturity bonds. Fluctuations in the slope of the spread curve will contribute to a bond's SpreadRet beyond the sector and spread level effects. Consequently, the Global Risk Model treats relative maturity (*i.e.,* a slope-factor) as a systematic risk factor. Finally, the Global Risk Model applies a geographical factor that explains the additional component of return that corresponds to potential return differential, arising from market segmentation effects, between U.S. and non-U.S. domiciled credit issuers.

Using this type of market analysis and intuition, we identify potential systematic spread risk factors and build the SpreadRet model corresponding to these market effects. Having decided on the form that the systematic risk factors will take, we fit the historical data to the model. Depending on the asset class and currency market, the SpreadRet model can vary considerably. We use robust statistical techniques to explain as much of the spread return of a security as possible by systematic spread risk factors. In this way, we produce a set of risk factors for each of the major asset classes in each currency market. By leveraging the vast quantity of data at our disposal—historical returns at the individual bond level going back more than a decade in many cases—we are able to form both systematic and non-systematic risk factors of considerable explanatory power, robustness, and intuitive interpretation. As of this publication, there are 152 spread risk factors for bonds in the Global Aggregate Index (75 US; 37 euro; 24 sterling; 12 yen; 1 canadian dollar; and 3 global EMG). In addition, the Global Risk Model includes complete SpreadRet models for U.S. and Euro high-yield, inflation-linked, and emerging market securities. This chapter will now discuss in more detail the SpreadRet models for several of the major asset classes.

i. Spread Return Models for Agency and Credit

The market spread return risk models for Agency and Credit are primarily based on issuer, industry and rating. The first step is to partition each sub-index into different "peer groups" or buckets."[41]

a. For U.S. Agency, we partition the index into five buckets based on issuer. There are 4 major issuers in the U.S. Agency Index: Fannie Mae (FNMA), Freddie Mac (FHLMC), Federal Home Loan Bank (FHLB) and Farmer Mac (FARM). The remaining bonds, issued by smaller issuers, are lumped together into a residual bucket (Other).
b. For U.S. Credit, including both investment-grade and high-yield, the partition is based on industry and rating. For Investment Grade bonds, we group them into 27 buckets by intersecting nine industries (Banking, Basic Industry, Cyclical, Communication, Energy, Financial, Non-Cyclical, Non-Corporate, and Utility) and three ratings (Aaa/Aa, A and Baa).
   For U.S. high-yield bonds rated at B and above, we group them into 11 industry buckets: Basic Industry, Capital Goods, Media, Communication, Cyclical, Non-Cyclical, Energy, Technology, Transportation, Utility and Financial. All high-yield bonds rated Caa and below are grouped into one single bucket: "Distressed Group." A fuller description of the risk model for high-yield assets— incorporating default risk—is presented later in this chapter.
c. The partitions for euro, sterling, and yen investment-grade credit are slightly different from those of U.S. Credit. For euro and sterling, we have 21 buckets across different ratings (Aaa, Aa, A, and Baa) and industries (Banking, Finance, Basic Industry, Cyclical, Non-Cyclical, Communication, Utility, Non Corporate and Collateralized) for each sub-index. For Japan, we have nine buckets across different ratings and industries (Agency, Banking/Financial, Industrial, Utility, and Non-Corporate).
   Euro high-yield bonds follow the same partitioning sheme as U.S. high-yield.

For each bucket, we have a spread risk factor for which the risk exposures are the spread durations of individual bonds. Since the spread return for an individual bond can be approximated by the product of its spread duration and change in OAS during the period, the risk factor can be interpreted as *average* OAS change for all bonds in the corresponding bucket. The only exception is the "Distressed" bucket for U.S. and Euro High-Yield where the risk exposure is simply unit. The corresponding "Distressed" factor is then the *average* excess return for all bonds rated at Caa and below. We make such a model choice because change of OAS is no longer a small number for bonds trading at Caa and below, and the first order approximation of spread return no longer holds. Also, market experience suggests that this asset class does not trade on spread but rather on price.

Beyond those bucket-specific factors, we include other systematic spread factors to capture different characteristics of individual bonds. For instance, we have a "slope" factor and an "OAS-level" factor for each sub-index (U.S. Agency/U.S. investment-grade; Credit/U.S. high-yield; Credit/euro; Credit/Euro high-yield; Credit/sterling; and Credit/

[41] For details on the U.S. dollar credit risk model, please refer to "The New Lehman Brothers Credit Risk Model," Marco Naldi, Kenny Chu, and Gary Wang, *Quantitative Credit Research Quarterly*, May 2002, Lehman Brothers.

yen Credit). The long and short bonds load with opposite signs for the slope factors while the high- and low- spread bonds load with opposite signs for "OAS" factors.

For U.S. investment-grade credit, we have three non-domestic issuer risk factors for each market corresponding to the three rating groups (Aaa/Aa, A, and Baa) and just one for euro and sterling. These non-domestic risk factors account for different spread behaviors of bonds issued by non-domestic entities compared to domestic issuers. For U.S. and Euro high-yield, we also have two additional risk factors for the distressed sector: a leverage factor and a subordinated type factor (U.S. only). The leverage factor captures the market's fluctuating treatment of high-leveraged firms relative to low-leveraged firms. A bond's "loading" on the leverage risk factor is the bond's relative leverage ratio with respect to its peers. This factor is designed to capture the common variation among highly leveraged firms. The subordinated factor is designed to capture the common movement for subordinated bonds. Only subordinated bonds have unit loadings for this factor.

Credit bonds issued in currencies outside the dollar, euro, sterling, and yen have their SpreadRet modeled with reference to the major market that most closely resembles their own, as will be explained in section F. Figure 40 summarizes the SpreadRet model risk factors for the Agency and Credit asset classes.[42]

ii. Spread Sector Return Models for MBS, CMBS, and ABS

The securitized sectors of the Global Aggregate currently comprise approximately 20% of the index's total market value. The three major securitized asset classes in the Global Aggregate Index are U.S. agency mortgage-backed securities (MBS), commercial mortgage-backed securities (CMBS), and asset-backed securities (ABS). There are other securitized asset classes in other currencies as well (*e.g.,* Pfandbriefes (euros)). Each securitized asset class has exposure to its currency's systematic yield curve and swap spread risk factors. However, for the SpreadRet component each securitized asset class has exposure to risk factors that are unique to its respective market. We now discuss the three main securitized asset classes in the Global Aggregate Index and their particular spread risk factors.

a. U.S. Dollar MBS

While the Agency-MBS holder is not realistically exposed to credit risk, the holder is exposed to the risk that the underlying mortgage loan will be prepaid by the homeowner.[43] This risk, called prepayment risk, involves either an earlier-than-expected return of principal when rates are low or a later-than-expected return of principal when rates are high. Either of these events would be detrimental to the total return for the MBS holder. Prepayment risk is a function of many variables, including implied interest rate volatility, the price of the MBS, and the age (or, weighted average loan age (WALA)) of the MBS. As interest rates are the key driver of mortgage prepayments, a prepayment model is used to estimate this effect when calculating the option-adjusted KRDs used to measure interest rate risk. Changes in mortgage prices not predicted by the prepayment model can be due to any of the other factors listed above. Consequently, MBS returns are sensitive to changes in risk factors that influence prepayment risk: changes in implied

---

[42] Credit assets in CHF, DKK, NOK, and SEK have as their systematic spread risk factor the average change in swap spreads in their respective markets.

[43] For a full description of the MBS Risk Model, please refer to: "The New Lehman Brothers MBS Risk Model," by Dick Kazarian, March 7, 2003, Lehman Brothers.

volatility; changes in spreads for various price-tiers of the MBS market (*i.e.,* discount, current-coupon and premium); and changes in spreads for various age cohorts of the MBS market (*i.e.,* new versus seasoned). An MBS's security's exposure to changes in spread arising from the MBS's price and age is measured by the MBS's OASD.

An MBS security is defined by its underlying particular mortgage underwriting program. Depending on the program and market environoment, an MBS security may have more or less prepayment risk compared to other MBS securities. Since relative MBS total returns are influenced by the nature of the underlying mortgage program, the MBS SpreadRet model includes risk factors corresponding to the main MBS programs

Figure 40. **Global Risk Model—Systematic Spread Risk Factors**
U.S., Euro, Sterling and Yen: Agency and Credit

Market	Asset Class	SpreadRet Risk Factors
U.S.	Agency	5 issuer factors (Farm, FHLMC, FNMA, FHLB and other); 1 spread slope factor; and 1 spread level factor
	Credit—Investment-Grade	27 sector factors: 3 qualities (Aaa/Aa, A, Baa) × 9 sectors (banking, finance, basic, energy, cyclical, non-cyclical, communication, utility and non-corporate); 1 spread slope factor; 1 spread level factor; 3 geographic factors (Aaa/Aa, A and Baa)
	Credit—High-Yield	12 sector factors: 11: 1 quality (Ba/B) × 11 sectors (financial, basic industry, energy, media, cyclical, non-cyclical, technology, transportation, communications, utility and capital goods) 1: distressed (*i.e.,* quality less than B); 2 slope factor for Ba/B and for distressed; 2 level factors: for Ba/B and for distressed; 1 leverage factor for distressed; 1 subordination factor for distressed
Euro	Agency—Pan Euro	2 issuer factors (Aaa and Aa-A-Baa) 1 spread slope factor; 1 spread level factor
	Credit—Investment-Grade	17 sector factors: 3 qualities (Aaa/Aa, A, Baa) × 7 sectors (banking, finance, basic, cyclical, non-cyclical, communication, and utility) - some cells merged; 4 non-corporate sector factors (Aaa, Aa, A and Baa); 1 spread slope factor; 1 spread level factor; 1 factor for U.S. issuers in Euro currency factor
	Credit—High-Yield	12 sector factors: 11: 1 quality (Ba/B) × 11 sectors (financial, basic industry, energy, media, cyclical, non-cyclical, technology, transportation, communications, utility and capital goods) 1: distressed (*i.e.,* quality less than B); 2 slope factor for Ba/B and for distressed; 2 level factors: for Ba/B and for distressed; 1 leverage factor for distressed
Sterling	Credit—Investment-Grade	17 sector factors: 3 qualities (Aaa/Aa, A, Baa) × 7 sectors (banking, finance, basic, cyclical, non-cyclical, communication, and utility) - some cells merged; 4 non-corporate sector factors (Aaa, Aa, A and Baa); 1 spread slope factor; 1 spread level factor; 1 factor for U.S. issuers in Sterling currency factor
Yen	Agency	2 sector factors (Aaa/Aa and A/Baa)
	Credit—Investment-Grade	5 sector factors: 2 qualities (Aaa/Aa and A/Baa) × 3 sectors (banking/financial, industrial, utility and non-corporate) 2 non-corporate sector factors (Aaa/Aa and A/Baa) 1 spread slope factor; 1 spread level factor.

(*i.e.,* 15-year and 30-year GNMAs and conventionals, and balloons). An MBS security's exposure to these program risk factors is also given by the MBS's OASD.

A summary of the ten MBS SpreadRet model risk factors (besides the yield curve, swap spread, and volitility risk factors) is provided in Figure 41.

While CMOs (collateralized mortgage obligations) are not part of the Lehman Indices, they are ubiquitous in investor portfolios. The Global Risk Model can accommodate Agency CMOs (coverage for Non-Agency CMOs, hybrid ARMs and IOs/POs is forthcoming). Lehman MBS analytics identifies the MBS collateral underlying a CMO and analyzes the CMO's cash flow structure. Based on this analysis, option-adjusted KRDs are calculated for the CMO tranche along with an OASD value. In addition, the CMO's sensitivity to prepayments relative to the sensitivity of the underlying MBS securities is measured. Based on this measure, the CMO's OASD is adjusted to better reflect the CMO's sensitivity to the MBS prepayment risk factors in the SpreadRet model. For example, a well-structured PAC generally has less sensitivity to prepayment risks than the underlying collateral. To reflect this, the Risk Model adjusts the CMO's OASD downward for the purposes of loading the CMO's exposure onto the MBS risk factors.

b. U.S. Dollar CMBS

Although commercial mortgages are mortgage-backed securities, the nature of the underlying collateral and the structure of the security itself give CMBS risk exposures not present for agency MBS. First, CMBS do not carry an agency guarantee and, therefore, involve credit risk. Consequently, CMBS are exposed to changes in spread associated with particular credit qualities. Second, CMBS returns may differ depending on their "window" to receive principal payments. Some CMBS are current-pay bonds while others may be locked-out for a period of time. Depending on the market environment, locked-out bonds may enjoy a return advantage over current-pay bonds. Consequently, CMBS are exposed to changes in spreads for bonds with varying payment "windows."

Third, CMBS can experience spread changes that depend on their average life. Some bonds may have long average lives whereas others may be shorter. This is basically spread curve exposure. Depending on the market environment, investors may have a stronger or weaker appetite for long average life assets, which will affect the returns on a CMBS depending on its average life.

A fourth factor influencing CMBS returns is the age of the commercial loans underlying the bond. Seasoned loans may have more or less prepayment risk and more or less default risk. As a result, market conditions may cause low WALA bonds to trade

Figure 41. **SpreadRet Models**
U.S. Dollar MBS Systematic Risk Factors

Market	Asset Class	MBS Spread Risk Factors
U.S.	MBS	6 Price-WALA factors (discount/new; discount/seasoned; current/new; current/seasoned; premium/new and premium/seasoned); and 4 sector factors (GNMA (15-year & 30-year); conventional 15-year; and balloon). There is no explicit 30-year conventional sector factor. Consequently, the four sector risk factors are interpreted as changes in spread relative to the 30year conventional sector.

differently than high WALA bonds. A fifth risk factor is related to the price level of the bond as higher price bonds may have more prepayment risk and different total return performance than discount priced bonds. Finally, due to structural or issuer characteristics, a CMBS may trade at a different spread than otherwise similar bonds. For example, a particular loan originator associated with a bond may be viewed as less diligent than other loan originators.

The twelve CMBS risk factors (besides the term structure risk factors) are shown in Figure 42.

c. U.S. Dollar ABS & Non-Dollar Securitized Assets

Besides the term structure risk factors, an ABS bond is exposed to systematic risk factors depending on the underlying collateral (*i.e.,* auto, credit card, manufactured housing, home equity, utility rate reduction, and all others) and on the quality of the bond (*i.e.,* Aaa-rated versus non-Aaa-rated). So, the total return of a credit card ABS will be driven by the change in credit card sector spreads weighted by the bond's OASD.

The total return on an ABS bond is also driven by changes in spreads for bonds depending on the average life of the bond; whether the bond is at a premium or discount; whether the assets underlying the ABS bond are seasoned or new (applicable to prepayment sensitive ABS only: home equity, manufactured housing, and auto loans); and whether the ABS is trading at a wider or narrower spread due to particular structural or issuer characteristics. The thirteen U.S. dollar ABS SpreadRet risk factors (besides the term structure risk factors) are summarized in Figure 43.

There are other mortgage-related securitized assets in other currency markets (*e.g.,* Pfandbriefes). For these asset classes (euro and sterling only), the Global Risk Model uses only a single SpreadRet factor and the bond's exposure to this risk factor is the bond's OASD.

iii. Default Risk Model for U.S. and Euro Baa and High-Yield Assets

In this section, we discuss the default risk model for Baa and high-yield securities.[44] In general, the broad concept of credit risk includes market spread risk and default risk. Market spread risk (discussed in Section 4Di) is the risk due to fluctuation in the level of credit spread (*i.e.,* the price of the bond) supposing that the issuer does not default

[44] For details on the high-yield credit risk model, please refer to *The New Lehman Brothers High Yield Risk Model*, Ganlin Chang, Lehman Brothers, November 2003.

Figure 42. **SpreadRet Models**
U.S. Dollar CMBS Systematic Risk Factors

Market	Asset Class	CMBS Spread Risk Factors
U.S.	CMBS	4 quality factors: Aaa, Aa, A, and Baa 1 payment "window" factor (current pay vs. non-current pay); 3 price factors— one each for current pay Aaa bonds, non-current pay Aaa bonds, and non-Aaa bonds; 1 average life factor; 1 age (WALA) factor; 1 OAS spread level factor; and 1 CMBS IO factor

Figure 43. **SpreadRet Models**
U.S. Dollar ABS and Non-Dollar Securitized Assets Systematic Risk Factors

Market	Asset Class	ABS Spread Risk Factors
U.S.	ABS	6 sector factors: auto, credit card, manufactured housing, home equity loan, utility, and "all others" representing collateral that does not belong to the other five categories. 1 quality factor: (non-Aaa rated bonds); 3 age (*i.e.,* WALA) factors—one each for auto, home equity loan and manufactured housing; 1 average life factor; and 1 OAS spread level factor 1 price level factor
Euro	Securitized	1 factor
Sterling	Securitized	1 factor

in the given period (spreads include a penalty due to the prospect of default). The standard multi factor risk model, as we have discussed so far, focuses on this source of risk. On the other hand, default risk is the risk that an issuer fails to meet its contractual obligation in a given period of time. While the default risk is relatively unimportant for investment-grade issues rated A or better due to small default probabilities, it is indeed a meaningful source of risk for Baa and high-yield issues. Our risk model provides a unified framework to quantify both risks.

The default risk for a single issue depends on its default probability and expected recovery rate upon default. In addition, when portfolio effects are calculated, we have to take default correlation into account.

In our model, the default risk for a single issue depends on its default probability and expected recovery rate upon default. The default probability is calibrated ex-ante using historical default data and the expected recovery rate is a function of the bond's seniority. Both the default and recovery rates are estimated using both long-term and 12-month trailing historical data. To convert default risk into units of return volatility, the standard units of the Risk Model, we multiply the square root of the issuer's default probability by one minus the recovery rate upon default. In addition, when portfolio effects are calculated, we have to take default correlation into account. Like market spread risk, it is widely acknowledged that default risk is also a type of systematic risk. Empirical evidence shows that aggregate default rates are related to general macro-economic factors and business cycle indicators. The financial distress of one firm can directly trigger the distress of other firms. Hence, defaults are correlated, which we have to model.

Our setup for default correlation follows a structural framework based on the value of the firm, along the lines of Merton (1974).[45] Under this approach, a default event is triggered whenever the firm's asset value falls below a threshold defined by the firm's liabilities. Hence, dependence of the default of one firm on the default of other firms can be modeled through the correlation among firms' asset value fluctuations. Because we cannot directly observe a firm's asset value, we use equity correlation as a proxy for asset correlation. Our model uses a t-dependence correlation structure under which extreme movements and co-movements are more likely. Using such a structural framework, we are able to generate realistic default correlations. So for both the U.S. and Euro High-Yield Risk Model, we estimate two correlation matrices: the systematic risk factor matrix and the issuer default correlation matrix.

[45] Robert Merton, "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance*, volume 29, 1974.

iv. Spread Return Model for Inflation-Linked Securities

The Global Risk Model includes a completely integrated risk model for inflation-linked securities. Inflation-linkers raise an interesting modeling question: What is the spread component of return for a linker? In other words, we seek to perform return splits for inflation linkers and isolate a spread return that contains not only country-related spread factors, as already exist in the Risk Model, but also a spread return arising from the inflation-linked nature of the security. To do this we need to estimate sensitivities to both the nominal curve and also to spread movements.[46]

The uncertainty with regard to the cash flows of an inflation-linked bond is different from a non-linked credit asset. For the latter, the uncertainty concerns whether promised cash flows will be paid. For a linker, however, the uncertainty is with regard to the size of the payment, which depends on the announced level of a particular index at some point in the future. (For a credit bond that is also inflation linked, there will be both types of uncertainty.) Nonetheless, despite these differences, the analytical approach taken in handling credit securities can also be adapted to our purpose.

For a credit security the uncertainty in the cash flows is reflected in its option-adjusted spread. We assume that the cash flows as given by the cash flow schedule at the time of evaluation are certain and solve the pricing equation to obtain a fixed spread above the discount curve that prices those cash flows correctly. The spread will capture the risk of uncertainty (along with any other sources of discount) and allows us to proceed to calculate analytics and performance attribution in a relatively simple manner. In terms of the pricing equation we write:

$$PV = \sum_i \frac{CF_i}{(1+y_i)^i (1+s)^i}$$

For inflation-linked securities we can adopt a similar approach which will allow us to look at these bonds as simple variations on bullet bonds with an appropriate spread. This translates into the pricing equation below:

$$PV = \sum_i \frac{CF_i (1+\pi)^i}{(1+y_i)^i}$$

The equivalence can be expressed, then, mathematically as:

$$1+\pi = \frac{1}{1+s} \quad \Rightarrow \quad s = \frac{-\pi}{1+\pi}$$

---

46 For more details see “Lehman’s Inflation-Linked Securities Risk Model” by Jeremy Rosten, Lehman Brothers, forthcoming.

The essential insight here is that the risk of default for a credit bond reduces the expected value of given cash flow leading to a positive spread. In contrast, the effect of index linking is to increase the expected value of a linker (from that of the real coupon) resulting in a negative spread. This thought process leads us to identifying a corresponding spread for a linker in the same way as for a credit security. It will be a negative spread of the order of inflation expectations out to the maturity of the bond but the similarity, in terms, of risk modeling is clear.

Consequently, we have cast the inflation linked security into a familiar form: that of a bullet credit bond with the associated spread. We then identify spread risk factors specific to the linkers markets and model the spread return of this asset class along with the other sources of return over and above those that they have in common with nominal securities (i.e., the effect of realized inflation).

In our model, the monthly spread return (i.e., total return less CarryRet and YieldCurveRet) is modeled as being driven by two sets of risk factors:

a. Changes in realized inflation during the month, and
b. Changes in breakeven inflation (i.e., inflation expectations). There is a short (5 years) and a long (20 years) inflation expectations risk factor

The sensitivity of a linker to realized inflation factor is the fraction of its market value that is represented by the unknown cash flows. The risk factor is the returns of the inflation index ratio where we use the latest index ratio available at the time of calibration and not the official index ratio used for quotation of the security price in the market place.

For the modeling of inflation expectations, expressed in the pricing of the bond via the breakeven spread, we model (in each currency market separately) the behavior of the term structure breakeven inflation rates along the same lines as we already do for the yield curve. In other words we use a few constant maturity points along the curve which will capture the bulk of the movements of breakeven inflation spreads of all securities in the market place. A bond's sensitivity to inflation expectations is its OASD that is apportioned across the two inflation expectations factors depending on the bond's maturity.

In summary, an inflation-linked bond will load on nominal curve risk factors with a sensitivity equal to its analytical OAD, as well as inflation specific factors, namely those reflecting the risk in realized and expected inflation movements.

v. Spread Return Model for Emerging Market Securities

The Global Risk Model also covers emerging market securities, both investment-grade and high-yield. The EMG spread return risk model framework mirrors that for investment-grade and high-yield credit bonds. In these models, spread return risk has two components: market spread risk driven by exposure to sectors of the marketplace and default risk. For investment-grade credit, sectors in the market spread risk model are based on country, industry and rating. For high-yield (rated Ba/B) credit bonds are grouped based on industry. For distressed high-yield (rated Caa and lower) a different strategy is used as all bonds are pulled together independently of country or industry. For purposes of modeling market spread risk for emerging markets bonds, what approach should we use?[47]

Emerging markets debt is defined as bonds from countries with sovereign ratings of Baa3 or below. The model covers debt denominated in all major currencies: EUR, GBP, JPY and USD. We first group the bonds into three major geographical regions - Latin America, Europe and Asia (including Middle East and Africa) - and three rating buckets (investment-grade, Ba/B and distressed). However, due to the limited number of investment-grade and distressed bonds in some of the three regions, we merge the three investment grade buckets and the three distressed buckets each into a single bucket.

For high-yield non-distressed bonds, the bulk of the EMG market, not only are there sufficient data to estimate individual factors for the three regions, but it is wise to do so as there have been several episodes where their behavior differs substantially. In fact, we went further with this exercise and estimated individual country factors. This should be reassuring to portfolio managers with exposures centered on a small set of emerging market countries who may worry that the country-specific risk their portfolios are exposed to is being washed away by the aggregation within blocks. To avoid this dilution we estimate individual factors for countries that are major issuers in the emerging markets. In summary, we partition EMG issues into twelve sectors (see Figure 44).

[47] For more details see "Emerging Markets in Lehman Brothers Global Risk Model," by Antonio Silva, Lehman Brothers, forthcoming.

Figure 44. **Global Risk Model–Systematic Spread Risk Factors Emerging Market Securities (USD)**

Market	Asset Class	SpreadRet Risk Factors
EMG	Investment-Grade	1 sector factor; 1 spread slope factor; and 1 spread level (liquidity) factor
	High-Yield, Non-Distressed	10 sector factors (EMG America, Argentina, Brazil, Mexico, Venezuela; EMG Asia, Philippines; EMG Europe, Russia and Turkey) 1 spread slope factor; and 1 spread level (liquidity) factor
	High-Yield, Distressed	1 sector factor; 1 spread slope factor; and 1 price level factor

We investigated whether to model sovereign and non-sovereign debt differently. However, the data indicated similar volatility behavior for these two types of bonds. Therefore, we decided not to model them separately. We should emphasize however that we do differentiate their default treatment. Finally, some of the bonds from emerging markets are “Brady bonds.” These are bonds whose collateral is partially guaranteed, usually by US government bonds. The existence of these guarantees distorts the usual bond analytics. Taking that into account, we use the corrected (“stripped”) analytics for these bonds, whenever needed.

We model EMG default risk in a similar fashion as the Lehman High-Yield Risk Model. However, we treat the recovery process for emerging market bonds differently. The experience with defaults in emerging markets is significantly different than that from the developed countries. The number of default is also much smaller, so we cannot model them with a partition as is done in the High-Yield Risk Model. Instead, we set recovery rates for emerging markets bonds using a major established fact about emerging markets defaults: recovery rate for sovereign bonds tend to be higher than their corporate counterparts. In particular, we set the recovery rates to 25% for emerging markets sovereigns bonds and 10% for emerging markets non-sovereign bonds. These numbers are conservative estimates.

E. Idiosyncratic Return Model

The variance that cannot be explained by systematic factors is called idiosyncratic variance. This risk is especially important for portfolios with few bonds.

The systematic factors explain about 30%-65% of the time variability of spread returns.[48] The variance that cannot be explained by systematic factors is called idiosyncratic variance. This idiosyncratic component of return uncertainty is especially important for portfolios with few bonds. We assume that the idiosyncratic variance is issuer–specific: only bonds issued by the same issuer have correlated idiosyncratic risks. For example, the idiosyncratic risk of a bond issued by Ford will be independent of the idiosyncratic risk of another bond issued by GMAC; however, it will be correlated with the idiosyncratic risk of another Ford bond even if these two bonds are issued in different currencies. An exception to this idiosyncratic correlation structure is the U.S. Agency sector. Because we partition the Agency index by issuer in the systematic model, the issuer effect for U.S. Agency has already been captured by those five bucket factors, hence, all idiosyncratic risks for U.S. Agency bonds are assumed to be independent. A similar model exists for euro treasuries (*e.g.,* Italy and Spain), which have designated factors in their domestic currencies.

The volatilities for the idiosyncratic risks are estimated using the residuals from the systematic model: the error terms which cannot be explained by systematic factors. The same industry/rating/issuer buckets used for systematic risks are used to estimate idiosyncratic volatilities. Therefore, all the bonds in a given bucket share the same (spread) idiosyncratic volatility. Such a methodology allows us to quantify the idiosyncratic volatility for securities from new issuers as they come to the market.

The idiosyncratic correlation among bonds issued by the same issuer depends on the average spread of all bonds issued by this issuer. The correlation structure applies across different currencies and sectors. We assign one correlation for all pairs, regardless of their currencies and sectors. In general, empirical studies show that the higher the spread, the higher the correlation.[49]

F. Putting Asset Class Models Together

The calibration of any risk model has to overcome certain practical hurdles. Frequently the lengths of history for different factors are unequal—often highly unequal. This presents the problem of measuring relationships between different pairs of market factors over different periods of time. To compare U.S. credit and U.S. yield curve factors may mean looking at data going back 13 years, whereas a similar comparison of U.S. Credit and Euro Credit can only cover the period from January 1999 onwards given the relatively recent emergence of a euro bond market. To simply use the data as such would be to compare apples and oranges—credit volatility has increased dramatically over the last 2-3 years, and we would expect both volatilities and correlations to have increased over such a period. In the early 90s, interest rate volatility was high in comparison to recent years. To combine these mismatched time series would be to use the relationship of U.S. Credit with U.S. rates over the last 13 years and that with Euro Credit over only 5 years. This inconsistency is clearly highly undesirable. In addition, using mismatched histories removes the guarantee of "positive-definiteness"—the Tracking Error Volatility can no longer be guaranteed to always be a positive number. Negative volatilities are obviously meaningless, and the covariance matrix, describing the relationship of all factors, must give rise to sensible Tracking Error Volatility estimates.

[48] Of course, the overall explanatory power using all risk factors (*e.g.,* the yield curve) is much higher for total returns.
[49] For more detail, please see *Are Credit Markets Globally Integrated?* by Albert Desclée and Jeremy Rosten, Lehman Brothers, March 2003.

These issues are not new, however. Techniques for dealing with missing data are well known and have been deployed. The new challenge was the new scale on which we seek to model global risk. We have moved from a model with approximately 75 factors in a single currency framework to one approaching 300 factors covering global fixed income markets. Back-filling is less of an option on this extended scale.

Furthermore, with so many factors and their mutual relationships to calibrate, we begin to run into problems in the form of dimensionality. In other words, we have more factors than we have data to estimate with in a stable and robust way. At most we have 13 years—156 months of factors realizations—often much less—and yet we seek to estimate covariances between almost 300 different factors.

To deal with both of these issues, we have developed a methodology that allowed us to reduce the scale of the problem, stabilizing the covariance matrices and allowing us to impute missing data with confidence.

The Core Factor approach postulates that across asset-class correlations between market factors are driven by a smaller set of fundamental factors. Each individual local factor—one of the 300 or so—is driven in part by its sensitivity to its relevant core factors. The supposition of the core factor methodology is that the core-driven part of each factor captures the commonality of behavior between factors from differing asset classes. So, the correlation between the 5-year point of the U.S. Treasury par curve and the corresponding 2-year point on the Sterling par curve will be captured by the relationship between the 3 core yield curve factors in each market: shift, twist and butterfly, one set of these three for each market. In so far as the 5-year U.S. point is sensitive to the U.S. shift, twist and butterfly core factors and the 2-year Sterling rate to its shift, twist, and butterfly core factors, so will the covariance of the USD 5-year and GBP-2year rates be a function of the 3 x 3 = 9 resulting cross-market covariances of these 3 + 3 = 6 core factors.

This is the technique that we have adopted, and the results that we have obtained have verified the veracity of the underlying hypothesis of the explanatory power of the core factors. Within asset blocs—USD Credit, Euro Volatility, Sterling Swap Spreads, Yen Credit and so on—the covariances are in keeping with the sample covariances (*i.e.,* the observed relationship between the factors). Covariances across asset-blocs are driven by the Core factors.

Finally, in seeking to cover currencies outside the major 4 markets, we have had to address the issue of how to model the smaller markets—Asia ex-Yen, Scandinavia, Switzerland, and Canada. The approach chosen was, where appropriate, to map a given market to one of the 4 major markets. We cannot identify a Swedish Kroner Communications Baa market factor, but we can make the approximation that they will move in a fashion closely related their Euro equivalent. CAD denominated securities are approximated by drawing from the USD market, while Switzerland and Scandinavia map to the Euro factors. Each of these markets has its curve risk—generally the major component of systematic tracking error volatility—modeled with respect to its local swap or treasury curve, and only the spread factors are “proxied” by other closely related markets.

Australia, New Zealand, Thailand, Singapore, and Korea are less clear. Our decision was to incorporate more general market information from the USD market and not to map directly to detailed-systematic factors as was done with Scandinavia, Switzerland, and Canada. Again, each has curve risk modeled locally.

5. PREDICTIVE POWER OF THE MODEL

A. Testing Model Performance

What is the ability of the Global Risk Model to predict the *ex-post* risk of a portfolio? To assess the predictive ability of our risk model methodology, we performed unit variance tests for several index pairs. Using the Risk Model (equal time weighting) we produced estimates (as of December 2002) of the total return volatilities for several indices and the tracking error volatilities of one index versus another. We used risk parameters available at the beginning of that month: covariance matrix between systematic risk factors and estimates of idiosyncratic spread volatility across market sectors.

We then calculated the actual long-term volatilities of monthly total return and tracking errors for the period January 1990 through February 2005 as well as out-of-sample volatilities for the period January 2003 through February 2005. The data are presented in Figure 45.

If the Risk Model is doing good job of estimating volatilities, then we would expect the ratio of the model volatility to the actual volatility to be close to one. Our test was therefore a variance ratio test of the model volatilities versus the long-term volatilities and the model volatilities versus the out-of-sample volatilities. In all but three of the models (shown in bold in Figure 45) we do not reject the hypothesis that the variance ratio is equal to one.[50]

These tests support the claim that the Risk Model produces good estimates of total return and tracking error volatilities, validating our risk modeling methodology.[51] We plan to publish a detailed report on our testing results and to make regular updates of our model testing program available to users of the Global Risk Model.

[50] The duration of the U.S. aggregate around December 2002 was at historical lows. This may explain the underestimation of its longer term volatility.
[51] We have conducted similar performance analysis, with similar results, for other components of the Global Risk Model. See, for example, *The New Lehman Brothers Credit Risk Model*, Quantitative Credit Quarterly, 2Q02, Lehman Brothers; *Testing the Lehman Brothers Agency Risk Model*, Liquid Markets Research, Lehman Brothers, June 2003, and *The New Lehman Brothers MBS Risk Model*, Lehman Brothers, March 2003.

Figure 45. **Total Return and Tracking Error Volatilities Model, Long-Term, and Out-of-Sample**

		Model Volatility (Dec 2002)		
Portfolio 1	Portfolio 2	Portfolio 1	Portfolio 2	TEV (1-2)
Global Agg	US Agg	146.3	88.2	115.0
US Credit	Euro Credit (USD)	136.4	293.1	286.2
Euro Agg	Asian Agg (EUR)	103.1	311.5	315.8
		Long Term Volatility (Jan 1990 - Feb 2005)		
Portfolio 1	Portfolio 2	Portfolio 1	Portfolio 2	TEV (1-2)
Global Agg	US Agg	150.8	**112.6**	102.7
US Credit	Euro Credit (USD)	139.5	318.1	273.6
Euro Agg	Asian Agg (EUR)	90.4	297.0	323.6
		Jan 2003 - Feb 2005 Volatility		
Portfolio 1	Portfolio 2	Portfolio 1	Portfolio 2	TEV (1-2)
Global Agg	US Agg	**184.1**	**128.5**	117.3
US Credit	Euro Credit (USD)	168.2	313.7	254.4
Euro Agg	Asian Agg (EUR)	88.8	254.8	274.3

B. Relevance of Changes in Swap Spreads as a Risk Factor?

The decomposition of Treasury spreads into swap spreads and spreads over swap rates seems to identify different sources of volatility. As seen in Chapter 1, this is useful for the stabilization of risk factor correlations. However, one must still check whether this separation is relevant for the different asset classes. That is, do we really need the two risk factors to explain the changes in the spreads over Treasuries of a particular asset class? If the true underlying risk is well captured by one single factor, the decomposition may be redundant.

To focus on the value added from adding swap spreads as a risk factor, we isolate the part of a bond's return -r_t^i- that is not explained by Treasury rate movements. Then, we run the following regression:

$$r_t^i = \beta_0 + \beta_1 F_t^{SS} + \beta_2 F_t^{Si} + v_{it}$$

where F_t^{SS} is the swap spread risk factor and F_t^{Si} is the asset class specific factor. Moreover, to understand the individual contribution of each of the factors, we also separately fit the non-Treasury component of a bond's return to the swap spread factor and to the asset class specific factor.

Figure 46 presents the results of these regressions for several U.S. asset classes. It suggests that, in general, the remaining risk factors do explain a significant part of the variance of returns not explained by changes in the Treasury rates. The R^2s are high—recall that this explanatory power is in addition to any that may be related to Treasury factors—ranging from 33% to 67% when both risk factors are considered. Moreover, one can see that swap spreads are an important independent source of risk. The coefficient β_1 is always significant at the 1% confidence level.

The same is not necessarily true for the asset classes' specific factor. In particular, the

Figure 46. **Regression Results by Asset Class**

	1990-2003		
Asset Class	**β_1 (Swaps)**	**β_2 (Asset Specific)**	**$\bar{R}^2$**
AGY	-2.69**	1.81**	33%
	-1.85**		20%
		0.33	0%
CRP	-5.68**	4.94**	63%
	-3.65**		14%
		3.78**	31%
MBS[a]	-3.71**	2.78**	39%
	-2.87**		18%
		1.88**	9%
CMBS[b]	-4.80**	2.94**	67%
	-3.87**		42%
		1.58*	6%
ABS[b]	-2.69**	1.56**	42%
	-1.66**		18%
		0.60	3%

[a] From January 1995
[b] From August 1999;
* Significant at the 5% level.
** Significant at the 1% level.

results suggest that for both the Agency and ABS this factor does not explain much of the returns left unexplained by Treasuries. The results seem to indicate that there is no role in these asset classes for an asset-specific risk factor. Alternatively, we believe that the result is due to the fact that we are looking at highly aggregated asset classes. The heterogeneities within each asset class are specifically considered in the Risk Model but are absent in this analysis.

In this regard, the results are interesting only if we hold portfolios highly correlated with the indexes for the overall asset class. With this in mind, we briefly analyze the results for each asset class separately. Swap spreads are the important independent source of risk for Agencies: this confirms the popular notion that agencies are a "swap product." We also find that the remaining class-wide specific systematic risk is very small and highly correlated with swap spreads. The analysis of the ABS sector follows the same lines. However, data are available only for the period beginning in August 1999, when swap spreads were extremely high. For this period, we fail to identify an important asset class specific factor. The variance in returns is mainly driven by swap rates. Once again, the correlation between the two risk factors is relatively high, approximately -0.50.

Regarding corporates, the results suggest that both factors explain a significant portion of the variance in excess returns over Treasuries. For this asset class, the factors represent two important and relatively independent sources of risk. In particular, the results suggest that portfolios of corporate bonds that hedge their exposure to swap spreads do continue to be exposed to significant (credit) risk.

The same happens with MBS. The returns from this asset class over the full sample are driven by two relatively independent sources of risk. However, the increase in the swap spread volatility after 1998 gave prominence to this factor as the explanatory variable (results not shown). The evidence suggests that a well diversified MBS portfolio hedged with respect to swap spreads may have been exposed only to minimal risk during the last five years. The recent decrease in swap spread volatility may re-shift the relative importance of the two risk factors to the pre-1998 scenario. The results from the CMBS follow the same pattern (again recall that data are available only after 1998).

Overall, the results show that swap spreads and asset class specific factors are relatively independent and important in explaining returns for several asset classes. Therefore, their separation delivers a better characterization of the nature of returns variability for those asset classes. In conjunction with the evidence discussed in Chapter 1, these results strongly support the decomposition of Treasury spreads into swap spreads and spreads over swaps as introduced in the new Global Risk Model.

6. RELATIONSHIP WITH OTHER MODELS

A. Scenario Analysis

For analyzing portfolio risk on a forward-looking basis, a manager has several tools at his disposal that complement each other in several ways. The simplest approach, conceptually, is scenario analysis (also discussed in Chapter 3). The manager projects what will happen to the market over a given horizon, in as much or as little detail as desired, and asks the question, "What will be my performance if this happens?"

The problem is that there are an endless number of market scenarios that could drive returns. Yields can change in parallel along the curve or can exhibit a complex combination of twists and curvature changes. Changes in credit spreads can affect the market as a whole, or focus on a particular industry or issuer. How much of this detail can a manager specify in a scenario definition? With a very simple scenario specification, there will be many market events that cannot be properly represented. Also, the output of the analysis is largely determined by a set of implicit assumptions rather than by the scenario specification itself. With a more detailed specification, a greater amount of work is required just to produce a single scenario, and an extremely large number of scenarios would be required to "cover all the bases." Furthermore, with so many interrelated parameters to specify, a scenario that seems plausible may in fact be largely self-contradictory, (i.e., it may specify a combination of events that is extremely unlikely given the historical correlations).

The Risk Model approaches the exercise of projecting portfolio returns on a forward-looking basis from a totally different viewpoint. Imagine the set of all possible market outcomes. Scenario analysis seeks to identify a single outcome within this set and calculates portfolio performance at that point. The Risk Model takes a step back and tries to characterize the distribution of returns across the entire set of outcomes. Without explicitly evaluating a precise return number for even a single scenario, the Risk Model effectively calculates the standard deviation of returns over all possible scenarios using a joint probability distribution consistent with historical observations.

To get a complete picture of risk, a manager may wish to combine the strengths of both of these models. The Risk Model provides an overview of all the different categories of risk to which a portfolio is exposed, showing the relative magnitudes of risk in each category. Within each category, it details the key exposures that drive portfolio risk. To further flesh out an understanding of the risks, a portfolio manager might use this information to build scenarios that are tailored to stress these most significant exposures. For example, if the Risk Report shows a mismatch in the key rate duration profile, an asset manager could use scenarios to see just how much underperformance would result from specific non-parallel yield curve changes. Similarly, sector spread risk exposures could be complemented by looking at total returns under different sector spread change scenarios.

The synergy between the two models can work in the other direction as well. In addition to using scenarios to support and augment risk analysis, we can use the risk model as part of the scenario design process. When specifying complex scenarios on many market parameters at once, a portfolio manager can easily generate scenarios that are inconsistent with historical correlations, or at least extremely unlikely. The Risk Model's covariance matrix can be used to form a measure of the historical likelihood of a scenario. This can be used to aid in the specification of scenarios by allowing a manager to specify partial information about a scenario and fill in the missing sections to be the most consistent (maximum likelihood) with the specified information.

B. Value-at-Risk and Monte Carlo Simulation

It is a well-known problem in modeling risk in corporate securities and portfolios that the bell-shaped Normal distribution fails to reflect the chance of extreme losses or gains that are occasionally noticed in this asset class. This risk is known as "tail risk." A related concept, Value-at-Risk (VaR), tries to identify the worst case performance over a given time horizon for a given probability. VaR is usually used in a somewhat different context: it is used to measure the risk of absolute losses for an institution as a whole, rather than portfolio returns relative to a benchmark. Also, VaR is typically assessed over a shorter time scale, from daily to biweekly, rather than monthly. For example, an institution might define VaR as the amount $x such that they are 99% confident of not losing more than $x over two weeks. So, it might be that the chance of losing $100 million over the next two weeks is estimated to be 1%. The 99% VaR statistic would then be $100 million.

There are a number of approaches commonly taken in forecasting VaR. The parametric approach takes a distribution (typically a Normal distribution) generated from a historic mean and standard deviation. A VaR calculated as a percentage of market value, at the 16.6% confidence level (i.e., one standard deviation from the mean), over a one month time horizon, is similar to our TEV (assuming that return differences between the portfolio and benchmark are Normally distributed). Simulation-based methods are also often used to calculate VaR. Essentially, a simulation approach attempts to approximate the distribution of projected returns by analyzing a large number of correlated, randomly-generated scenarios. The key to the accuracy of such an approach is in the generation of these random scenarios. What kind of distribution should be used and with how many degrees-of-freedom? Is there an accurate model for the extent of the correlation and the tail dependence among all the different factors?

In theory, the simulation approach is more general than the Risk Model. For example, a manager could design a simulation procedure based on the Risk Model (and making the same assumptions about risk factor distributions) that would produce results consistent with the Risk Model. The manager could then change some of the distributional assumptions in the simulation, to obtain results that could not be obtained from the Risk Model itself.

In practice, simulation methods are generally not used for such high dimensional challenges as the management of global bond portfolios. The complexity of the problem has two main drawbacks. First, when we simulate many sources of risk at once, the number of simulated scenarios required to get a good estimate of the distribution (and particularly its tail) becomes very large. This method is, therefore, much more computationally intensive than the multi-factor approach. Second, the complexity of the scenario generation process, and the many assumptions required along the way, particularly about the interdependence of the outcomes of different risk factors, can raise many questions about the reliability and accuracy of the simulation process. For this reason, simulation-based approaches tend to be much more focused in nature. For example, detailed simulations of individual issuer defaults are used to analyze credit risk, and detailed simulations of the evolution of the Treasury yield curve evolution are used in the analysis of MBS portfolio performance.

C. Performance Attribution

Scenarios and simulations, like the Risk Model, are forward-looking (ex-ante) tools for analyzing how a given investment strategy might fare (whether in terms of returns or risk) over some future time period. Performance attribution, by contrast, is an ex-post tool that seeks to explain the sources of realized returns, and specifically the performance of a portfolio relative to its benchmark. This backward-looking analysis of the single course of events that actually transpired might seem to be a simple exercise in accounting, having little in common with the complex forward-looking models that must consider the probabilities of every possible outcome.

Yet the relationship between these two types of models is very close. Portfolio managers take risks only in order to generate rewards. The same portfolio attributes and exposures that the Risk Model uses in its forward-looking projections of tracking error volatility should ultimately determine whether, and by how much, the portfolio will outperform its benchmark.

Lehman Brothers has developed a new version of its performance attribution model. This model is a "hybrid" model, in which each security's return is first split into components due to currency, yield curve, volatility, and spread.

Lehman Brothers has developed a new version of its performance attribution model. This model is a "hybrid" model, in which each security's return is first split into components due to currency, yield curve, volatility, and spread. Each component of portfolio-level outperformance is then analyzed separately, using an approach that mirrors very closely that of the Risk Model. Outperformance in yield curve returns is explained in terms of KRD exposures, and spread return outperformance in terms of spread duration contributions to different market cells.

Why not take the above arguments even further and develop a pure "risk-based" attribution model, in which realized performance is analyzed entirely based on the set of factor exposures from the Risk Model? We have not adopted this approach because the structure of the performance attribution exercise may differ from manager to manager. There are many possible ways to do a performance attribution, and none of them can be deemed "correct." Rather, for each manager, the best attribution is the one that corresponds most closely to the manager's decision process. For this reason, we have placed a premium on making our attribution module highly customizable, rather than insisting on a perfect one-for-one correspondence with risk factors.

D. Asset Allocation

The standard approach to portfolio asset allocation today is the mean-variance optimization model put forward by Markowitz.[52] Such models seek the "efficient frontier"—the set of allocations that can provide a given amount of expected return for the smallest amount of risk. A central element of these models is the covariance matrix of asset class returns, which is used to generate the risk estimate to be minimized. In this sense, these

[52] Harry Markowitz, "Portfolio Selection," *Journal of Finance*, 1952.

models are quite similar to our Risk Model: a tracking error is computed based on differences between portfolio and benchmark allocations and a covariance matrix built from historical data.

The two big differences lie in the construction of the covariance matrix and in the level of detail of the analysis. Typically, asset allocation models take a macro view of a portfolio and a benchmark. The market is carved up into a set of broad asset classes, and the analysis seeks the optimal allocation among these asset classes. The implementation of these allocations in terms of individual securities is outside the scope of the model, as are the additional risks that might be incurred as a result. The Risk Model, by contrast, is concerned with portfolio allocation within a single macro asset class (i.e., fixed income) and evaluates the risk of the portfolio down to the specific set of industry and issuer exposures within the asset class. Similarly, the covariance matrix in asset allocation models is formed from historical total returns of entire asset classes. For a fixed-income risk model, however, a covariance matrix of total returns can display extremely high correlation among fixed-income assets. This can be partially addressed by using excess returns over Treasuries for spread asset classes. In our Risk Model, the risk of every asset class is decomposed into exposures to a set of systematic risk factors, each of which can affect multiple asset classes where appropriate. This better reflects the hierarchical nature of the market, in which common risk factors exist at several levels. For example, our model has features that address interest rates, swap spreads, corporate spreads in general, industry-specific, and even issuer-specific spreads.

E. Optimal Risk Budgeting

The Risk Model is also closely related to portfolio management tools that help find optimal (e.g., maximum information ratio) allocation of the overall portfolio risk to its various sources, often represented by distinct investment strategies. In other words, these tools help answer questions like "How big a duration exposure to take?" "How much of a credit under- or overweight?" "What should be the exposure to movements in implied volatility?" etc.

Obviously, the optimal investment strategy mix depends on the skill levels of the managers making each investment decision. The optimal solution also depends on the variance of each strategy's performance and covariances among the different strategies—the core idea underlying the Risk Model. Although skill is a critical factor determining portfolio performance, skill is rarely measured in any disciplined way or formally incorporated in the portfolio construction process. We have performed studies[53] in which skill was central in the historical simulation of various investment strategies. In these studies, skill was defined as the relative likelihood of making right and wrong decisions. For example, when choosing between right and wrong alternatives, a manager without any skill (0% skill level) would be equally likely to make each of the two choices (50% probability). A "perfect" manager (100% skill level) would always make the right choice (100% probability). Skill levels between these two extremes are interpolated, so that, for example, the skill level of 20% means making the right choice 60% of the time and the wrong choice 40% of the time.

---

[53] See, for example, *Value of Security Selection versus Asset Allocation in Credit Markets: Part II—An Imperfect Foresight Study,* Lehman Brothers, June 2000.

Skill-based historical simulation of different investment strategies shows that information ratios of very diverse strategies are quite similar for a given skill level. When performance is measured on a risk-adjusted basis, the particular nature of an investment strategy is not important. Performance is determined by the skill and dimensionality (the number of independent decisions) of a strategy.

These empirical results confirm the "Fundamental Law" of active management defined by Grinold and Kahn[54] as:

$$\mathrm{IR} = \mathrm{IC} \cdot \sqrt{\mathrm{BREADTH}}$$

where IR is the information ratio, IC is the "skill" or "information coefficient," and BREADTH is the number of independent decisions made in the strategy.

The information coefficient is based on the correlation between predictions and realizations and is closely related to our probability-based skill measure. Information ratio is outperformance (alpha) divided by risk (tracking error volatility, or TEV). Rewriting the formula, we obtain a simple expression for alpha:

$$\mathrm{IR} = \frac{\alpha}{\mathrm{TEV}} \Rightarrow \alpha = \mathrm{TEV} \cdot \mathrm{SKILL} \cdot \sqrt{\mathrm{BREADTH}}$$

The expected outperformance of an investment strategy is proportional to the skill associated with the strategy, tracking error volatility, and breadth.

This idea has fundamental implications for portfolio optimization. Asset managers have traditionally used the mean-variance approach to find the asset allocation that maximizes expected outperformance, or alpha, for a given level of risk (or minimizes risk for a target alpha). The Achilles' heel of this approach is the expected returns of asset classes (or strategies) used in the optimization. Historical returns are poor predictors of future returns, and scenario- or consensus-based projections present their own problems. Experienced asset managers, who often make correct directional predictions of particular market moves, are much less likely to accurately forecast magnitudes of the moves. Performance expectations based on the above three factors, *i.e.* skill, risk, and breadth, are less subjective.

Suppose a portfolio manager specifies a maximum allowable ex-ante TEV (i.e., the "risk budget") for his or her portfolio versus the benchmark. Using the relationship above to estimate alpha for individual strategies (asset classes, exposures, etc.), the total risk budget can be optimally allocated to maximize the overall outperformance. Once each exposure is assigned a particular amount of risk, one can determine the size of active position that corresponds to that risk.

---

[54] Grinold R. and Kahn R., *Active Portfolio Management*, McGraw-Hill, 1999.

The Lehman Brothers proprietary risk budgeting methodology—ORBS (Optimal Risk Budgeting with Skill) relies on manager-supplied skill levels, breadth, and directional market views to allocate the risk budget across macro strategies to maximize portfolio alpha. The risk allocated to an individual strategy is then translated into the size of active position that corresponds to that risk. At the core of this risk budgeting framework is a covariance matrix of returns for all underlying asset classes. A combination of the active positions created across all strategies produces a vector of portfolio exposures. Multiplying this vector by the covariance matrix obtains the overall portfolio tracking error volatility (constrained to be less than the risk budget). This framework is extremely flexible and can be applied to any combination of asset classes and investment strategies with any number of different constraints.

CONCLUSION

Lehman Brothers has provided Fixed Income Risk Models to investors since the early 1990s. We believe that our historical-parametric approach to multi-factor risk modeling offers an objective and realistic tool for forward-looking risk measurement. We also believe that Lehman's risk modeling approach offers several distinct benefits to portfolio managers.

First, our dominant position as provider of fixed-income market indices to U.S. domestic and global investors gives us access to high quality historical bond-level pricing with which to calibrate our risk models. Managers using our risk models can do so confident that the best market data available have been used to estimate its parameters.

Second, our modeling approach stresses the use of an intuitive set of risk factors. While our risk factors are not independent and do not comprise the smallest possible set of risk factors, our risk factors are easily interpretable by portfolio managers. For example, a portfolio manager can usually interpret our risk factors as changes in rates, spreads, or volatilities, which greatly facilitates understanding portfolio risks and how best to manage them.

Third, Lehman's modeling approach (which is contrary to the conventional risk modeling approach) imposes risk factor sensitivities (e.g., OASD) and then estimates the risk factor volatilities. This offers two key advantages. As many investors are aware, Lehman uses state-of-the art modeling efforts in interest rates, prepayments, and volatilities to generate risk sensitivity measures (key-rate-durations, spread durations, and vegas) for individual bonds. The same models are used to produce risk sensitivities for both portfolios and indices which enables an "apples-to-apples" comparison. When we fit bond returns to the risk factor model, we use these sensitivity measures. We then estimate the risk factors which can be readily interpreted as changes in rates, spreads, and volatilities. If the manager wishes to reduce his risk exposure to a particular risk factor, he can rely on a well-understood risk factor sensitivity (e.g., OASD) to build a trade.

Finally, since the Lehman Risk Model works with bond-level returns data, we can quantify security-specific risk. Diversification risk (especially credit risk) is very high on the investor's agenda which our idiosyncratic risk model can quantify.

The Global Risk Model covers all assets and currencies in the Lehman Global Aggregate Index. It also handles several other asset classes including floating-rate bonds, interest rate and bond futures, interest rate and cross currency swaps, several classes of derivatives, and an array of structured securities. Global investors can incorporate currency hedges in the analysis.

Over the years, our modeling choices have evolved as fixed income markets have changed. First, swaps have achieved a prominent role as a reference asset class. Investors are increasingly using swap-based indicators of relative value, such as LIBOR-OAS and asset swap spreads. Active managers are increasingly making bets on swap spreads and evaluating excess returns to the swap curve. In our own analysis, we find correlations of spreads to the swap curve to be more stable over time than correlations of spreads to the local treasury curve. As a result, we have modified the risk model and introduced swap spreads as a risk factor.

Second, our approach to modeling of credit has been expanded, for high-yield securities, to incorporate default and recovery considerations in addition to changes in market prices and spreads. We find that explicit consideration of default leads to improved estimates of tracking error. In addition, we have noted the historical clustering of defaults across firms and capture it using models of default correlation. These methods are identical to the models developed by Lehman to price CDOs and other structured credit transactions based on a portfolio of collateral. As a consequence, we now decompose the total tracking error volatility into three components: systematic market risk, idiosyncratic risk, and default risk.

With expanded asset coverage, we were faced with the problem of relatively short data history for several asset classes. The Lehman Indices provide us with a large proprietary database of bond-level price data on many asset classes going back to the 1970s. However, for other classes such as ABS and CMBS, the available history is shorter. The currency unification in Europe in 1999 presented a similar problem. We have developed and used sophisticated estimation procedures to obtain stable and reliable covariance matrices. As always, our access to Index data allows us to estimate risk factors using individual bond prices rather than industry averages and leads to reliable quantification of non-systematic risk and the penalty for insufficient diversification.

In addition to the Global Risk Model, we support investors with tools to construct portfolios with low tracking error (the portfolio optimizer), asset allocation that accounts for relative risks and expected returns (Risk Budgeting), and evaluation of the impact of large market events (Scenario Analysis). Lehman Brothers Fixed-Income Research uses the Risk Model on a regular basis to help investors structure active or replicating portfolios, rebalance to changing objectives with minimum turnover, and optimize risk budget allocation.

We believe that risk is measured in many ways, and we also plan to introduce alternative measures of risk, such as expected performance shortfall, probability of extreme losses, value on default, and the properties of loss distributions as measured by historical simulations. We have been exploring for some time the possibility of forward-looking measures of risk, such as implied volatility, as well as time varying models of volatility, such as GARCH models. As our research leads to better estimators of tracking error volatility, we will introduce these models into our suite of tools.

The most exciting future developments are the enhanced portfolio structuring and analysis tools that take advantage of the Global Risk Model.

The most exciting future developments are the enhanced portfolio structuring and analysis tools that take advantage of the Global Risk Model. We introduced scenario and total return analysis for portfolios in 2003 and hope to combine this with the Risk Model for scenario optimization: maximize the expected return of a portfolio over a set of scenarios with a constraint on tracking error volatility. We expect the next generation of tools to consist of global constrained optimizers and enhanced methods for risk budgeting.

APPENDIX A: A MULTI-FACTOR RISK MODEL TUTORIAL

This appendix offers a brief sketch on how risk models work.

We begin with the analysis of the risk of a single security and then move to an analysis of the risk of a portfolio of bonds. We then measure the risk of one portfolio versus another and show how the tracking error volatility (TEV) value is calculated.

a. Risk and Return of a Fixed Income Security

Imagine your fixed-income portfolio contains a single bond: the Wells Fargo (WFC)-Global 5%s of 11/15/2014. This is a bullet bond issued by a strong U.S. super-regional bank. The issue is rated Aa2/A+ (i.e., Lehman index rating of A) and has roughly 10 years remaining to maturity. As of this writing (3/16/04), the bonds are trading at a 78 bp spread to the on-the-run 10-year Treasury for a yield-to-maturity of 4.555% and a dollar price of 103-23.

What will determine the one-month holding period return[55] for this bond? Most investors would say that the return on the WFC bond will depend on the change in the 10-year UST yield (weighted by WFC's duration), the change in the spreads for WFC's "peer group," A-rated–bank sector, (weighted by WFC's spread duration), and any WFC company-specific event that would cause WFC's spread to move differently than its sector (weighted by WFC's spread duration). In other words,[56]

$$
\begin{aligned}
&\text{Return}_{\text{WFC}} \\
&\quad \approx -(\text{OAD}_{\text{WFC}} \times \Delta\text{yield}_{\text{10-yearUST}}) \\
&\qquad -(\text{OASD}_{\text{WFC}} \times \Delta\text{Sector\_spreads}_{\text{A,banking}}) \\
&\qquad\quad -(\text{OASD}_{\text{WFC}} \times \Delta\text{idioWFC\_spread}). \qquad \text{(A1)}
\end{aligned}
$$

The term ΔidioWFC_spread refers to the change in the WFC bond's spread, *net* of the change in spreads for the A-rated – banking sector.

What's the risk of holding this bond? Here we are discussing absolute risk, not the risk of outperforming some other asset such as cash, a Treasury bond or an index. In other words, over a reasonably short holding period (say, one month), what are the factors that will cause the total one-month holding-period return on this bond to fluctuate? Given the return equation (A1), it is clear that the volatility of returns (*i.e.,* the risk) for this bond will be driven by three risks: (1) volatility of changes in 10-year UST yields; (2) volatility of changes in sector spreads; and (3) volatility of changes in the idioWFC spread. So, the risk of the bond's price return can be summarized as in equation (A2):

---

55 For this discussion, we are ignoring the deterministic (or, carry) component of return.

56 Note the negative sign in front of each term: an increase in rates or spreads causes returns to fall. Also, the Risk Model uses the WFC bond's Treasury curve exposure to the six key rate points, not to a single point on the yield curve.

$$\sigma_{WFCpr\_ret} = f(OAD_{WFC} \times \sigma_{USTyield,}, OASD_{WFC} \times \sigma_{A/bank,}, OASD_{WFC} \times \sigma_{idioWFC\_spread}) \quad (A2)$$

The volatility of the UST yield is often referred to as interest rate risk, the volatility of sector spread changes is referred to as sector spread risk, and the volatility of isolated WFC events is referred to as security-specific (or, idiosyncratic) risk. For the WFC position, how much return volatility can be ascribed to each of these three sources of risk?

i. Interest Rate Risk

The return on the WFC bond will fluctuate as the yield on the underlying 10-year Treasury note fluctuates, holding the bond's spread constant. Currently, the on-the-run Treasury is the 4% of 2/2015 with a yield of 3.775%. Given the duration of the WFC bond, if the yield on the Treasury were to increase to 3.875%, at the same spread of 78 bp, the price of the WFC bond would decline to 102-28, producing a negative price return of approximately 81 bp.

This is an example of a realized return effect of a known change in the Treasury yield. However, when we talk about "risk" we are referring to the potential variability (*i.e.,* standard deviation) in the WFC bond's return due to changes in the Treasury yield. To measure the standard deviation of WFC returns due to changes in Treasury yield, we simply need to know the standard deviation of the 10-year Treasury yield change over the specified holding-period and the sensitivity (*i.e.,* duration) of the WFC bond to changes in the Treasury yield. In other words:

$$\sigma_{WFC(interest\_rate\_risk)} = OAD_{WFC} \times \sigma_{USTyield}$$

The duration for the WFC bond is 8.45 and the monthly standard deviation of changes in the 10-year Treasury yield is approximately 27.25 bp.[57] Consequently, the interest rate risk of the WFC is roughly 230 bp per month (= 8.45 × 27.25 bp).[58]

ii. Sector Spread Risk

The return on the WFC bond will also fluctuate as its spread to its "parent" Treasury bond (*i.e.,* the on-the-run 10-year) fluctuates, holding the Treasury's yield constant. Currently, the spread is 78 bp. Given the spread duration of the WFC bond, if the bond's spread were to increase to 85 bp, holding the Treasury's yield constant, the price of the WFC bond would decline to 103-4, producing a negative price return of approximately 57 bp.

[57] To estimate the risk of holding the bond, we would ideally want to know what the standard deviation will be during the forthcoming holding period. Unfortunately, this value is not known and must be estimated. The Lehman Risk Model uses historical data to estimate the standard deviations and correlations of risk factors. Please see Chapter 1 for a discussion of this "historical-parametric" risk model approach.

[58] We have not made any distributional assumptions about changes in the 10-year Treasury yield. If one were to assume that monthly yields changes are distributed normally, then a confidence interval could be constructed for the price return on the WFC bond due to interest rate risk. For example, a 95% confidence interval would be $\pm 1.96 \times \sigma_{WFCpr\text{-}ret}$ about the mean return difference.

To measure the standard deviation of WFC returns due to changes in its spread we simply need to know the standard deviation of spread changes for the bond over a specified holding-period and the bond's sensitivity (*i.e.,* spread duration) to changes in its spread.

The change in WFC's spread has two components: a portion that is common for all A-rated – bank sector bonds (*i.e.,* WFC's peer group) and another portion that is specific to Wells Fargo. The latter component of spread change we assign to the WFC-specific category (*i.e.,* idiosyncratic risk) which is described below. For measuring spread risk, we are concerned with the spread risk for the bond's sector. In other words, the price risk of the WFC bond arising from sector spread risk is:

$$\sigma_{WFCspread\_risk} = OASD_{WFC} \times \sigma_{A/bank}$$

The spread duration for the WFC bond is 8.23, and the monthly standard deviation of changes in OAS for the A–bank credit sector is approximately 9.4 bp. Consequently, the spread sector risk of the WFC bond is roughly 77 bp per month (= 8.23 × 9.4 bp).

These first two risks are common to many other bonds besides our WFC bond (e.g., a 10-year BAC bond). This is why we refer to interest rate and spread risk as "systematic" risks. In other words, the WFC bond contains two systematic risks: 10-year UST yields (*i.e.,* interest rate risk) and A-bank sector spreads (*i.e.,* sector spread risk). What is the overall systematic risk of the bond? It is unlikely to be the sum of the two risks as the interest rate changes and spread changes will not be perfectly correlated. In general, the risk of a portfolio containing two risks, A and B, is given by:

$$\sigma_{(A+B)} = \sqrt{}\{\sigma_A^2 + \sigma_B^2 + 2\times\rho_{A,B}\times\sigma_A\times\sigma_B\} \quad \text{(A3)}$$

If interest rate changes and spread changes were perfectly correlated (*i.e.,* $\rho_{A,B} = 1$), then $\sigma_{(A+B)} = (\sigma_A + \sigma_B)$. However, if $\rho_{A,B} < 1$, then $\sigma_{(A+B)} < (\sigma_A + \sigma_B)$.

Using historical data for 10-year Treasury yield changes and A- bank sector spread changes, we find that the correlation coefficient, ρ, is -0.35. Consequently, the systematic risk of our position is

$$\sigma_{WFCsystematic\_risk} = \sqrt{}\{(230 \text{ bp})^2 + (77 \text{ bp})^2 + 2 \times (-0.35) \times 230 \text{ bp} \times 77 \text{ bp}\}$$

$$= 215 \text{ bp per month.}$$

Note that the total systematic risk of 215 bp is less than the sum of the two individual systematic risks (230 bp + 77 bp). In this particular case, the total systematic risk is less than the interest rate risk by itself. The explanation, of course, is that the two risk factors have relatively high negative correlation. In other words, when the 10-year UST yield rises, producing a negative total return, there is a tendency for sector spreads to tighten, which will help to offset some of the loss due to rising rates.

An investor knows that the WFC bond may not strictly follow movements in the 10-year UST yield or spread changes in the A-bank sector. In fact, WFC bonds may have their own specific risk (also known as idiosyncratic, or, non-systematic, risk) which is assumed to be *independent* of the systematic risk factors. Together, systematic risk and idiosyncratic risk comprise the entire risk of holding the WFC bond. How is the idiosyncratic risk measured?

iii. WFC-Specific Risk

The return on the WFC bond will also fluctuate if its spread moves independently of the systematic risk factors. For example, all A–bank bonds may have widened five basis points over the month, whereas WFC issues tightened three basis points because of a favorable litigation result. Given this idiosyncratic-WFC spread move of eight basis points and given the spread duration of the bond, holding the Treasury's yield and A–bank spreads constant, the price of the WFC bond would rise to 104-13, producing a positive price return of approximately 67 bp.

To measure the standard deviation of WFC returns due to idiosyncratic changes in its spread we simply need an estimate for the volatility of idiosyncratic spread changes for the bond[59] and the bond's sensitivity (*i.e.,* spread duration) to changes in these idiosyncratic spread changes. Chapter 4 describes how the Global Risk Model estimates a bond's idiosyncratic spread volatility by measuring the idiosyncratic spread volatility of the bond's peer group. In this case, the relevant sector is A-bank and the Risk Model estimates this sector's idiosyncratic spread volatility to be 14.8 bp per month. Therefore, the price risk of the WFC bond arising from idiosyncratic spread risk is:

$$\sigma_{\text{WFCidio\_risk}} = \text{OASD}_{\text{WFC}} \times \sigma_{\text{idioWFC}}$$

$$\sigma_{\text{WFCidio\_risk}} = 8.23 \times 14.8 \text{ bp per month} = 122 \text{ bp per month}$$

The idiosyncratic risk for WFC bonds is measured by multiplying the monthly idiosyncratic spread volatility of 14.8 basis points by the 8.23 spread duration, to produce a monthly idiosyncratic risk of 122 basis points.

So, the systematic risk of the WFC bond is 215 bp per month, and the idiosyncratic risk is 122 bp per month. What is the total risk for a holder of the bond? Since the systematic and idiosyncratic risks are assumed to be independent of each other (so $\rho_{\text{systematic,idiosyncratic}} = 0$, see equation (3)), the total risk of the bond is as follows:

$$\begin{aligned}\sigma_{\text{WFCtotal\_risk}} &= \sqrt{\{\sigma_{\text{WFCsystematic}}{}^2 + \sigma_{\text{WFCidiosyncratic}}{}^2\}} \\ &= \sqrt{\{215^2 + 122^2\}} \\ &= 247 \text{ bp per month.}\end{aligned}$$

[59] Estimation of idiosyncratic risk requires a history of prices for *individual* bonds that the Risk Model obtains from the extensive database of the Lehman Brothers Family of Indices.

We began this discussion by asking what are the total return risks of holding this WFC bond? Most investors would respond by saying that the biggest factors that will cause the returns on this bond to fluctuate would be changes in the 10-year UST yield, changes in spreads for the A–bank sector and any company event that is specific to WFC. Using the historical volatility of these risk factors, the correlations among these risk factors, and the sensitivity (*i.e.,* duration) of the bond to these risk factors, we were able to estimate the standard deviation of the WFC bond's monthly total returns to be 247 bp.[60]

This is exactly how a linear multi-factor risk model operates. A risk model specifies the appropriate risk factors, estimates the volatilities of the risk factors and their correlations, calculates each bond's sensitivity to those risk factors, and produces an estimate of the total return volatility for each bond. Generally, a risk model will identify more than just two risk factors. For example, the Lehman Risk Model will assume that the WFC bond is exposed to several points along the UST curve (not just the 10-year), depending on the key rate duration profile of the bond. In addition, the risk model will assume that the bond is exposed to a "convexity risk factor," a "liquidity risk factor," and to a corporate "spread slope risk factor." The example above was designed to be relatively simple to highlight the basic mechanics of a risk model.

b. Risk and Return of a Fixed Income Portfolio

The value of a risk model becomes even more apparent when there is more than one bond in an investor's portfolio. Recall that for the single WFC bond portfolio, the correlation between changes in the 10-year UST yield and changes in A–bank sector spreads was important for deriving the total systematic risk. For a single bond, many investors have a well-developed intuitive feeling for how the various risk factors are interrelated. However, when there is more than one bond in a portfolio, the number of relevant risk factors may increase, and the number of correlations that must be taken into account to derive total systematic risk increases, in turn, even more rapidly.

For example, suppose the investor holding the WFC bond decides to split his portfolio equally (in market value terms) into two positions, the WFC bond and the Verizon (VZ)-Global 4%s of 1/2008, an A-rated bond from the Communications sector. The bond has roughly 4 years remaining to maturity, and, as of this report, the bonds are trading at a 27 bp spread to an off-the-run 5-year Treasury for a yield-to-maturity of 2.98% and a dollar price of 103-21. While the investor has reduced his exposure to the 10-year UST yields and to A-bank spread sector, he has now added exposure to both the 4-year portion of the UST curve and to the A-communications spread sector. In addition, while the investor has reduced his portfolio's exposure to the idiosyncratic WFC risk, he has added exposure to VZ idiosyncratic risk. What is the effect on the total return risk of the investor's portfolio by adding the VZ position? Has it decreased, increased, or stayed the same? How can we quantify the diversification benefits of this trade? The answer will depend on the volatilities of the new risk factors, the level of exposure of the portfolio to the new risk factors, and the correlations among all the risk factors. This type of calculation is difficult for a portfolio manager to do without the aid of a risk model.

[60] According to the Lehman Brothers Risk Model, which takes into account several additional risk factors, the WFC bond has an expected monthly total return volatility of 254 bp.

Let's quickly estimate the risk for the VZ bond in isolation, then we'll see how adding it to the WFC holding affects the risk of the overall portfolio.

Using the same analysis as for the WFC bond in isolation, the investor would view the VZ bond having risk exposure to changes in the 5-year UST yield, changes in spreads for the A-communications sector and to idiosyncratic VZ risk. Assuming that the monthly standard deviation of changes in the 5-year[61] Treasury yield is approximately 30.4 bp and OAD_{VZ} equals 3.52, the interest rate risk of the VZ bond, in isolation, is roughly 107 bp per month (= 3.52 × 30.4 bp). Assuming the monthly standard deviation of changes in the A-communication sector is 9.6 bp and $OASD_{VZ}$ equals 3.57 the spread sector risk of the VZ bond, in isolation, is roughly 34 bp per month (= 3.57 × 9.6 bp).

Using historical data for 5-year Treasury yield changes and A-communication sector spread changes, we find that the correlation coefficient, $\rho_{\text{5-yearUSTyield,A-communication}}$ is -0.39. Consequently, the systematic risk of our position is

$$\sigma_{VZsystematic\_risk} = \sqrt{\{(107\text{ bp})^2 + (34\text{ bp})^2 + 2 \times (-0.39) \times 107\text{ bp} \times 34\text{ bp}\}}$$

$$= 99\text{ bp per month}$$

The idiosyncratic risk for the VZ bond is measured by multiplying the A-communication sector's monthly idiosyncratic spread volatility of 17.6 basis points (supplied by the Risk Model) by the VZ bond's 3.57 spread duration to produce a monthly idiosyncratic risk of 63 basis points.

So, the systematic risk of the VZ bond is 99 bp per month and the idiosyncratic risk is 63 bp per month. What is the total risk for a holder of the bond? Since the systematic and idiosyncratic risks, by assumption, are independent of each other, the total risk of the bond is as follows:

$$\sigma_{VZtotal\_risk} = \sqrt{\{\sigma_{VZsystematic}^2 + \sigma_{VZidiosyncratic}^2\}}$$

$$= \sqrt{\{99^2 + 63^2\}}$$

$$= 117\text{ bp per month.}$$

Using the historical volatility of these risk factors, the correlations among these risk factors, and the sensitivity (*i.e.,* duration) of the bond to these risk factors, we were able to estimate the standard deviation of the bond's monthly total returns to be 117 bp.[62]

---

[61] The VZ bond has direct exposure to 4-year UST yields. Here we are simplifying the presentation. In the Risk Model, VZ exposure to various points on the yield curve would be measured by VZ's key rate duration profile. See Chapter 4 for details.

[62] According to the Lehman Risk Model, which takes into account several additional risk factors, this VZ bond has an expected monthly total return volatility of 121 bp.

We have estimated the total risk for each of the two bonds in isolation. What is the risk of a portfolio that has equal market value holdings of the two bonds? Note that the portfolio has exposure to four systematic risk factors: 5-year UST yields, 10-year UST yields, A–bank sector spreads, and A-communication spreads. To calculate the portfolio's total systematic risk, not only do we need estimates for the volatilities for each of the four risk factors, but we need estimates for their six correlations. The calculation of the total systematic risk is very similar to what was done for each bond in isolation—just think of the portfolio as a single bond with exposure to the four risk factors. The exposure of the portfolio to each of the risk factors is measured by the market value of the bond in the portfolio with exposure to the relevant risk factor multiplied by the bond's own exposure (*e.g.,* OASD) to the risk factor. Because of the large number of risk volatilities and correlations, the systematic risk calculation becomes cumbersome and is most easily performed by a computer.[63]

Based on historical movements in the risk factors, the estimated 4X4 correlation matrix is shown in Figure A1.

This correlation matrix tells us a great deal about the possible diversification benefits of adding the VZ bond to the portfolio. Note that the 5-year and 10-year yield changes are, not surprisingly, highly correlated (almost equal to 1.0). Although the VZ bond has exposure to a different part of the UST curve than the WFC bond, since the two yields are so highly correlated, there is little diversification benefit.

In contrast, while the spread sectors are positively correlated (0.70), their correlation coefficient is not as close to 1.0. Consequently, adding the VZ bond to the portfolio originally containing only the WFC bond can help reduce, but only somewhat, the systematic risk arising from corporate sector exposures.

Finally, note that both sector spread risk factors have similar negative correlations with changes in UST yields. As a result, adding the VZ bond will not help reduce systematic risk by increasing the negative correlation between the corporate spread risk factors and the interest rate risk factors.

[63] The Global Risk Model has 281 risk factors. Imagine calculating the total systematic risk of a global portfolio without the use of a risk model.

Figure A1. **Correlations,** As of March 16, 2004

	A-Comm	A-Banking	5-Year UST Yield	10-Year UST Yield
A-Communication	1.00			
A-Banking	0.70	1.00		
5-Year UST Yield	-0.39	-0.42	1.00	
10-Year UST Yield	-0.32	-0.35	0.96	1.00

Since the two bonds are highly correlated in terms of their exposure to interest rate risk and have only somewhat lower correlation in terms of their exposure to sector spread risk, we would expect the portfolio's total systematic risk to be close to the weighted average of the two bonds' systematic risk (*i.e.,* 0.5×215 bp $+ 0.5 \times 99$ bp $= 157$ bp. Using a spreadsheet and some matrix manipulation, we estimate the total systematic risk of the WFC-VZ portfolio to be

$$\sigma_{\text{systematicWFC-VZ}} = 156 \text{ bp per month}$$

If new bonds have similar risk exposures to the risk factors already in the portfolio, then the portfolio's total systematic risk will change relatively little. If the added bonds introduce new systematic risk factors to the portfolio, then the portfolio's total systematic risk may change more substantially, but this will depend on the volatility and correlation of the new risk factor with the other risk factors. In general, however, if the added bonds have similar risk exposures to the risk factors already in the portfolio, or if any new risk factors are highly correlated with existing risk factors, then the total systematic risk of the portfolio will change only modestly as new bonds are added.

What is the idiosyncratic risk of the portfolio? To calculate the total idiosyncratic risk, we first modify equation (A3) to incorporate the fact that the bonds have market value weights within the portfolio (in this case the weights, $w_{WFC} = w_{VZ}$, are equal at 0.5). So, the idiosyncratic risk of the portfolio equals

$$\begin{aligned}\sigma_{\text{total\_idiosyncratic\_risk\_WFC-VZ}} \\ &= \sqrt{}\{(w_{WFC} \times \sigma_{WFCidio})^2 + (w_{VZ} \times \sigma_{VZidio})^2 \\ &\quad + 2 \times \rho_{WFCidio,VZidio} \times w_{WFC} \times \sigma_{WFCidio} \times w_{VZ} \times \sigma_{VZidio}\} \quad \text{(A4)}\end{aligned}$$

By assumption, WFC's idiosyncratic risk is independent of VZ's idiosyncratic risk, and both are independent of the systematic risk factors. In other words, $\rho_{WFCidio,VZidio} = 0$.

Consequently, using equation (A4) the idiosyncratic risk of the portfolio is simply the square root of weighted average of the squared idiosyncratic risks of each bond where the weights are the market values.

$$\begin{aligned}\sigma_{\text{idio\_WFC\_VZ}} &= \sqrt{}\{(0.5 \times \sigma_{WFCidio})^2 + (0.5 \times \sigma_{VZidio})^2\} \\ &= \sqrt{}\{(0.5 \times 122 \text{ bp})^2 + (0.5 \times 63 \text{ bp})^2\} \\ &= 69 \text{ bp per month}\end{aligned}$$

Notice that the idiosyncratic risk of the portfolio has fallen from 122 bp (the WFC bond alone), to 69 bp, after adding the VZ bond (which has idiosyncratic risk of 63 bp). In fact, as more and more bonds are added to the portfolio, the portfolio's idiosyncratic risk typically continues to decline.

So, the total systematic risk of the WFC-VZ portfolio is 156 bp per month, and its total idiosyncratic risk is 69 bp per month. What is the total risk for a holder of the portfolio? Since the systematic and idiosyncratic risks are independent of each other, the total risk of the portfolio is now:

$$\begin{aligned}\sigma_{\text{WFC-VZ(total\_risk)}} &= \sqrt{\{\sigma_{\text{systematic}}{}^2 + \sigma_{\text{idiosyncratic}}{}^2\}} \\ &= \sqrt{\{156\text{ bp}^2 + 69\text{ bp}^2\}} \\ &= 171\text{ bp per month.}^{64}\end{aligned}$$

As new bonds are added to the portfolio, the portfolio's total idiosyncratic risk typically declines. In contrast, as more bonds are added, the total systematic risk will change depending on the risk exposures of the bonds being added.

c. Risk and Return of One Portfolio versus Another

We have measured the absolute risk of a single bond and the risk of a two-bond portfolio. If cash were the benchmark for the investor, then these risk calculations would serve as measures of **"tracking error volatility"** (or, TEV)—the volatility of the portfolio's (or, single bond's) return versus the benchmark.

However, one of the most valuable uses of a risk model is to measure the relative risk of one portfolio versus another. Instead of measuring the total absolute return volatility of a portfolio, the risk model can be used to measure the total *relative* return volatility between one bond and another bond (or one portfolio versus another portfolio or benchmark). To keep the presentation simple, we assume the investor's portfolio includes just the VZ bond discussed above and the investor's benchmark is the single WFC bond.

To calculate a tracking error volatility, we proceed much as we did above to calculate the total risk of a portfolio. However, for the tracking error volitility calculation we use ***net*** (*i.e.*, portfolio minus benchmark) exposures to each risk factor. So, if a portfolio and its benchmark both have the same factor exposure to a particular risk factor, the net exposure to the risk factor is zero. In our simple example, however, the portfolio bond (VZ) and the benchmark bond (WFC) do not have exposures to common risk factors. So, there is no netting of risk exposures.

Consequently, the return difference between the portfolio and benchmark is:

$$\begin{aligned}\text{Return}_{\text{diff}} &= \text{Return}_{\text{VZ}} - \text{Return}_{\text{WFC}} \\ &= -\,(\text{OAD}_{\text{VZ}} \times \Delta\text{yield}_{\text{5-yearUST}}) \\ &\quad -\,(\text{OASD}_{\text{VZ}} \times \Delta\text{Sector\_spreads}_{\text{A,communications}}) \\ &\quad -\,(\text{OASD}_{\text{VZ}} \times \Delta\text{idioVZ\_spread})\end{aligned}$$

[64] According to the Lehman Risk Model, this WFC-VZ portfolio has an expected monthly total return volatility of 168 bp!

$$+ (OAD_{WFC} \times \Delta yield_{10\text{-}yearUST})$$

$$+ (OASD_{WFC} \times \Delta Sector\_spreads_{A,bank})$$

$$+ (OASD_{WFC} \times \Delta idioWFC\_spread)$$

The variance of $Return_{diff}$, which is TEV^2, is therefore:

$$\begin{aligned}
TEV^2 = \{ & OAD^2_{VZ} \times \sigma^2_{5\text{-}yearUSTyield} + OAD^2_{WFC} \times \sigma^2_{10\text{-}yearUSTyield} \\
& + OASD^2_{VZ} \times \sigma^2_{A,communications} + OASD^2_{WFC} \times \sigma^2_{A,bank} \\
& - OAD_{VZ} \times OAD_{WFC} \times 2 \times \rho_{5\text{-}yearUSTyield,10\text{-}yearUSTyield} \\
& \qquad \times \sigma_{5\text{-}yearUSTyield} \times \sigma_{10\text{-}yearUSTyield} \\
& + OAD_{VZ} \times OASD_{VZ} \times 2 \times \rho_{5\text{-}yearUSTyield,A,communications} \\
& \qquad \times \sigma_{5\text{-}yearUSTyield} \times \sigma_{A,communications} \\
& + OAD_{WFC} \times OASD_{WFC} \times 2 \times \rho_{10\text{-}yearUSTyield,A,bank} \\
& \qquad \times \sigma_{10\text{-}yearUSTyield} \times \sigma_{A,bank} \\
& - OASD_{VZ} \times OASD_{WFC} \times 2 \times \rho_{A,communications,A,bank} \\
& \qquad \times \sigma_{A,communications} \times \sigma_{A,bank} \\
& - OAD_{VZ} \times OASD_{WFC} \times 2 \times \rho_{5\text{-}yearUSTyield,A,bank} \\
& \qquad \times \sigma_{5\text{-}yearUSTyield} \times \sigma_{A,bank} \\
& - OASD_{VZ} \times OAD_{WFC} \times 2 \times \rho_{10\text{-}yearUSTyield,A,communications} \\
& \qquad \times \sigma_{10\text{-}yearUSTyield} \times \sigma_{A,communications} \} \\
& + \{OASD^2_{VZ} \times \sigma^2_{VZidio} + OASD^2_{WFC} \times \sigma^2_{WFCidio}\}
\end{aligned}$$

The first group of terms in brackets is the square of the systematic component of TEV while the last group in the second set of brackets is the square of the idiosyncratic TEV,

$$TEV^2 = \text{Systematic } TEV^2 + \text{Idiosyncratic } TEV^2$$

We have values for all of the variables, so all we need to do is plug in. Solving for SystematicTEV^2 and Idiosyncratic TEV^2 we have

$$\text{Systematic TEV}^2 = 24{,}366 \text{ bp}^2$$

$$\text{or, Systematic TEV} = 156.1 \text{ bp/month}$$

And,

$$\text{Idiosyncratic TEV}^2 = 18{,}784 \text{ bp}^2$$

$$\text{or, Idiosyncratic TEV} = 137.1 \text{ bp/month}$$

Note that the idiosyncratic risk contributes almost as much to total TEV as does the systematic risk exposures even though the portfolio has about a duration of 3.52 years, compared with its benchmark duration of 8.45 years. Since the portfolio contains only a single bond, as does the benchmark, and given that each bond is from a different issuer, idiosyncratic risk contributes a relatively large amount to TEV.

Solving for TEV we get

$$\begin{aligned} \text{TEV}^2 &= \text{Systematic TEV}^2 + \text{Idiosyncratic TEV}^2 \\ &= 24{,}366 \text{ bp}^2 + 18{,}784 \text{ bp}^2 \\ &= 43{,}150 \text{ bp}^2 \end{aligned}$$

So,

$$\text{TEV} = 208 \text{ bp/month}^{65}$$

[65] The Risk Model shows a TEV of 196 bp/month. The difference between our result and the Risk Model is due to the larger set of risk factors in the Risk Model.

APPENDIX B. BASIC RISK MODEL MATHEMATICS

Overview

The primary goal of the Risk Model is to project how well a portfolio is likely to track its benchmark over the coming month. To accomplish this goal, the model establishes a relationship between individual security returns and a set of risk factors that drive them. This relationship forms the bridge by which market experience in the form of past returns can be applied to characterize the expected distribution of future returns. In this appendix, the model is viewed as a probabilistic model for future returns. The difference between portfolio and benchmark returns over the coming period is represented by a random variable, and we characterize its distribution in terms of the distribution of the risk factors.

The basic assumption of the model is that the covariance matrix composed of volatilities and correlations of historical risk factor realizations is a reasonable characterization of the risk factor distribution for the coming period. The model extrapolates only these second-moment statistics. It does not attempt to project expected values of portfolio return or outperformance ("alpha") based on historical returns.

Modeling Returns

Let us assume that our investment universe consists of a finite set of N securities. The performance of the entire universe over the coming month can then be represented by an $N \times 1$ random vector r of (unknown) individual security total returns. The multi-factor model attempts to explain the return r_i on any bond i in terms of broader market movements. A set of M risk factors ($M<<N$) is chosen to represent the primary sources of risk (and return) to which a portfolio may be exposed. The extent to which bond i is exposed to a particular risk factor j is modeled by a fixed factor loading f_{ij}. The $1 \times M$ row vector f_i thus characterizes the exposure of security i to systematic risk.

The return of any bond i can be expressed in terms of the $M \times 1$ random factor vector **x** by

$$r_i = \sum_{j=i}^{M} f_{ij} x_j + \varepsilon_i = f_i x + \varepsilon_i \tag{B1}$$

where $f_i = \{f_{ij}\}$ is the known vector of factor loadings that characterizes bond i, and ε_i is the non-systematic random error. That is, ε_i is the portion of the return r_i that is not explained by the systematic risk model. This reflects the possibility of events specific to a given issue or issuer, such as a sudden demand for a particular Treasury security, or a takeover announcement by a particular corporate issuer.

If we let **F** be the $N \times M$ matrix containing one row for the factor loading vector of each of the N bonds in our universe and denote by ε the $N \times 1$ vector of non-systematic random errors, we can restate Equation B1 in matrix form,

$$r = Fx + \varepsilon. \tag{B2}$$

It then becomes clear that (to the extent that the non-systematic error vector is small, or $\varepsilon << r$) the factor vector $\mathbf{x}$ summarizes the holding period performance of our universe.

The distribution of possible returns on individual securities and portfolios can thus be expressed in terms of the distributions of values of the random factor vector $\mathbf{x}$ and the random error vector ε. Specifically, the systematic risk can be expressed in terms of the $M \times M$ covariance matrix $\Omega = \{\Omega_{jk}\}$, where $\Omega_{jk} = COV(x_j, x_k)$. (On the diagonal, $\Omega_{jj} = VAR[x_j]$.)

Application to Portfolio Management

We can represent a given portfolio p by a $1 \times N$ allocation vector q_p, which states the proportion of the market value of the portfolio allocated to each of the N securities in our universe. The portfolio return r_p is then given by

$$\begin{aligned} r_p &= q_p r \\ &= q_p F x + q_p \varepsilon \\ &= f_p x + q_p \varepsilon \end{aligned} \tag{B3}$$

where $f_p = q_p F$ is the factor loading vector that summarizes the systematic risk exposure of a portfolio as a weighted sum of the exposures of its constituent securities.

Of primary importance in assessing portfolio risk are the second-moment statistics, the return volatilities. The variances σ_p^2 and σ_b^2 of the portfolio and benchmark returns r_p and r_b may be expressed as

$$\begin{aligned} \sigma_p^2 &= VAR(r_p) = f_p \Omega f_p^T + q_p \Gamma q_p^T \\ \sigma_b^2 &= VAR(r_b) = f_b \Omega f_b^T + q_b \Gamma q_b^T \end{aligned} \tag{B4}$$

where the covariance matrix Ω isthe $M \times M$ matrix described above, which contains the covariances of the systematic risk factors, and Γ is a sparse $N \times N$ matrix, which contains the covariances of the security-specific residual risk terms, Γ_{ij} = COV $(\varepsilon_i, \varepsilon_j)$. The portfolio variance can be seen to be composed of one term due to systematic risk and another due to security-specific risk. There are no cross terms, due to our assumptions that the error vector ε and the systematic factor vector x are uncorrelated ($E[\varepsilon_i x_j] = 0$ for all i, j), and that the errors have mean zero ($E[\varepsilon_i] = 0$ for all i).

In the context of portfolio/benchmark comparison, we report the return volatilities σ_p and σ_b of the portfolio and benchmark, respectively, as given by Equation B4. In addition, we report the tracking error σ_{TE} and the β given by

$$\sigma_{TE}^2 = VAR(r_p - r_b) = (f_p - f_b)\Omega(f_p - f_b)^T + (q_p - q_b)\Gamma(q_p - q_b)^T \tag{B5}$$

$$\beta = \frac{COV(r_p, r_b)}{VAR(r_b)} = \frac{1}{\sigma_b^2}\left(f_p \Omega f_b^T + q_p \Gamma q_b^T\right)$$

The tracking error measures the dispersion between portfolio and benchmark returns. The β measures the sensitivity of the portfolio return to changes in the benchmark return. From the definition of tracking error, it is obvious that the smaller the value of σ_{TE}, the closer the portfolio tracks the benchmark. If the portfolio and the benchmark are identically composed ($q_p = q_b$), then r_p will be identical to r_b under all random outcomes, and we will have $\sigma_{TE} = 0$ and $\beta = 1$. This is the only way that a zero tracking error may be achieved; other portfolios, however, might achieve $\beta = 1$.

The β is closely related to both the tracking error σ_{TE} and the correlation coefficient ρ between portfolio and benchmark returns. These relationships may be expressed as

$$\rho = \frac{COV(r_p, r_b)}{\sigma_p \sigma_b} = \frac{\sigma_b}{\sigma_p}\beta \tag{B6}$$

$$\sigma_{TE}^2 = \sigma_p^2 + \sigma_b^2 - 2\rho\sigma_p\sigma_b = \sigma_p^2 + \sigma_b^2 - 2\beta\sigma_b^2$$

Thus, when $\beta = 1$, the variance of outperformance (σ_{TE}^2) reduces to a difference between the variances of the returns of the portfolio and the benchmark; in the other extreme, when $\beta = 0$, the tracking error becomes the sum of these variances. The correlation coefficient measures the extent to which portfolio and benchmark returns move in the same direction. It may take values from –1 to 1, and is unaffected by the relative magnitudes of the portfolio and benchmark risk. While the Risk Model does not report this quantity, it may be easily calculated from the reported β using Equation B6.

APPENDIX C. RISK MODEL TERMINOLOGY

This document presents the general terminology used in the Lehman Brothers Global Risk Model Report.

General Terminology

Risk Model: Tool designed to help investors quantify their portfolio's risk and to determine the sources of risk. The risk is defined as the expected volatility of portfolio returns (usually relative to a Benchmark).

Benchmark: Portfolio (or Index) against which the portfolio's performance is measured.

Risk Factor: A market change that affects returns of all securities in a certain market segment (e.g., changes in interest rates, changes in sector spreads, changes in volatility of interest rates, etc.) In the Lehman Global Risk Model, some risk factors, such as the 10-year Treasury par rate, are directly observed in the financial markets. Others, such as the sector spread of Financial AA or better rated bonds, are not measured directly but are estimated using cross-sectional regression.

Tracking Error (TE): The difference between portfolio and benchmark returns.

Tracking Error Variance (TE Variance): The projected monthly variance of the difference between portfolio and benchmark returns. It is estimated from historical return data and from portfolio and benchmark characteristics. It can be decomposed into three sources: Systematic, Idiosyncratic and Default.

Tracking Error Volatility (TEV): Monthly standard deviation of the difference between portfolio and benchmark returns. It is the square root of the TE Variance.

Systematic (Market) Risk: Risk due to the effect of all systematic factors of the Lehman Brothers Risk Model. Systematic risk can be measured at the security or portfolio level.

Idiosyncratic (Non-Systematic) Risk: Risk not explained by the combination of all systematic risk or default factors. Represents risk due to non-default events that affect only the individual issuer or bond. Idiosyncratic risk can be diversified by increasing the number of bonds and issuers in the portfolio.

Default Risk (only bonds rated Baa and lower): Risk due to an obligor's failure to meet its contractual obligation. This risk can be reduced by diversification, but cannot be eliminated entirely due to default correlations. We only model default risk for issues rated Baa and below.

Report I: User-Defined Parameters

The model can be customized to fit investor preferences via the following parameters:

Base Currency: Reference currency for all statistics calculations. Returns on bonds denominated on other currencies will be converted into the Base Currency for aggregation purposes.

Time-Weighting: Controls the calibration of the model to historical data. It can be specified separately for the three different components of the model: Systematic, Idiosyncratic and Default. The two choices in each case are:

"No": The statistics (variances, correlations and default rates) are calculated from historical data using an equally-weighted methodology. This means that the same weight is given to all historical observations.

"Yes": The statistics are calculated using a time-weighted (exponential) methodology (1 year half-life). This means that recent observations are assigned a greater weight in the calculation of the different statistics. In particular, every observation has about 6% more weight than the one from the preceding month.

(Implicit) Currency Hedging:

"No implicit currency hedging": It is assumed that all currency hedging is explicitly captured in transactions in the portfolio, for example using FX forwards or by explicit infusion of cash in various currencies. In this mode, the model's risk estimates will include a currency component, to reflect the risk due to both imperfect hedging and intentional currency positions.

"Both benchmark and portfolio are implicitly hedged": If the user hedges currency risk separately, and these hedges are not a part of the portfolio, he or she might be interested in the risk of the portfolio from all sources other than currency. This choice offers the convenience of implicitly assuming that currency risk has been hedged out, and removes all currency exposure from the risk calculation.

"Benchmark is implicitly hedged but not portfolio": Combines the two alternatives above. All currency risk comes from portfolio exposures.

Report II: Portfolio/Benchmark Comparison

This report presents the major statistics of the portfolio and the benchmark, as well as the portfolio's TEV and Beta. Most of these statistics are market value weighted averages for the portfolio and for the benchmark.

Market Value: The sum of the market capitalization (in the base currency) over all instruments in the portfolio (or benchmark), in the appropriate currency units

Coupon: Market-value weighted average coupon rate for a portfolio (or a benchmark), in percentage points.

Average Life: A measure of how long it takes, on average, for the security to repay its principal. It is calculated as the par-weighted average time (in years) to principal repayment, in years.

Yield to Worst: The yield computed assuming the worst scenario for the investor: the lowest of the yield to maturity or yield to call for every possible call date, in percentage points.

ISMA Yield: The standard Yield to Maturity, calculated as recommended by the International Security Market Association (ISMA), in percentage points.

OAS: "Option-adjusted spread" is the incremental spread above the benchmark spot rates after accounting for embedded options, in basis points.

OAD: "Option-adjusted duration" is the modified duration of a security, in years, calculated using a model that accounts for embedded options. It indicates how changes in the benchmark curve affect the price of the security.

ISMA Duration: Standard modified duration using the ISMA date conventions, in years.

Duration to Maturity: Standard modified duration. Change in the value of a security in response to a change in yield, assuming that bond will not be called, in years.

OA Spread Duration: "Option-adjusted spread duration" is the modified spread duration of a security, in years, calculated using a model that accounts for embedded options. It indicates how changes in option-adjusted spread (OAS) affect the price—the benchmark curve is held constant while the OAS changes.

Vega: A measure of the sensitivity of the price of an option (or a bond with embedded options) to a change in implied yield volatility, in the same unit as market value (e.g. thousands of dollars).

OA Convexity: A measure of the curvature of the price-yield relationship of a fixed-income security, calculated using a model that accounts for embedded options. It is used to estimate the second order effect of changes in the reference interest rate curve on the price of the security.

Total TE Volatility: See TEV above. For example, a TEV of 30bp indicates that the portfolio returns may deviate from the benchmark returns with a standard deviation of 30 bp per month. In basis points per month.

Systematic Volatility: The portion of the TEV that is attributable to the systematic factors, in basis points per month.

Default Volatility: The portion of TEV explained by the default risk of the portfolio. It will be zero for portfolios not holding securities rated Baa and below. The Risk Model assumes the correlation between default risk and the systemtic risk factors is zero. In practice this correlation is very close to zero. In basis points per month.

Non-Systematic Volatility: The portion of TEV attributable to the idiosyncratic risk. It is independent of the other sources of TEV. In basis points per month.

Total Volatility: The expected total volatility of the portfolio (and benchmark) return. This is a measure of the total risk of the portfolio (compared to TEV, which measures the risk of the portfolio relative to the benchmark). In basis points per month.

Portfolio Beta (β): The sensitivity of the portfolio's return to benchmark return. If beta is 0.9, then the model projects that if the return for the benchmark over a given period is 100 bp, the return for the portfolio will be 90 bp.

Report III: Tracking Error Report

This report details the contributions of the different sources of risk to total TEV.

Isolated TEV: Monthly tracking error volatility due to a single group of risk factors in isolation; no other forms of risk are considered. It is independent of the order of presentation. The tracking error that the portfolio would have if net exposure to the other factors were zero. In basis points per month.

Cumulative TEV: Monthly tracking error volatility due to cumulative effect of several groups of risk factors. Used sequentially to calculate the incremental impact on tracking error volatility as a result of incorporating an additional risk factor to a set of risk factors already considered. It is therefore dependent on the sequence in which risk factors are accounted for. The addition of a risk factor could cause the cumulative tracking error volatility to drop should this risk factor have a low enough correlation with previous factors. In basis points per month.

Difference in Cumulative: The incremental value of the cumulative TEV, in basis points. Note: the value for the Investment-Grade Spreads is the sum over the subsequent subcategories.

Percentage of Tracking Error Variance: Contribution, in percentage terms, of each set of factors to the variance of the portfolio return over the benchmark (the square of the TEV). This includes the effect of the variance of that factor as well as the covariance with each of the other factors.[66] In percent.

Systematic Beta: This beta is constructed in a slightly different way than the one from the previous report. It measures the sensitivity of the portfolio's systematic return to changes in the benchmark's systematic return, when only the specific subset of systematic risk factors under analysis is considered.

Report IV: Factor Exposure—Full Details

This report details the portfolio's exposure to the different risk factors. See Risk Factor Description in Appendix D for a more detailed explanation.

Sensitivity (Factor Loading): Sensitivity of a given security (or portfolio) to a particular risk factor (e.g. key rate duration, option adjusted convexity, option adjusted spread duration or vega). It also describes the units in which the loadings (sensitivities) are expressed and any normalization performed.

Note: By default, the sensitivities are presented in units (e.g. durations are in years). However, there are some exceptions, both due to the nature of the factors or for a better interpretation of some of the statistics (e.g. "Marginal Contribution to the TEV"). For more details regarding each factor see "Factor Volatility" below and the Risk Factor Descriptions in Appendix D.

---

[66] The distribution is made accordingly to the following reasoning. Suppose we only have two factors, F1 and F2. Then the total variance from these factors is VAR(F1+F2)=VAR(F1) + VAR(F2) + 2 COVAR(F1,F2). The percentage of tracking error variance from factor 1 (%F1)is defined as:

%F1=[VAR(F1)+COVAR(F1,F2)]/VAR(F1+F2)

Exposure: Market-value-weighted factor loading for a portfolio, benchmark, or the difference between a portfolio and a benchmark with respect to a given risk factor. The exposure determines the portfolio's return sensitivity to changes in the risk factors. The units are given by the "Sensitivity" column.

Factor Volatility: Monthly standard deviation of a particular risk factor, estimated from historical data.

*Note: By default, the units for the factor volatility are presented in basis points. However, there are exceptions: the units for factor volatility are adjusted to keep factor volatility times exposure (e.g. as presented in the "TE impact columns") in basis points. Example: the currency exposures are multiplied by 100 (they are presented in percentage points—e.g. 34(%) - instead of the default units - 0.34). Therefore, the factor volatility is displayed divided by 100 (is presented in percentage points instead of basis points—e.g. 1 instead of 100). Without the normalization, the product of loading times volatility is 0.34x100=34 basis points. With the normalization we also have 34%*1%=34 basis points. For more details see Risk Factor Descriptions in Appendix D.*

TE Impact of an isolated 1 std. dev. Up change: The negative product of exposure (the difference between the benchmark and the portfolio) and factor volatility for a given risk factor. It indicates the return difference between the portfolio and the benchmark given a one standard deviation increase for the given risk factor, assuming all other risk factors do not change. In basis points.

Note: The relationship between factor and return movements is usually negative: e.g., if net exposure to key rates is positive, we expect a negative impact on returns from an increase in the key rates. The three exceptions are the currency, convexity and high-yield distressed factors. These three groups of factors have a positive relation with returns: e.g. if the portfolio has a positive net exposure to EUR, then we expect positive returns from its appreciation.

TE Impact of a Correlated 1 std. dev. Up change: The return difference between the portfolio and the benchmark given one standard deviation increase for the given risk factor, assuming all other risk factors change according to the correlations implied by the covariance matrix. In basis points. See "TE Impact of an isolated 1 std. dev. Up change" for further details.

Marginal Contribution to TEV: The effect on TEV of an increase in the exposure to a particular factor. In basis points per month. This number should be read with the exposure units of the respective factor in mind. Suppose this field is 2.4 for the EUR currency. Recall that the currency factors are expressed in percentage points. Therefore, if we increase the exposure to EUR by 1 percentage point, the TEV will increase by 2.4 basis points. [This example shows also why normalizing the sensitivities is useful - without it, the previous example would read: TEV would increase by 240 basis points when exposure to the EUR increases by 100 percentage points - clearly a less intuitive reading]. This column may be read across lines: e.g. if the value for 5-year key rate (KR) duration is 3 and for the 6-month duration is 0.5, then reducing the exposure to the 5-year KR by 1 year while increase the exposure to the 6-month KR by also one year decreases the TEV by approximately 2.5 basis points (0.5-3.0=-2.5).

Report V: Portfolio Issue-Specific Risk

This report details contributions for the TEV per security. The report lists the top 100 issues in terms of market value.

Market Value Issue Weight: The percentage market value weight of the issue in the portfolio.

Market Value Issue Net Weight: The difference between the percentage market value weight of the issue in the portfolio and in the benchmark.

Market Value Issuer Net Weight: The difference between the percentage market value weight of all issues from the specific issuer in the portfolio and in the benchmark.

Marginal Systematic TEV: The effect on systematic TEV of an increase in the weight of a particular security. A value of 3.4 means that if the MV weight for this issue increases by 1 percentage point (against cash), the systematic TEV increases by 3.4 basis points. This column should be read across lines: e.g. if the value for bond A is 3.4 and for bond B is 1.4, then selling bond A against bond B does decrease the systematic TEV by approximately 2.0 basis points (1.4-3.4=-2.0).

Systematic TEV (Isolated): The systematic TEV of the portfolio if the net position in all other issues is set to zero, in basis points.

Idiosyncratic TEV (Isolated): The contribution of this issue to the idiosyncratic TEV, ignoring the correlations with the idiosyncratic error of issues from the same issuer. In basis points.

Issuer Idiosyncratic TEV: The contribution of the issuer to the portfolio idiosyncratic TEV. Because idiosyncratic errors are uncorrelated across issuers, the sum of squares of all issuer's idiosyncratic TEV equals the portfolio idiosyncratic variance. In basis points.

Report VI: Credit Tickers

This report details the portfolio's composition by credit ticker/issuer.

Net Contribution to OASD: Difference between portfolio and benchmark contributions to spread duration in each concentration source (spread duration times percentage of market value). This is the key risk exposure in the calculation of non-systematic TEV.

Report VII: Warnings and Exclusions

This report lists the specific instruments that were not incorporated into the risk analysis and lists the reason for their exclusion (e.g., the calculated OAS is invalid).

APPENDIX D. RISK MODEL FACTOR DESCRIPTIONS

In this section, we detail the meaning of each of the risk factors, describing their units and provide examples of their interpretation.

The numbers referred to below are given for explanatory purposes only. For simplicity, we interpret them as if the benchmark chosen is cash, meaning that the net loadings are also the portfolio exposures.

The factors and variables in this description are found in the "Factor Exposure - Full Details" report. In particular the columns "Portfolio Exposure," "Benchmark Exposure" and "Net Exposure" are in the same units as "sensitivity/exposure" below. "Factor Volatility" is in the same units as "Factor Value" below.

The definition of these units are such that the product of exposures and factor volatilities is interpreted as returns in basis points (e.g. the "TE impact" columns have precisely this interpretation: a value of 3.5 means that returns are expected to increase by 3.5 basis points). Figure D1 presents a summary of the units used.

Notes

1. In what follows, we present factor blocks for a particular currency. The corresponding factor blocks for other currencies have similar interpretations and are presented in the same units.

2. Factor and factor volatilities have the same units.

3. See the referenced Risk Model papers for further details.

Figure D1. **Summary of Units**

Factor	**Exposure Units**	**Factor Volatility Units**	**Exposure x Factor**
All Factors, Except:	Units	Basis Points (bp)	Basis Points (bp)
Convexity	Units/100	Basis Points*100 (100th bp)	Basis Points (bp)
Liquidity	Percentage Points (pp)	Percentage Points (pp)	Basis Points (bp)
All Market Weighted Loaded Factors (e.g., Currency)	Percentage Points (pp)	Percentage Points (pp)	Basis Points (bp)

BLOCK 1: Currency

These factors measure the exposure of the portfolio to the different currencies and therefore to the different exchange rate risks (should the portfolio have holdings other than in the base currency). Currency exposures of both portfolio and benchmark are assumed to be 100% in the base currency if the "Both benchmark and portfolio are implicitly hedged" option is selected.

Example: EUR Currency		**Units**	**Value**
Factor captures:	Percentage change in the EUR/(Base Currency) exchange rate	pps	2.92
Loading is:	% of portfolio's Market Value [MV(%)]	pps	31.650

Interpretation: The portfolio has 31.65% of its market value in EUR, including cash, securities, and hedge transactions. The typical monthly change in the EUR/USD exchange rate is 2.92%. Therefore, if the EUR appreciates by 2.92%, we expect returns to go up by 2.92% x 31.65% = 92.56 bps.

BLOCK 2: Key Rates and Convexity

This block measures the exposure of the portfolio to shifts in the treasury yield curve for the different currencies. For each currency, this exposure is measured by two types of factors: those related to durations for the different points on the yield curve and one related to the portfolio's convexity.

Example 1: EUR 6M key rate		**Units**	**Value**
Factor captures:	Change in the 6M Treasury par yield	bps	24.37
Loading is:	Duration, in years, to the 6M Treasury par yield key rate [KRD (Yr)]	Unit	0.073

Interpretation: The portfolio's duration to the EUR 6-month key rate is 0.073 years. The typical change in the EUR 6-month key rate is 24.37 bps. Therefore, if this key rate goes up by 24.37 bps, we expect returns to change by -0.073 x 24.37bps = -1.78 bps.

Example 2: EUR Convexity		**Units**	**Value**
Factor captures:	Squared average change of the 6 key rates (x0.5)	bps*100	3.96
Loading is:	Normalized portfolio's convexity [OAC (Yr^2/100)]	Unit/100	-0.161

Interpretation: The (normalized) portfolio's convexity is -0.161. Half of the typical squared average change in the six key rates considered is 0.0396 percentage points (e.g., the typical average change is .2814 percentage points). Therefore, in a typical month, we expect the change in return due to convexity to be 3.96 bps x (-0.161) = -0.64 bps.

BLOCK 3: Swap Spreads

Similar to the previous block, this one measures the exposure of the portfolio to shifts in swap spreads for the different currencies. However, this time the exposure is measured only by one type of factor: the swap spread durations for the points along the swap spread curve. Swap spreads are attributed to the different points along the curve based on the distribution of key rate durations.

Example: JPY 6M swap spread		**Units**	**Value**
Factor captures:	Change in the 6M JPY swap spread	bps	12.08
Loading is:	Duration, in years, to the 6M swap spread [SSKRD (Yr)]	Unit	0.097

Interpretation: The portfolio's duration to the JPY 6 months swap spread is 0.097 years. The typical change in this swap spread is 12.08 bps. Therefore, if this swap spread goes up by 12.08 bps, we expect returns to change by -0.097x12.08 bps = -1.17 bps.

BLOCK 4: Volatility (non-USD)

This block captures the exposure of the portfolio to shifts in the volatility of non-USD bonds (USD-denominated bonds' volatility have a separate treatment - see details in what follows). The risk model has two independent non-USD volatilities, one for EUR and the other for GBP. Their factor realization is proxied by swaption volatilities and their sensitivities by the volatility durations. Therefore, EUR or GBP denominated bonds with embedded options will load on this factor.

BLOCK 5: Treasury Spread and Volatility

This block is the first of the asset-class-specific blocks. Its goal is to measure the exposure of the portfolio to shifts in spreads over the yield curve (usually this asset class does not load on the swap spreads block). As with the other asset classes, we capture the sensitivity of returns to changes in spreads with four different types of factors. The first factor captures the return due to changes in volatility. The second looks at the return due to the average change in spread of the overall treasury class. The third captures the potential shift in the slope of the spread curve—e.g. if spreads widen more for longer maturities. Finally, some bonds trade systematically with spreads different than their peers. The level of this systematic difference shifts constantly. The return due to this shift is captured by the fourth factor.

In particular, the asset class specific return due to changes in spreads is modeled as:

$$R\_spread = -OASD * (Change\_OAS) = -OASD * (F_{SPREAD,i} + \beta_s F_{SLOPE} + \beta_O F_{OAS})$$

where i indicates that we may want to calculate F_{SPREAD} —the average change in spread—for different subgroups (e.g. different industries in the corporate block).

Example 1: USD Treasury Volatility		**Units**	**Value**
Factor captures:	Change in US TSY Volatility	bps	94
Loading is:	Volatility Duration of the portfolio [Volatility Duration]	Unit	0.000001

Interpretation: The volatility duration gives you how much the market value of the portfolio changes if volatilities change by 1 percentage point.In our case, the duration = 0.01 bps. The typical change in the treasury's volatility is 94 bps. Therefore, if volatility does increase by 94 bps, we expect returns to change by -0.000001x94bps = -0.000094 bps.

Example 2: USD Treasury Spread		**Units**	**Value**
Factor captures:	Average OAS change for all Treasury Spreads	bps	1.44
Loading is:	The OASD from the portfolio [OASD(Yr)]	Unit	0.532

Interpretation: The portfolio's return sensitivity to the change in the treasury's spreads (over the fitted Treasury spline curve) is 0.532 years. The typical change in treasury spreads is 1.44 bps. Therefore, if spreads increase by 1.44 bps, we expect returns to change by -0.532x1.44bps = -0.77 bps.

Example 3: USD TSY Spread Slope		**Units**	**Value**
Factor captures:	Change in the slope of the Treasury's spread	bps	0.0428
Loading is:	OASD* β_{SLOPE} =OASD*(TTM-MedianTTM) [(Yr^2)]	Unit	3.4

Interpretation: The loading units should be interpreted as follows: this factor captures the extra change in OAS - above that accounted for by the previous factor - that comes from a twist in the spread curve. We then multiply this extra change by the OASD to go from changes in OAS to returns. Suppose the OASD of the portfolio is 3.4 years. [Therefore, (TTM-MedianTTM)=1. This means that our portfolio is relatively long in maturity. If the spread curve flattens, our portfolio benefits, and would benefit more if the mismatch in maturity were larger.] Therefore, if the slope decreases by 0.0428 bps, we expect returns to change by -3.4x-0.0428bps = 0.15 bps.

Example 4: USD Treasury Liquidity		**Units**	**Value**
Factor captures:	Change of TSY "Liquidity premium" (or OAS difference)	pps	14.32
Loading is:	OASD* β_{SLOPE} =OASD* (OAS-MedianOAS) [(Yr*pps)]	pps	-0.007

Interpretation: Again, we begin by interpreting the loading: it captures the extra return that comes from the fact that systematic differences in OAS among similar bonds change. Suppose the OASD of the portfolio is 1 year, but our portfolio has spreads that are on average smaller than the typical treasury portfolio (e.g. the median OAS is 5bps, while our portfolio's average is only 4.3 bps). In effect we are paying a liquidity premium to hold this portfolio. If this premium decreases (i.e., a negative factor realization), our portfolio will register an extra positive return. Suppose the "liquidity premium" increases by 14.32%: we expect returns to change by -0.007%x14.32% = -0.10 bps.

BLOCK 6: Agency Spread and Volatility

This block uses the same kind of factors described in the previous block. There are two differences only: the first one is that spreads are defined against the swap curve. The second is that we have several factors to capture the average change in spreads. Each will capture this average for a particular sub-group. Specifically we use five subgroups for the agency block (see details on the Lehman Brothers Agency Risk Model Research Paper available through POINT).The loadings and factors from this block have similar interpretations as those from the Treasury block. Therefore, we do not extend the analysis here.

BLOCK 7: Credit IG Spread & Volatility

This block uses the same kind of factors described in block 5. Note that as in block 6, spreads are defined against the swap curve. Moreover, several factors are used to capture average change in spreads across different industries. In addition, an extra series of factors that are used to capture additional changes in the OAS for bonds with different qualities issued by non-local firms (for non-US we have three such factors, while only one for the EUR and GBP credit blocks). In particular, these factors loadings and definitions are similar to the other corporate spread factors (see details on the Lehman Brothers Credit Risk Model Research Paper available through POINT).

Example: GBP US issuers		**Units**
Factor captures:	Changes in average spreads for US-issuers	pps
Loading is:	OASD (Yr)	pps

Interpretation: See "USD Treasury Spread" example.

BLOCK 8: Credit HY Spread & Volatility

This block uses the same kind of factors described in the previous block. The differences arise from the fact that bonds are divided into distressed and non-distressed. The model for the non-distressed follows closely the IG model. However, the return from spreads for the distressed bonds is modeled directly:

$$R\_spread\_distressed = F_{RETURNi} + \beta_S F_{SLOPE} + \beta_p F_{PRICE} + \beta_L F_{LEVERAGE} + \beta_{SUB} F_{SUBORDINATED}$$

The liquidity factor is replaced by the price factor. The distress return is explained by two extra factors: one that controls for leverage and the other for the collateral-type underlying the security - see example below. More details are available on the Lehman Brothers High Yield Credit Risk Model Research Paper available through POINT.

Example: Distressed Subordinated		**Units**
Factor captures:	Average extra Return from High Yield Subordinated issues	pps
Loading is:	Unit (*100)	pps

Interpretation: Additional average return for subordinated bonds.

BLOCK 9: MBS Spread & Volatility

This block uses the same kind of factors described in block 7. However, MBS risk is modeled taking into account two volatilities - short and long term. Moreover, the average change in spreads is calculated for several (non disjoint subgroups) based on type, term, government agency, age and price (see details on the Lehman Brothers MBS Risk Model Research Paper available through POINT).

BLOCK 10: CMBS Spread & Volatility

This block closely follows the previous one, with the following differences: The slope factor is based on Average Life - not maturity- and the model uses also three other factors:

Example 1: USD CMBS Principal Payment Window		**Units**
Factor captures:	Additional average spread change for issues at or near principal payment	bps
Loading is:	OASD*WINDOW (Yr^2)	Unit

Interpretation: Extra return for issues at or near principal payment. These bonds are more sensitive to prepayment risk.

Example 2: USD CMBS Age		**Units**
Factor captures:	Additional spread changes for issues with different WALAs.	bps
Loading is:	OASD*(AGE-MedianAGE) (Yr^2/100)	Unit

Interpretation: Extra change in OAS per extra year of WALA of the portfolio. "Older" bonds have different prepayment and default probabilities than “younger” bonds.

Example 3: USD CMBS Price Current Pay AAA		**Units**
Factor captures:	Additional (normalized) spread change for issues at premium/discount	bps
Loading is:	OASD*(Price-MedianPrice) (Yr*$)	Unit

Interpretation: Interpretation: Extra change in OAS per extra dollar of average price. Proxies for sensitivity to prepayment risk: premium bonds are more sensitive to prepayments.

BLOCK 11: ABS Spread & Volatility

This block closely follows the previous one. Here, however, we apply an extra factor to capture the extra change in OAS for a non-AAA rated bond. The treatment of this factor is the same as any of the spread factors above.

Example: USD ABS non-AAA		**Units**
Factor captures:	Additional spread change for non-AAA issues.	bps
Loading is:	OASD*Indicator (Yr)	Unit

Interpretation: Extra average change in OAS for non-AAA issues.

The views expressed in this report accurately reflect the personal views of Albert Desclée, Lev Dynkin, Tony Gould, Jay Hyman, Dev Joneja, Dick Kazarian, Vasant Naik, Marco Naldi, Bruce Phelps, Jeremy Rosten, Antonio Silva, and Gary Wang, the primary analyst(s) responsible for this report, about the subject securities or issuers referred to herein, and no part of such analyst(s)' compensation was, is or will be directly or indirectly related to the specific recommendations or views expressed herein.

Any reports referenced herein published after 14 April 2003 have been certified in accordance with Regulation AC. To obtain copies of these reports and their certifications, please contact Larry Pindyck (lpindyck@lehman.com; 212-526-6268) or Valerie Monchi (vmonchi@lehman.com; 44-(0)207-102-8035).

Lehman Brothers Inc. and any affiliate may have a position in the instruments or the companies discussed in this report. The firm's interests may conflict with the interests of an investor in those instruments.

The research analysts responsible for preparing this report receive compensation based upon various factors, including, among other things, the quality of their work, firm revenues, including trading, competitive factors and client feedback.

Lehman Brothers usually makes a market in the securities mentioned in this report. These companies are current investment banking clients of Lehman Brothers or companies for which Lehman Brothers would like to perform investment banking services.

Publications-L. Pindyck, B. Davenport, W. Lee, D. Kramer, R. Madison, A. Acevedo, T. Wan, M. Graham, V. Monchi, K. Banham, G. Garnham, Z. Talbot