

Replicating Bond Indices With Liquid Derivatives

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Benchmarks are used by investors to communicate to managers the desired portfolio risk characteristics and to measure performance. The widespread acceptance of Modern Portfolio Theory increased the desire for broad-based passive strategies to capture the “market portfolio,” which in turn created demand for indexation strategies.¹ While some investors complain about the “tyranny of the benchmark,” many others recognize the advantages of portfolios constructed to perform closely in line with benchmarks. Such portfolios offer diversification and low issuer-specific risk, consistency of returns versus the benchmark, and so allow investors to focus on asset allocation. However, much of the recent interest in tracking benchmark returns has been in *replication* rather than in *passive indexation*.

These terms merit clarification. Passive management strives to minimize tracking error (expected return deviation) against the benchmark, with a portfolio of hundreds or, if size permits, even thousands of securities. Over a long period of time, the benefits of low tracking error versus the benchmark will outweigh the costs of assembling a portfolio of many cash bonds. By contrast, index replication does not seek to match the performance of a given index exactly, but rather to generate returns close to those of the index while focusing on minimal trading costs and using instruments with a high degree of liquidity.

Ironically, the recent substantial increase in demand for replication strategies has come largely from investors more interested in risk

taking than in risk reduction. As yields have fallen in fixed-income markets, and equity returns have moderated following the outsize gains of the 1990s, the search for alpha has become ever more critical. In particular, pension funds have become more interested in strategies that allow them to achieve twin objectives: increase fixed-income exposure (to better match pension liabilities) and generate returns in excess of the growth rate of liabilities. A portable alpha strategy, which involves the combination of alpha with a market exposure, or beta, independent from the alpha strategy, achieves both objectives. For example, many pension funds benchmarked to the Lehman Brothers aggregate Index look at portable alpha strategies (combining an alpha source with the aggregate beta) as a way of adding high excess returns to their fixed-income allocation.

A recent popular application of portable alpha has been in the realm of hedge funds and fund-of-funds which often aim at minimizing market exposure. If they succeed, their returns can be defined and marketed as “pure alpha.” By transporting this alpha to a fixed-income target index, an investor can achieve fixed-income returns plus hedge fund alpha. For some investors, this can be an attractive strategy when compared with the alternative of hiring an active fixed-income manager.

In most portable alpha strategies, the desired market exposure is achieved using derivatives replication, freeing the cash for the alpha strategy. For example, if a \$100 million allocation is made to a hedge fund portable

alpha strategy, \$100 million will be invested into the hedge fund, and a derivatives portfolio will be created to generate \$100 million exposure to a desired fixed-income index. Tracking errors for derivatives replication strategies are typically higher than for cash replication strategies. Nevertheless, they are sufficiently low compared with the alphas and volatilities of hedge funds.

In this article, we consider various approaches to generating fixed-income market exposure using, as an example, strategies to replicate the Lehman Brothers Global Aggregate Bond Index ("Global Aggregate") as well as its largest regional components (U.S. Aggregate and dollar bloc, Euro and Pan-European Aggregate, and Asia-Pacific Aggregate). The Global Aggregate is the most widely used index for benchmarking global bond portfolios. Part of the reason for its widespread use is that it fairly represents the broad investable universe of investment-grade fixed-income securities, including government bonds, credit instruments, and securitized assets. The breadth of the index, comprising more than 10,000 securities denominated in 24 different currencies, can make it a challenging benchmark for investors. However, that breadth is actually an advantage when it comes to designing strategies to replicate the index. The multiple exposures contained within the Global Aggregate diversify its overall risk (and help diversify the tracking errors of replication strategies).

As we discussed above, the objective of a replication strategy is often not to build a passive portfolio with thousands of securities that need constant rebalancing; rather, it is to achieve acceptably low tracking errors using a relatively small number of highly liquid instruments. This reflects the various uses made of replicating portfolios by investors:

- as part of a portable alpha strategy,
- to "fill out" an existing portfolio,
- for tactical asset allocation,
- for asset allocation transitions, and
- for management of inflows and outflows.

Because the Global Aggregate Index is fast becoming the benchmark of choice for many sponsors, managers with expertise in a specific market would have to forgo an opportunity of participating in much of the growth in global fixed income assignments. A strategy of replicating segments of the Global Aggregate as a way of filling out an existing fixed-income product allows such managers to offer a Global Aggregate service. In particular, European

investors have been interested in techniques to replicate the U.S. portion of the Global Aggregate, in particular its mortgage component.

Global Aggregate managers frequently divide their portfolios among various teams, so that, for example, the U.S. portion is managed by U.S. fixed-income managers. A country allocation shift can upset the sector allocations within each regional portfolio. For example, a 5% portfolio shift from Treasuries to Bunds may represent 15% of the U.S. fixed-income portfolio, possibly eliminating the U.S. Treasury exposure. By selling a U.S.-replicating portfolio of derivatives and buying a euro-replicating portfolio, the trade can be executed more cheaply than with cash instruments and with no disruption to the underlying portfolio.

Alternatively, a replicating strategy can be used to express a negative view on a given segment of the Global Aggregate. For example, a bearish view on the euro credit market may lead managers to reduce their cash bond holdings, which may have taken months to accumulate. By selling a replicating portfolio of derivatives, they can easily reduce market exposure and retain the ability to generate outperformance from security selection.

Plan sponsors engaged in asset allocation shifts between equities and fixed income or from one fixed-income benchmark to another can use replication strategies to achieve the desired asset allocation quickly, rather than waiting for managers to liquidate existing investments and reinvesting in the desired asset classes. Portfolio managers raising or investing cash can also use replication strategies to retain or eliminate exposure to asset classes, lessening the effect of inflows and outflows on portfolio performance.

SOURCES OF RISK IN THE LEHMAN BROTHERS GLOBAL AGGREGATE INDEX

The Global Aggregate Index comprises 24 currencies (Exhibit 1). Just four of those, U.S. dollar, euro, yen, and sterling, make up almost 93% of the index. This suggests that a portfolio comprising only those four currencies may do an adequate job of replicating the Global Aggregate, simplifying the replication greatly. More than 50% of the Global Aggregate is represented by non-treasury securities (Exhibit 2), dominated by credit and collateralized securities (with the inclusion of U.S. mortgages). Approximately 80% of the credit component is in the United States or Europe.

The sources of volatility in the underlying index can give valuable insights into the likely success of any

replication strategy. The Lehman Brothers Global Multi-Factor Risk Model quantifies the ex ante tracking error volatility (the expected volatility of the return deviation) of a portfolio versus a benchmark and the absolute volatility of a portfolio or index. The model is based on historical returns of individual securities across all Lehman Brothers bond indices, in many instances dating back more than a decade, and derives historical magnitudes of

different market risk factors and the relationships among them. The model measures current mismatches between the portfolio and benchmark sensitivities to these risk factors and multiplies the mismatches by historical volatilities and correlations ("covariance matrix") to produce its output.

Exhibit 3 shows the model's analysis of the absolute volatility of the Global Aggregate Index. The risk breakdown shown there suggests that, in order to replicate the unhedged Global Aggregate, it is important to manage currency exposure, which represents two thirds of the variance of the index. In the model, swap spread factors are disaggregated from investment-grade spread factors and, globally, are a more significant source of risk. We note, however, that the relative importance of spread factors varies by currency bloc. For example, within the dollar bloc, investment-grade spreads (particularly credit/agency spreads and MBS spreads) are a larger source of risk than swap spreads, while, in the European bloc, swap spread risk is much higher. This suggests that interest-rate swaps are likely to replicate European investment-grade sectors more effectively than U.S. investment grade. We also note that, in the yen bloc, credit and agency spread risk is not significant.

EXHIBIT 1

Global Aggregate Composition by Currency, December 31, 2005

Currency	Issues	Outstanding (MM)	% MV	Cumul. % MV
United States Dollar	4,664	8,175,900	39.440	39.440
European Euro	2,533	6,007,112	30.947	70.387
Japanese Yen	1,500	3,618,276	17.340	87.727
U.K. Pounds Sterling	733	971,273	5.075	92.802
Canadian Dollar	289	420,451	2.237	95.039
Korean Won	103	239,286	1.107	96.146
Danish Krone	44	139,749	0.688	96.834
Swedish Krona	29	93,783	0.492	97.326
Australian Dollar	102	96,174	0.472	97.798
Taiwan Dollar	67	85,179	0.467	98.266
South African Rand	43	79,266	0.356	98.622
Polish Zloty	13	57,356	0.280	98.902
Malaysia Ringgit	30	38,815	0.193	99.095
Mexican Peso	13	39,000	0.192	99.287
Singapore Dollar	19	31,603	0.153	99.439
Norwegian Krone	9	23,896	0.126	99.566
Hungarian Forint	18	24,544	0.120	99.685
Thai Baht	27	22,145	0.105	99.790
Czech Koruna	13	17,442	0.089	99.879
New Zealand Dollar	12	13,596	0.066	99.945
Slovakian Koruna	7	5,471	0.028	99.972
Chilean Peso	5	2,482	0.012	99.985
Slovenian Tolar	4	2,281	0.011	99.996
Hong Kong Dollar	2	800	0.004	100.000
Total	10,279	20,205,880	100.000	

FORMING A DERIVATIVES REPLICATION STRATEGY

Replication Instruments

Three broad categories of instruments may be used to replicate bond indices:

1. Cash instruments (i.e., "real" bonds, not derivatives)
2. Derivatives
3. Total-return index swaps.

EXHIBIT 2

Global Aggregate Composition by Sector and Major Currencies, December 31, 2005

	Market Value %	Treasury	Agency	Credit	MBS	Collat	Others
Total	100.00	49.50	10.12	20.68	13.46	6.17	0.07
U.S. Dollar	39.39	9.75	4.11	10.80	13.46	1.27	
Euro	30.96	18.51	2.62	5.65		4.18	
Yen	17.36	13.77	1.98	1.59		0.02	
Sterling	5.08	2.50	0.12	2.15		0.24	0.07
Others	7.21	4.97	1.29	0.49		0.46	

Replication with cash instruments is appropriate for passive managers who want to achieve low return deviations from benchmark by building large well-diversified portfolios.

EXHIBIT 3

Sources of Risk in Lehman Brothers Global Aggregate Index, Basis Points per Month, December 31, 2005

Global Risk Factor	Isolated TEV (bp)	Percentage of tracking error variance (%)
GLOBAL		
Currency	127.33	65.98
Yield Curve	85.03	33.95
Swap Spreads	7.24	1.31
Volatility	1.94	-0.38
Investment-Grade Spreads	6.64	-0.85
Treasury Spreads	1.22	-0.20
Credit and Agency Spreads	5.64	-0.67
MBS/Securitized	2.42	0.05
CMBS/ABS	0.19	-0.02
Emerging Markets Spread	0.68	-0.02
Systematic risk	170.94	100.00
Idiosyncratic risk	0.92	0.00
Credit default risk	0.25	0.00
Total risk		100.00
Portfolio volatility (bp/month)		170.94
DOLLAR BLOC (USD + CAD + AUD + NZD)		
Yield Curve	50.31	
Swap Spreads	5.98	
Volatility	1.94	
Investment-Grade Spreads	5.31	
Treasury Spreads	0.41	
Credit and Agency Spreads	4.53	
MBS	2.41	
CMBS/ABS	0.19	
Emerging Markets Spread	0.57	
Cumulative	48.99	
EUROPEAN BLOC (EUR + CHF + DKK + NOK + SEK)		
Yield Curve	29.24	
Swap Spreads	2.49	
Volatility	0.00	
Investment-Grade Spreads	1.59	
Treasury Spreads	0.94	
Credit and Agency Spreads	0.96	
Securitized	0.25	
Emerging Markets Spread	0.09	
Cumulative	28.73	
GB POUNDS STERLING BLOC		
Yield Curve	6.20	
Swap Spreads	0.92	
Volatility	0.00	
Investment-Grade Spreads	1.03	
Credit and Agency Spreads	1.00	
Securitized	0.10	
Emerging Markets Spread	0.01	
Cumulative	6.10	
JAPANESE YEN BLOC		
Yield Curve	11.33	
Swap Spreads	0.36	
Investment-Grade Spreads	0.68	
Treasury Spreads	0.51	
Credit and Agency Spreads	0.40	
Emerging Markets Spread	0.00	
Cumulative	11.47	

These replications typically use a stratified sampling approach, in which the index is dissected into cells, and bonds are selected to represent the characteristics of each cell. This makes sense for purely passive mandates, or for active managers looking to replicate a portion of their benchmark for which they do not have expertise, while exercising their skill in other sectors. The use of cash instruments, however, reduces the total alpha that can be generated from the portfolio. Derivative instruments may be preferable, allowing alpha to be generated from 100% of portfolio assets.

Managers who do not wish to use cash instruments and not willing to manage a portfolio of derivatives may choose a total-return index swap. Under a total-return swap, investors are guaranteed to receive the total return on the selected index in return for paying the floating-rate LIBOR plus a spread, to compensate the counterparty (usually a broker-dealer) for the risk in hedging the index exposure. This approach is appropriate for investors with a high degree of risk aversion or those with relatively long (6 months and longer) time horizons, owing to the limited liquidity and higher transaction costs associated with a swap.

In most other situations, replication with derivative instruments is likely to be preferable. Derivative instruments are unfunded, highly liquid, and have low transaction costs. While there may be some basis risk between the derivative and underlying instruments, this is likely to be lower than the security-specific risk in a typical portfolio of actively managed cash instruments.

Approaches to Replicating Index Exposures

The three main approaches are:

- *Stratified sampling* divides the index into cells along one or more risk dimensions (e.g., duration). Each cell is populated to match the chosen risk exposures and weighted according to its weight in the index.
- A *duration-matched* approach attempts to match the overall duration exposures of the index. If there are sufficient number of replicating instruments, a key-rate duration (KRD) matching method can be used. KRD measure sensitivity to shifts at specific "key rate" points along the yield curve (and, therefore, measure the effect

of nonparallel yield curve shifts). The “conventional” duration, on the other hand, measures sensitivity to parallel yield curve shifts.² This approach ensures an efficient representation of the interest rate risk but does not cover spread risk.

- A *minimum-variance hedge* approach, with the help of a risk model, seeks to minimize the expected tracking error of a replicating portfolio against the index. Therefore, the replicating portfolio’s construction reflects the historical correlations between sectors and instruments in the portfolio and index, for example, between corporates and governments.

In the past, our replication techniques used mostly the stratified sampling approach. Since 2001, we have been computing KRDs, which we found to deliver modestly lower tracking errors than the stratified sampling approach. The minimum-variance hedge approach is more model driven and less transparent than the other two. Furthermore, it relies on the relationships between different risk factors—

for example, between term structure movements and credit spread changes—that may change over time. Accordingly, this article examines the performance of various replication strategies using the KRD-matching approach.

Replication Strategies

The aim of this article is to assess various practical approaches to replicating the Global Aggregate and its major subindices. Most investors would not wish to trade 24 different currencies and alter their positions in line with index changes on a monthly basis. A more acceptable strategy (subject to achieving a reasonable tracking error) would be to use instruments from the four largest constituent currencies (USD, EUR, JPY, GBP), which together make up 93% of the Global Aggregate. In each region, as detailed in Exhibit 4, we map each component of the Global Aggregate to a currency and a set of instruments. For example, Swedish Krona-denominated instruments will be replicated by a variety of Euro derivative

EXHIBIT 4

Replication Currency/Instruments Mapping Table, December 31, 2005

Index Currency	% of Currency Bloc	Replicating Currency	Instruments
United States Dollar	92.98	U.S. dollar	Futures, Swaps, CDX, TBA
Canadian Dollar *	5.27		
Australian Dollar *	1.11		
Mexican Peso	0.45		
New Zealand Dollar	0.15		
Chilean Peso	0.03		
European Euro	93.39	Euro	Futures, Swaps, iTRAXX
Danish Krone	2.08		
Swedish Krona	1.48		
South African Rand	1.07		
Polish Zloty	0.85		
Norwegian Krone	0.38		
Hungarian Forint	0.36		
Czech Koruna	0.27		
Slovakian Koruna	0.08		
Slovenian Tolar	0.03		
U.K. Pound Sterling	100.00	U.K. Pound	Futures, Swaps, iTRAXX
Japanese Yen	89.53	Japanese Yen	Futures, Swaps
Korean Won *	5.72		
Taiwan Dollar	2.41		
Malaysia Ringgit	1.00		
Singapore Dollar	0.79		
Thai Baht	0.54		
Hong Kong Dollar	0.02		

*In unhedged strategies, the replicating portfolio contains the exposure to this currency

instruments, depending upon the strategy chosen, which will include either futures, swaps, or swaps + iTraxx. For replicating the unhedged index, the weight of the Swedish Krona in the Global Aggregate will be represented by Euro cash.

In all the replication strategies, we examine various portfolios of derivative instruments, constructed to match the interest rate profile of the relevant index. Interest-rate swaps are an excellent choice for a replication strategy, since they are available in a broad range of maturities and currencies. Embedded in the pricing of interest-rate swaps are credit risk premia and liquidity premia that can be expected to help in replicating the returns of non-treasury components of the Global Aggregate. In addition, the swap curve is effectively continuous, so we can select six instruments to match exactly the KRD profile of the index.

The historical relationships between yields on various indices and on portfolios of duration-matched interest rate swaps can be examined using the Lehman Brothers Mirror Swaps Indices. These are baskets of six swaps with weights selected to match the KRD profile of the target index. For the investors who do not wish to construct such indices themselves, Lehman Brothers offers total-return swaps on various Mirror Swap Indices. Because hedging such indices is much easier than hedging a "real" cash index, spreads on such total-return swaps are correspondingly lower. Such swaps also eliminate the need to rebalance the portfolio as the index KRD profile changes from month to month and swap instruments age.

Replication of the U.S. Aggregate. The number of bond futures available for replicating bond indices (4) is less than the number of key rates in the Lehman Brothers yield curve model (6). In order to match the KRD profile of the index, we combine the 6-month and 2-year KRDs, as well as the 20-year and 30-year KRDs. Separately, we use interest rate swaps with maturities of 6 months, 2, 5, 10, 20, and 30 years. We also examine a strategy that combines treasury futures, for replicating the treasury component of the U.S. Aggregate, with interest-rate swaps, for the nontreasury component. TBAs provide an attractive vehicle for replicating the U.S. mortgage index, which represents 13.46% of the Global Aggregate. By rolling

from month to month, no cash settlement is required and principal paydowns are avoided.

While interest-rate swap spreads are at times highly correlated with credit spreads, there have been extended periods during which this relationship has broken down. In such periods, LIBOR spreads have typically remained stable while credit spreads have been volatile. For example, Exhibit 5 shows that 2002 was a period of great volatility for U.S. credit spreads, while swap spreads, as measured by the Mirror Swap Credit Index, were relatively stable. Portfolio credit default swap (CDS) baskets now provide a very liquid instrument that investors can use to take long or short exposures to credit. The widely traded CDX.NA.IG products are baskets of 125 equally weighted CDS available in maturities between 2 and 10 years. As Exhibits 6 and 7 show, CDX and their European equivalents (iTraxx) have tracked credit spreads closely.

For replicating the Credit Index, we use 5- and 10-year CDX, in proportions to match the spread duration of the index, with the constraint that their notional market values sum to the notional value of the desired credit exposure.³ Every 6 months, a new set (series) of CDX instruments is created, although existing instruments continue to trade. In the replication strategies, we assume that the replicating portfolio comprises the most-recently issued instruments. CDX was first issued in October 2003.

EXHIBIT 5

Option-Adjusted Spreads for the U.S. Credit and Mirror Swap Credit Indices, Basis Points

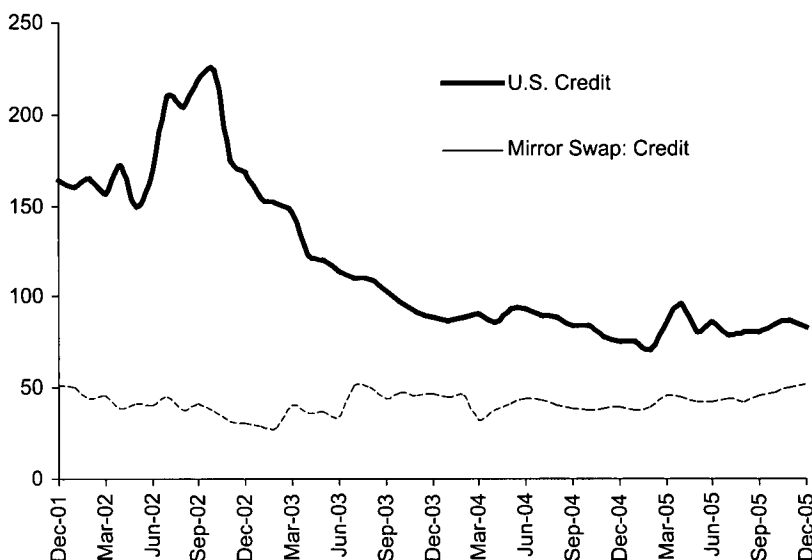


EXHIBIT 6

Relationship between U.S. Credit and CDX Spreads, Basis Points

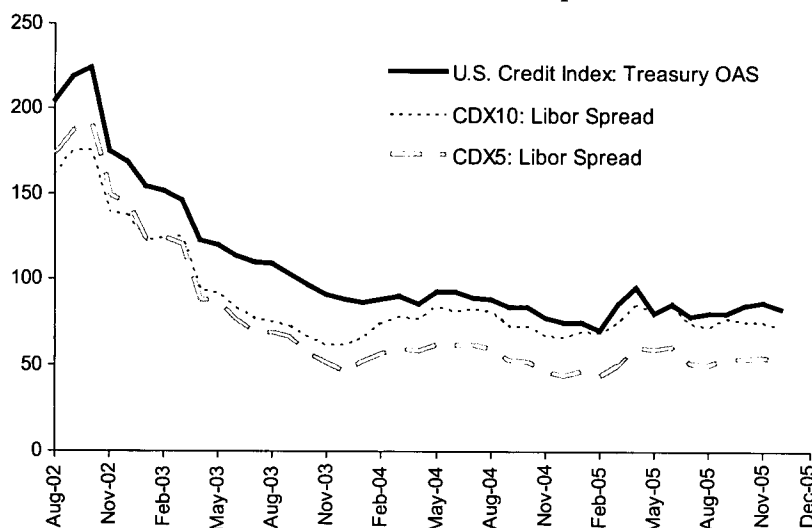
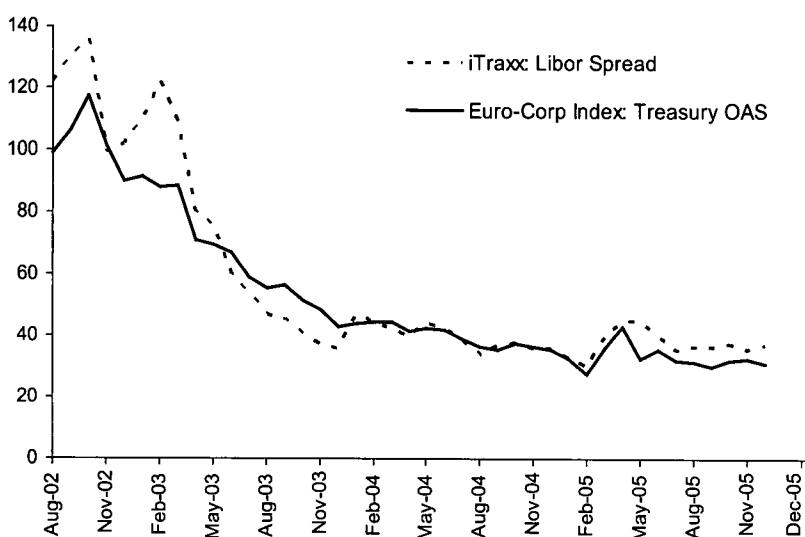


EXHIBIT 7

Relationship between Euro-Corporate and iTraxx Spreads, Basis Points



Therefore, we supplemented the CDX data by valuing portfolios of CDS instruments constructed from the issuers that composed the CDX basket as of October 2003 for the period from August 2002 to September 2003. We would caution that a look-forward bias is introduced by doing this. By construction, CDX-IG comprises only investment-grade issuers. In constructing a basket in

October 2003 valued back to July 2002, we are certain to avoid some issuers that were downgraded over the period that may have been included in a basket actually constructed in 2002.⁴ The large number of names in the basket (125) should mitigate this risk. Additionally, while the traded spread for CDX tracks very closely the intrinsic value of the sum of the individual name CDS, it is not identical. Data for the iTraxx contract are available only since June 2004. Between April 2002 and June 2004, spreads and sensitivities for the contract were estimated using single-name CDS data, according to the iTraxx inclusion rules.

Replication of the Pan-European and euro aggregate. The European portion of the Global Aggregate Index can be split into three parts: the Euro Aggregate Index, a very popular benchmark for euro-based investors; the Sterling Aggregate Index; and the all the other markets that together account for 4.3% of the Pan European Aggregate and 1.6% of the Global index.

Swaps replicate the Euro Aggregate Index returns much more accurately than futures contracts. Indeed, swap spreads in euro are generally tighter and less volatile than in the U.S. market, a reflection of the diversity of treasury issuers in the euro-zone. Many sectors of the euro market, including collateralized, credit, and some treasury markets, are priced off the swap curve. This reflects the importance of floating-rate buyers (e.g., banks) in the European fixed-income markets. In replicating portfolios that are allowed to hold both swaps and futures contracts, there is no reason to use futures, since swaps generate lower tracking errors.

For replicating the credit portion of the Euro and Sterling Aggregates, we use iTraxx Europe 5-year, a portfolio of 125 equally weighted credit-default swaps, to match DTS (duration times spread) of the indices.⁵ While other maturities are available, they offer only limited liquidity and were not included in the study. A position in the portfolio CDS improves the tracking error versus the Euro Aggregate Index only marginally, though we saw a clearer benefit in recent months as spread volatility has risen. Credit represents only 14.7%

of the index; therefore, the risk reduction associated with iTraxx inclusion is more visible when replicating the Euro Corporate Index.

Although much smaller, the Sterling Aggregate Index cannot be replicated as accurately as its euro counterpart. A portfolio holding only the 10-year Gilt contract leaves substantial curve and spread risk unmatched, while the swap replication is less efficient because swap spreads are substantially more volatile in sterling than in the euro market. There is no sterling equivalent to iTraxx or CDX, so we proxy the credit spread exposure of the sterling market with iTraxx Europe 5-year. This should also be expected to add some tracking error, given the longer maturity of the sterling spread market compared with that of the iTraxx contract used, which is composed of 5-year CDS.

Replication of the Asia-Pacific Aggregate. The Asia-Pacific Aggregate Index is dominated by Japan; we therefore use yen instruments, with two exceptions, to replicate the Asia-Pacific Aggregate. The Australian and New Zealand currencies and bond markets have higher correlations with U.S. dollar than with yen and are better replicated with U.S. instruments. The only widely traded bond future in Japan is the 10-year future, with a deliverable basket of bonds with maturities between 7 and 11 years. Therefore, in the Asia-Pacific ex-AUD, ex-NZD replication, interest rate swaps achieve a better match of the yield curve exposure.

PERFORMANCE SUMMARY OF REPLICATION STRATEGIES

The performance of various replication strategies is measured using tracking error volatility (TEV), which is preferable to using average out- or underperformance, for several reasons. The volatility of returns tends to be much more persistent than the returns themselves; that is, history is a much better guide for predicting volatility than for predicting return. It is also not likely that a period of substantial underperformance (or outperformance) of a given replication strategy will persist, since this would imply a secular cheapening (or richening) in a group of highly liquid derivative instruments, or a secular trend in credit or MBS spreads. Finally, the objective of any replication strategy is to replicate the index, not outperform. Outperformance is what active managers are paid for. Nevertheless, we report out- or underperformance of each replicating strategy to give a flavor of the historical means.

Exhibit 8 presents the detailed results of the historical simulation, for different subsets of the Global Aggregate as

well as for different combinations of the instruments used in the replication portfolio.

In Europe, where volatilities have been consistently lower, the benefit of adding iTraxx to the replicating portfolio has manifested itself only recently. This reflects the lower correlation between changes in credit spreads and changes in swap spreads in the last year.

When tracking either the Euro Treasury or Euro Aggregate Index, duration-matched portfolios of the three German contracts (2-, 5-, and 10-year) display tracking errors substantially higher than those associated with Mirror Swap Index replication. This is due both to the better yield-curve match that can be achieved with six interest-rate swaps than with three bond futures and to the better tracking of non-German markets offered by swaps. Adding iTraxx brings only small benefits to a euro aggregate portfolio because of the relatively small share of corporate bonds in the Euro Aggregate Index, currently under 15%. iTraxx brings more tangible benefits when replicating the Euro Corporate Index.

Sterling indices are more difficult to track than their euro equivalent. Swaps or combinations of swaps and iTraxx—there is no CDS basket trading in the sterling market—display larger tracking errors with respect to the sterling aggregate or corporate indices than to the equivalent euro indices. Nevertheless, iTraxx exposure helps reduce tracking error when hedging exposure to the Sterling Corporate Index.

The tracking errors for the Euro Aggregate replications are lower than for the U.S. Aggregate replication. This reflects differences both in the sectoral composition of the two indices and in the relative volatilities of credit spreads in both regions. Treasury securities represent 25% of the U.S. Aggregate and 60% of the Euro Aggregate. Additionally, the composition of the credit indices are very different, as displayed in Exhibit 9. The euro credit index is of higher credit quality, with a greater proportion of financial issuers. Exhibit 10 further illustrates this, by showing that the U.S. credit excess return volatility is more than twice that of the euro credit and 12 times that of the yen credit. Both characteristics suggest that credit spreads would track swap spreads (which in part reflect the credit quality of the financial system) more closely in Europe than in the United States.

For the Global Aggregate replication, portfolio CDS are clearly beneficial and reduce tracking errors by 2–3 bp/month. To the extent that CDS add exposure to credit spreads, they increase returns in the replicating portfolio because of higher carry and spread contraction. The effect

EXHIBIT 8

Replication Results, Basis Points per Month, August 2002 to December 2005

		Unhedged		Hedged	
		Mean Outperformance	Tracking Error Volatility	Mean Outperformance	Tracking Error Volatility
Dollar Bloc	Futures	-3.3	19.7	-3.3	19.6
	Swaps	-7.3	17.9	-7.3	17.7
	Swaps + Futures	-6.2	17.2	-6.3	17.0
	Swaps + Futures + TBA	-5.0	17.3	-5.0	16.9
	Swaps + CDX	-1.9	14.3	-1.9	14.1
	Swaps + CDX + TBA	-0.7	15.8	-0.7	15.3
	Swaps + Futures + CDX	-0.9	12.2	-0.9	12.1
	Swaps + Futures + CDX + TBA	0.4	12.6	0.4	12.1
U.S. Aggregate	Futures	-3.3	18.8		
	Swaps	-6.9	16.1	-	-
	Swaps + Futures	-5.8	15.9	-	-
	Swaps + Futures + CDX	-0.4	10.5	-	-
	Swaps + CDX	-1.4	12.0		
	Swaps + CDX + TBA	-0.1	11.6		
	Swaps + Futures + CDX + TBA	0.9	8.8	-	-
Pan-Euro Bloc	Futures	-2.5	26.8	-3.1	16.2
	Swaps	-2.3	8.9	-0.3	7.6
	Swaps + iTraxx	0.6	8.7	2.6	7.8
Euro Aggregate	Swaps	2.4	6.1	-	-
	Swaps + iTraxx	0.2	6.2	-	-
Yen Bloc	Futures	-10.7	34.7	-11.4	34.9
	Swaps	-3.8	10.6	-4.7	10.6
Total Global Aggregate	Futures	-4.7	14.9	-4.9	13.6
	Swaps	-4.8	9.0	-4.2	8.7
	Swaps + Futures	-4.4	8.9	-3.8	8.6
	Swaps + Futures + TBA	-3.8	9.3	-3.3	8.7
	Swaps + CDX/iTraxx	-1.3	7.1	-0.7	6.8
	Swaps + CDX/iTraxx + TBA	-0.8	7.8	-0.2	7.2
	Swaps + Futures + CDX/iTraxx	-0.9	6.3	-0.3	6.0
	Swaps + Futures + CDX/iTraxx + TBA	-0.4	6.6	0.2	5.9

of adding TBAs depends on the period; while TBAs reduced risk in some subperiods, for the overall study period their inclusion did not lead to tracking error improvement. Overall, a strategy that makes use of all available hedging instruments considered here is likely to deliver the lowest tracking errors.

Because non-treasury instruments represent a larger proportion of the U.S. market than of the non-U.S. markets, it is not surprising that the tracking error for the dollar bloc is higher than for the other blocs. As a whole, the results for the Global Aggregate demonstrate the power of diversification. The tracking error of the "full

replication" strategy is lower than that of any of the constituents. Exhibit 11 illustrates the diversification achieved by combining replication strategies for different regions, by showing that the correlations of monthly tracking errors of the regional replication strategies are low or even negative.

The relatively small difference in the risk profiles of the hedged and unhedged replications suggests that the currency risk derived from using only seven currencies to track the performance of 24 currencies is limited, but could be reduced somewhat by increasing the number of currencies held.

USING A RISK MODEL TO FORECAST REPLICATION RISK

An empirical analysis is valuable in forecasting the likely tracking errors of various replication strategies, but there are some drawbacks to this approach. Most importantly, the weightings of countries, currencies and sec-

tors, and their risk characteristics change over time, which will change the likely performance of a particular replication strategy. Exhibit 12 shows how the currency distribution and duration of the Global Aggregate have changed over time.

The Lehman Brothers Global Multifactor Risk Model provides a way of forecasting the likely risk of a

EXHIBIT 9

U.S. and Euro Credit Index: Market Value by Sector and Rating, December 31, 2005

Market Value %	Total	Aaa	Aa	A	Baa
US Credit	100.00	11.76	19.52	36.83	31.89
Euro Credit	100.00	18.51	21.99	40.55	18.95
Gov-Related					
U.S. Credit	17.63	7.55	3.93	2.85	3.30
Euro Credit	20.24	12.64	1.05	2.98	3.57
Corporate Industrial					
U.S. Credit	39.39	0.89	2.96	15.70	19.84
Euro Credit	30.10	0.57	2.64	14.52	12.37
Corporate Utility					
U.S. Credit	7.17		0.11	1.75	5.31
Euro Credit	7.25		1.29	4.80	1.16
Corporate Financial Institutions					
U.S. Credit	35.81	3.32	12.52	16.53	3.44
Euro Credit	42.41	5.30	17.01	18.25	1.85

EXHIBIT 10

Excess Returns Averages and Volatility, Basis Points per Month

	Average Excess Return	Monthly Volatility
U.S. Credit	19.4	53.1
Euro Credit	8.8	22.5
Yen Credit	3.0	4.4

given replicating strategy that takes into account the current characteristics and risk profile of the Global Aggregate Index. Exhibit 13 presents a risk analysis of the currency-hedged replicating portfolio of interest-rate swaps, U.S. treasury futures, TBAs, CDX, and iTraxx. The predicted tracking error volatility is higher than that shown in our empirical analysis. In part, this reflects the changes in the nature of the Global Aggregate, as shown in Exhibit 12. This also reflects that in the period prior to our empirical analysis, volatility was somewhat higher (reflected in the covariance matrix used in the risk model). The model provides a risk attribution, giving us insight into the remaining sources of risk in the replication strategy. Most of the risk comes from term structure exposures, a reflection of the fact that, while most of the risk can be eliminated by using swaps in four currencies, there are still term structure mismatches from, for example, using U.S. interest-rate swaps to hedge Canadian interest-rate risk.

A comparison with the overall volatility of the Global Aggregate is also instructive. Exposures to almost all the risk factors match the benchmark reasonably well. The exceptions are high yield spreads and credit default risk, because the exposures to some credits in equal-weighted CDX and iTraxx are very different from the benchmark. Besides this additional idiosyncratic (issuer-specific) risk,

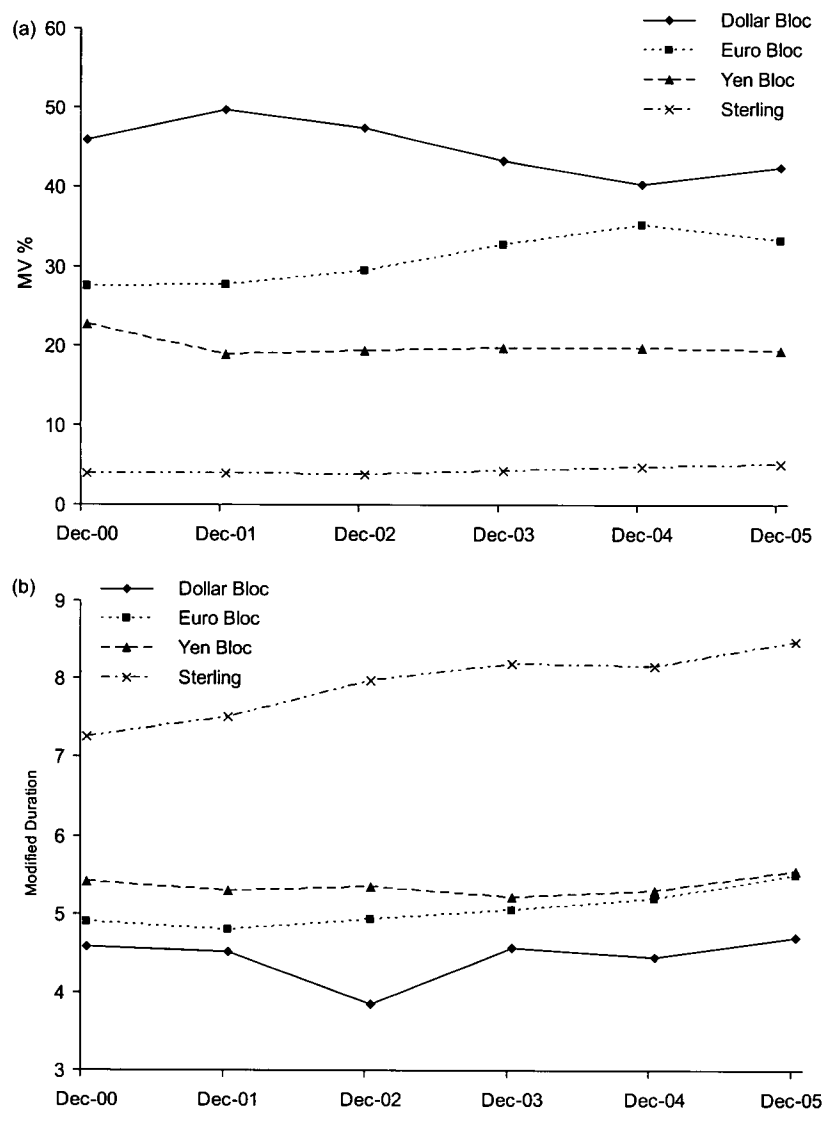
EXHIBIT 11

Correlations of Realized Return Differentials among the Blocs within the GAI, August 2002 to December 2005; Swaps + Futures + CDX/iTraxx + TBA

	Unhedged				Hedged			
	Dollar Bloc	Pan-Euro Bloc	Yen Bloc	GAI	Dollar Bloc	Pan-Euro Bloc	Yen Bloc	GAI
TEV (bp/mo)	12.6	8.7	10.6	6.6	12.1	7.8	10.6	5.9
Dollar Bloc	1	0.21	-0.41	0.83	1	0.22	-0.47	0.85
Pan-Euro Bloc	0.21	1	0.00	0.65	0.22	1	-0.15	0.61
Yen Bloc	-0.41	0.00	1	-0.05	-0.47	-0.15	1	-0.16
Global Aggregate	0.83	0.65	-0.05	1	0.85	0.61	-0.16	1

EXHIBIT 12

(a) Changing Currency Allocation of the Global Aggregate Index, and (b) Changing Duration of the Global Aggregate Index



there is the CDS versus cash basis risk. So while CDX/iTraxx do reduce credit spread risk, they also add a new source of risk.

REPLICATION DETAILS

In our empirical studies, we assume that all positions are rebalanced monthly. In practice, most investors will make only small monthly adjustments to allow for the changing characteristics of the index and the aging of

derivative positions. On a quarterly basis, futures will be rolled to prevent the exercise of the delivery option, and swaps will be rolled into the "on-the-run" maturities. TBAs are rolled monthly to avoid pool delivery. New CDX/iTraxx instruments are created semi-annually, and we assume in our studies that a roll into the new instrument is executed with that frequency.

During the period between the creation of new portfolio CDX instruments, it is possible that an issuer will be downgraded, causing it to fall out of the Global Aggregate (but remain in CDX/iTraxx). During this period, investors may be subject to tracking error, as the performance of the "fallen angel" may not match that of the investment-grade credits. However, this risk can be largely eliminated if investors buy single-name default protection for the downgraded issuer.

An all-derivatives portfolio, by definition, does not require cash, outside of that needed to meet variation margin for futures or mark-to-market collateral calls for swaps. We assume in our work that cash is invested in 1-month LIBOR. In practice, for futures, investors will be required to deposit initial margin with the clearing firm, which will average 1.0–1.5% of the notional portfolio amount. However, both this and any variation margin can be posted in the form of T-bills. As a result, only a small portion of funds will be invested below LIBOR.

Transaction costs will depend on the choice of strategy and the frequency of rebalancing. Exhibit 14 displays estimated transaction costs, assuming monthly rebalancing.

CONCLUSION

The scope of the Global Aggregate Index, which today comprises more than 10,000 securities, actually makes it easier to replicate than single-country indices. This reflects the low or negative correlations between the replication errors of the currency bloc components of the index. The advent of portfolio CDS has had an important effect on the success of replication strategies, and it is now reasonable to expect that replication strategies can be

EXHIBIT 13

Sources of Risk in the Replication of the Global Aggregate Index (Hedged), December 31, 2005;
Swaps + Futures + CDX/iTraxx

Global Risk Factor	Index Isolated Total Volatility (bp/mo)	Replicating Portfolio vs. Index Isolated Total Volatility	Percentage of Tracking Error Variance (%)
GLOBAL			
Yield Curve	85.03	3.20	14.10
Swap Spreads	7.24	1.78	4.46
Volatility	1.94	2.02	8.91
Investment-Grade Spreads	6.64	3.44	15.53
Treasury Spreads	1.22	1.21	3.55
Credit and Agency Spreads	5.64	2.13	0.46
MBS/Securitized	2.42	2.53	11.05
CMBS/ABS	0.19	0.20	0.47
High Yield Spreads	-	0.60	-1.74
Emerging Markets Spread	0.68	0.68	2.37
CDS Basis	-	4.39	27.11
Systematic risk	82.90	6.76	70.75
Idiosyncratic risk	0.92	4.11	26.21
Credit default risk	0.25	1.40	3.04
Total risk	82.90	8.03	
Empirically Derived Risk		6.00	

Exponentially-weighted covariance matrix

EXHIBIT 14

Estimated Monthly Transaction Costs, Basis Points

Global Aggregate: Swaps	0.8
Global Aggregate: Swaps, TBA, CDX, iTraxx	1.0
Dollar Bloc: Swaps, TBA, CDX	1.1
Pan-Euro Bloc: Swaps, iTraxx	0.9
Asia-Pacific Bloc: Swaps	0.8

constructed with tracking error volatility of less than 10 bp/month. This relatively low level of volatility makes a derivatives replication strategy suitable for a variety of needs, from portable alpha to asset allocation shifts. At the margin, replication results could be improved by adding additional currencies or markets, but a meaningful reduction in tracking error from those reported would be impossible to achieve without the use of cash instruments.

Lehman Brothers has developed RBISM (Replicating Bond Index) baskets, which provide a way for investors to follow the performance of various strategies for replicating bond indices.⁶ Daily returns for RBI baskets that

track various Lehman Brothers indices are available. Lehman Brothers offers total return swaps on RBISM baskets, allowing investors to receive the return of a replicating strategy, rather than having to build a replicating portfolio and rebalance every month.

ENDNOTES

¹In a strict sense, the market portfolio comprises all (fixed-income) instruments, while the most widely used indices do not capture all fixed-income instruments. The Lehman Brothers Universal Index is the most comprehensive index of U.S. dollar-denominated instruments, covering high yield and emerging markets in addition to U.S. investment-grade fixed income, while the Multiverse Index is a similarly comprehensive index of global fixed-income securities.

²For example, the 5-year KRD measures the sensitivity of the price to a shift in the 5-year par yield, assuming no shift in the 2- and 10-year rates, and linearly interpolated the shifts between 2- and 5-year and 5- and 10-year points.

³Various alternative weighting schemes could have been used for CDX instruments. These include matching the spread

of the combined CDX portfolio to the LIBOR spread of the Credit Index or matching the duration times spread (DTS). Both schemes, however, lead to much more unstable allocations between CDX instruments and, in some cases, to short positions.

⁴In particular, EP and AHOLD were investment-grade issuers that were downgraded below investment grade and that might reasonably have been expected to be included in a CDX basket issued at the time. They represented 0.4% and 0.1% respectively of the U.S. Credit Index in the month prior to downgrade.

⁵While we have endeavoured to synthesize the iTraxx contract to allow us to extend our analysis further back than the launch of the contract (see results in Exhibit 8 for Euro and Pan Euro Aggregate Indices), the process of synthesis makes various assumptions that affect reported results. The iTraxx contract does not behave precisely as the sum of its parts and,

in addition, 125 names were not generally available, especially further back in the past. Results based on observed prices for the contract after its launch carry more authority, although any results will reflect the short period over which such data are available.

⁶An RBI basket is a portfolio of derivative instruments, plus cash, designed to track relevant Lehman Brothers indices. The basket is reconstituted each month, using a mechanistic algorithm, to match as closely as possible the term structure and spread exposures of the relevant Lehman Brothers index. Returns on RBI baskets are available daily.

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