Portfolio Risk Budgeting

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LEHMAN BROTHERS

Portfolio Risk Optimization

- Risk budgeting of macro strategies with limited skill
- Issue-level portfolio optimization using the Lehman multi-factor risk model

Risk Budgeting of Macro Strategies

Arguments for Global Macro Strategies ("top-down" approach)

- Macro forces (rates, spreads, FX) largely determine index returns
- Macro strategies involve changing exposures to the most basic drivers of index returns using the most liquid instruments
- Ease of replication of index returns with derivatives demonstrates dominant role of macro positioning
- A "bottom-up" approach across such diversified indices as the Global Aggregate would require a tremendous amount of resources and lead to many small and less liquid positions

⌧ What combinations of macro strategies are the most risk-effective?

Strategy Simulation Example: FX Allocation, 20% skill

Asset	Ret (bp)	Long JPY	Long EUR	Long USD	Short JPY	Short EUR	Short USD
JPYcash	-24.5	**4.5%**	-2.7%	-2.4%	**-4.5%**	2.7%	2.4%
EURcash	27.7	-2.3%	**5.4%**	-2.4%	2.3%	**-5.4%**	2.4%
USDcash	-340.3	-2.3%	-2.7%	**4.9%**	2.3%	2.7%	**-4.9%**
Overall strategy:							
	Return (bp)	**6.0**	**11.3**	**-16.6**	**-6.0**	**-11.3**	**16.6**
Selection Probabilities for:							
	0% skill	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
	100% Skill	33.3%	33.3%	0.0%	0.0%	0.0%	33.3%
	20%	20.0%	20.0%	13.3%	13.3%	13.3%	20.0%
	(R-Mean)^2	13.9	80.9	356.5	68.1	182.5	206.4
	Mean Return	**2.3**					
	Variance	**141.2**					
	Volatility	11.9					

Performance Summary for Core Strategies (I) January 1990 - December 2002

	Global Duration			Market Duration			FX Overlay in G3 Currencies		
Skill Level	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio
0%	0.0	44.9	0.00	0.0	44.7	0.00	0.0	52.5	0.00
5%	6.2	44.8	0.14	6.0	44.7	0.13	6.8	52.5	0.13
10%	12.3	44.7	0.28	12.0	44.6	0.27	13.6	52.3	0.26
15%	18.5	44.6	0.41	18.0	44.4	0.41	20.4	52.2	0.39
20%	24.6	44.3	0.56	24.0	44.2	0.54	27.2	51.9	0.52
40%	49.3	42.6	1.16	48.0	42.5	1.13	54.4	50.1	1.09
60%	73.9	39.5	1.87	72.0	39.6	1.82	81.6	46.9	1.74
80%	98.5	34.8	2.83	96.0	35.1	2.73	108.9	42.1	2.59
100%	123.2	27.5	4.48	120.0	28.3	4.23	136.1	34.9	3.90

- Achieved volatilities are close to the targeted 50 bp/year
- IR increases more than linearly with skill, because in addition to increase in mean outperf., we also see lower vol. at high skills

Performance Summary for Core-Plus Strategies: Long-Only, De-Meaned

	U.S. Credit *Aug 1988 - Dec 2002*			*Euro Credit* *Jan 1999 - Dec 2002*			*Emerging Markets* *Jan 1993 - Dec 2002*			*U.S. High Yield* *Aug 1988 - Dec 2002*		
Skill Level	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio
0%	0.0	7.0	0.00	0.0	3.4	0.00	0.0	53.4	0.00	0.0	25.4	0.00
5%	0.5	7.0	0.08	0.3	3.4	0.08	4.7	53.1	0.09	2.2	25.4	0.09
10%	1.0	6.9	0.15	0.6	3.4	0.17	9.5	52.8	0.18	4.4	25.3	0.17
15%	1.6	6.9	0.23	0.9	3.4	0.25	14.2	52.4	0.27	6.6	25.2	0.26
20%	2.1	6.9	0.31	1.1	3.4	0.34	18.9	51.9	0.36	8.7	25.1	0.35
40%	4.2	6.7	0.63	2.3	3.3	0.70	37.9	49.7	0.76	17.5	24.5	0.71
60%	6.3	6.4	0.98	3.4	3.1	1.09	56.8	46.8	1.21	26.2	23.7	1.11
80%	8.4	6.1	1.38	4.6	2.9	1.55	75.7	43.1	1.76	35.0	22.5	1.55
100%	10.5	5.7	1.84	5.7	2.7	2.10	94.7	38.2	2.48	43.7	20.9	2.09

- Long-only strategies exhibit a nonzero mean return at 0% skill. This represents the trend over the time period of the study, and has been subtracted out
- Information ratios much lower than core strategies at given skill. For example, at 20% skill, all core strategies showed IR above 0.50
- Reason: “no shorts” constraint means inability to capitalize on negative views

Pair-Wise Performance Correlations Among Sample Pure Tilt Strategies

Market Duration Pairs		Pre-EMU	Post-EMU	Overall
EUR-JPY	EUR-USD	0.29	-0.55	0.12
EUR-JPY	EUR-GBP	0.10	-0.57	-0.01
EUR-GBP	EUR-USD	0.33	0.53	0.37
EUR-CAD	EUR-USD	0.61	0.72	0.61
USD-JPY	USD-GBP	0.25	0.45	0.30
Long Glob Dur	EUR-JPY	-0.32	0.47	-0.17
Long Glob Dur	EUR-USD	-0.51	-0.81	-0.59
Long Glob Dur	EUR-GBP	-0.66	-0.64	-0.66
Long Glob Dur	USD-JPY	0.13	0.75	0.31
Long Glob Dur	USD-GBP	-0.20	0.32	-0.09

Twist Pairs		Pre-EMU	Post-EMU	Overall
EUR Steepener	USD Steepener	0.04	0.53	0.23
EUR Steepener	JPY Steepener	0.09	-0.12	0.04
USD Steepener	JPY Steepener	-0.03	-0.12	-0.06
USD Steepener	USD-EUR	0.32	0.28	0.30
All 3 Steepeners	Long Glob Dur	0.10	0.23	0.14
EUR Steepener	Long EUR FX	-0.22	0.14	-0.11
USD Steepener	Long USD FX	-0.38	-0.28	-0.33
JPY Steepener	Long JPY FX	0.00	-0.05	-0.01

FX Pairs		Pre-EMU	Post-EMU	Overall
Long JPY FX	Long EUR FX	-0.55	-0.64	-0.56
Long JPY FX	Long USD FX	-0.63	-0.50	-0.60
Long USD FX	Long EUR FX	-0.30	-0.35	-0.32
Long JPY FX	Long Glob Dur	0.07	0.04	0.06
Long EUR FX	Long Glob Dur	-0.07	0.17	0.00
Long USD FX	Long Glob Dur	0.01	-0.23	-0.05
Long JPY FX	JPY-EUR	-0.11	-0.08	-0.11
Long EUR FX	EUR-USD	-0.23	-0.18	-0.22
Long USD FX	USD-EUR	-0.17	-0.34	-0.21

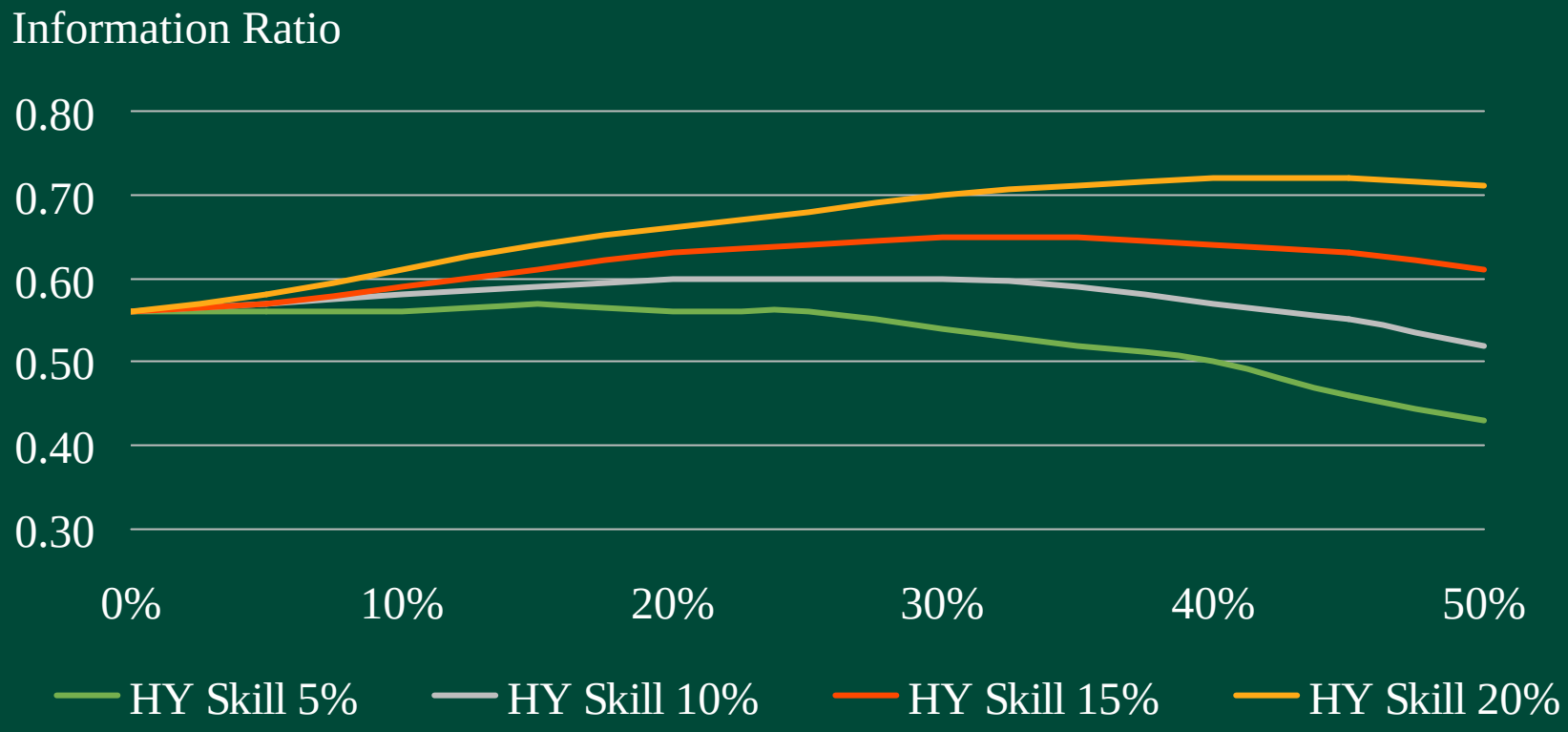
Core-Plus Pairs		Pre-EMU	Post-EMU	Overall
Emerging Mkts	Long Glob Dur	0.24	-0.05	0.15
High Yield	Long Glob Dur	0.33	-0.08	0.18
Euro Credit	Long Glob Dur	-1.00	-0.31	-0.31
Euro Credit	EUR Steepener	N/A	-0.38	-0.38
High Yield	USD Steepener	0.10	-0.28	-0.08
Emerging Mkts	USD Steepener	0.01	-0.22	-0.07
Emerging Mkts	High Yield	0.63	0.51	0.49
US Credit	Long Glob Dur	-0.09	-0.35	-0.18
US Credit	High Yield	0.55	0.77	0.67
US Credit	Euro Credit	N/A	0.85	0.85
US Credit	Long USD FX	0.31	0.20	0.24
US Credit	USD-EUR	-0.19	-0.47	-0.30
US Credit	USD Steepener	-0.26	-0.32	-0.29

Performance of a Combination Strategy with Unequal Skills

Strategy	Mean Outperf. (bp/yr)	Volat. (bp/yr)	Inform. Ratio
Global Duration (20% skill)	25.6	46.3	0.553
High Yield (10% skill)	14.6	60.9	0.240
Blend (75% Global Duration, 25% High Yield)	28.6	47.8	0.599

Performance of a Combination Strategy as a Function of Weight and Skill Level

20% skill at Global Duration strategy; High Yield skill as shown



- Optimal allocation to high yield depends on relative skill levels

The "Fundamental Law of Active Management"

- In previous "imperfect foresight" studies, we found performance to depend on the number of independent decisions in a strategy
- In *Active Portfolio Management* (1999, McGraw-Hill), Grinold and Kahn define the "fundamental law of active management":

$$IR = IC \cdot \sqrt{BR}$$

- The "information coefficient" IC is defined as the correlation between forecast and realized returns, and corresponds roughly to our measure of skill
- The "breadth" BR of a strategy is defined as the number of independent decisions taken a year. For example, strategies that make a single decision each month have BR=12, and we should expect information ratio to equal $skill \cdot \sqrt{12}$

Lehman Brothers Risk Budgeting Tool

- What is outperformance (alpha) of a strategy?

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

- The user provides skill levels for all strategies
- We set up an optimization process that maximizes the combined alpha subject to the overall risk budget (tracking error) constraint
- The optimization finds individual strategies' TE which in their turn determine position sizes in each strategy

Lehman Brothers Risk Budgeting Tool

Customized to the style of a U.S. Aggregate Index manager

- No pure duration positions – not viewed as efficient
- Yield curve view is a choice among many different bullet/barbell positions (2-5-10, 5-10-30, etc.)
- Long/short credit vs. Treasuries
- Long/short swap-based assets (agencies, MBS, ABS, CMBS) vs. Treasuries
- Long/short MBS vs. Agencies (within swaps-based assets)
- Long or neutral in various core-plus assets:
  - High yield
  - Emerging markets
  - Inflation-protected securities (TIPS)
  - Euro-denominated Treasuries

Lehman Brothers Risk Budgeting Tool

- Several factors help determine the optimal allocation
- Front page inputs:
  - Set of directional views
  - Skill levels assigned to each view
  - Risk budget (target tracking error)
- Important behind-the-scenes data:
  - Historical volatilities and correlations of strategy returns (computed for specific views, based on asset class returns)
  - Constraints of various types

Example 1: Base Case

10% skill at all strategies, Risk budget 125 bp

		Active Position		Skill/Confidence
U.S. Curve Exposure		Barbell 2-10-30	☑	10 %
Investment Grade Credit		Long Credit	☐	10 %
Swap-Based Assets		Long Swap-Based Assets	☐	10 %
MBS vs. Agency		Long MBS vs. Agency	☐	10 %
Core-Plus Assets	HY	Long High Yield	☐	10 %
	TIPS	Long TIPS	☐	10 %
	EM	Long Emerging Markets	☑	10 %
Euro Treasury Exposure		Long All	☐	10 %
Total Risk Budget (Tracking Error, bp/yr)				125
Maximize		Portfolio Alpha		
Total Portfolio TE (bp/yr)				125
Systematic		122		
Non-Systematic		27		
Portfolio Alpha				64
Information Ratio				0.51

Optimize

Interactive Portfolio Positions Editor

View Asset Correlation Matrix

View Strategy Correlation Matrix

View Pair Wise Combination Graph

Print Summary Report

Last optimization status:
OK

Asset	Active Position	Index %	Total Allocation	Chg vs. Current
USD Cash	0.00%	-	0.00%	-3.00%
Maturity cell 1-3	5.14%	18.04%	23.18%	17.44%
Maturity cell 3-7	0.00%	17.40%	17.40%	5.01%
Maturity cell 7-10	-10.96%	10.96%	0.00%	-27.48%
Maturity cell 10+	5.82%	15.10%	20.92%	12.92%
Investment Grade Credit	0.00%	27.46%	27.46%	8.89%
MBS	12.16%	34.17%	46.33%	24.33%
Agency	-12.16%	12.16%	0.00%	-14.84%
ABS/CMBS	0.00%	4.33%	4.33%	4.33%
High Yield	3.99%	0.00%	3.99%	-1.01%
TIPS	13.52%	0.00%	13.52%	13.52%
Emerging Markets	3.88%	0.00%	3.88%	-0.62%
EUR Trs 1-3	0.13%	0.00%	0.13%	-3.02%
EUR Trs 3-7	0.17%	0.00%	0.17%	-4.03%
EUR Trs 7-10	0.10%	0.00%	0.10%	-2.30%
EUR Trs 10+	0.09%	0.00%	0.09%	-2.05%

Strategy	Isolated TE (bp/yr)	R-squared	Contrib. to Var.
U.S. Curve Exposure	21.6	28.8%	9.7%
Investment Grade Credit	0.0	0.0%	0.0%
Swap-Based Assets	0.0	0.0%	3.3%
MBS vs. Agency	9.9	15.8%	
Long High Yield	43.4	60.7%	28.4%
Long TIPS	42.2	13.2%	12.9%
Long Emerging Markets	65.2	68.8%	45.4%
Euro Treasury Exposure	1.4	9.5%	0.4%

Broad Asset Allocation	Portfolio	Benchmark	Difference
Treasuries	0.00%	21.88%	-21.88%
Credit	27.46%	27.46%	0.00%
Swaps-based	50.66%	50.66%	0.00%
Out-of-Benchmark Assets	21.88%	0.00%	21.88%

Covariance matrix: Equal Weight 01/31/98 - 06/30/03

Example 2: Change Curve Strategy

More curve risk, less Core+ risk, better alpha and IR

		Active Position		Skill/Confidence
U.S. Curve Exposure		Barbell 2-mid-30	☑	10 %
Investment Grade Credit		Long Credit	☐	10 %
Swap-Based Assets		Long Swap-Based Asset:	☐	10 %
MBS vs. Agency		Long MBS vs. Agency	☐	10 %
Core-Plus Assets	HY	Long High Yield	☐	10 %
	TIPS	Long TIPS	☐	10 %
	EM	Long Emerging Markets	☑	10 %
Euro Treasury Exposure		Long All	☐	10 %
Total Risk Budget (Tracking Error, bp/yr)				125
Maximize		Portfolio Alpha		
Total Portfolio TE (bp/yr)				125
Systematic		122		
Non-Systematic		27		
Portfolio Alpha				66
Information Ratio				0.53

Optimize

Interactive Portfolio Positions Editor

View Asset Correlation Matrix

View Strategy Correlation Matrix

View Pair Wise Combination Graph

Print Summary Report

Last optimization status:
OK

Asset	Active Position	Index %	Total Allocation	Chg vs. Current
USD Cash	0.00%	-	0.00%	-3.00%
Maturity cell 1-3	17.33%	18.04%	35.37%	29.63%
Maturity cell 3-7	-17.40%	17.40%	0.00%	-12.39%
Maturity cell 7-10	-8.54%	10.96%	2.42%	-25.06%
Maturity cell 10+	8.61%	15.10%	23.71%	15.71%
Investment Grade Credit	0.00%	27.46%	27.46%	8.89%
MBS	12.16%	34.17%	46.33%	24.33%
Agency	-12.16%	12.16%	0.00%	-14.84%
ABS/CMBS	0.00%	4.33%	4.33%	4.33%
High Yield	2.75%	0.00%	2.75%	-2.25%
TIPS	15.41%	0.00%	15.41%	15.41%
Emerging Markets	3.72%	0.00%	3.72%	-0.78%
EUR Trs 1-3	0.00%	0.00%	0.00%	-3.15%
EUR Trs 3-7	0.00%	0.00%	0.00%	-4.20%
EUR Trs 7-10	0.00%	0.00%	0.00%	-2.40%
EUR Trs 10+	0.00%	0.00%	0.00%	-2.14%

Strategy	Isolated TE (bp/yr)	R-squared	Contrib. to Var.
U.S. Curve Exposure	40.7	36.6%	20.6%
Investment Grade Credit	0.0	0.0%	0.0%
Swap-Based Assets	0.0	0.0%	3.5%
MBS vs. Agency	9.9	17.6%	
Long High Yield	30.0	55.9%	18.8%
Long TIPS	48.1	15.2%	15.7%
Long Emerging Markets	62.5	62.4%	41.3%
Euro Treasury Exposure	0.0	11.2%	0.0%

Broad Asset Allocation	Portfolio	Benchmark	Difference
Treasuries	0.00%	21.88%	-21.88%
Credit	27.46%	27.46%	0.00%
Swaps-based	50.66%	50.66%	0.00%
Out-of-Benchmark Assets	21.88%	0.00%	21.88%

Covariance matrix: Equal Weight 01/31/98 - 06/30/03

Example 3: Low TE

Risk budget 60 bp; allocations don't hit 0 constraint in 7-10 year, Agency cells; better strategy diversification (bigger % of var to curve, swaps); higher IR

		Active Position	Skill/Confidence
U.S. Curve Exposure		Barbell 2-10-30 ☑	10 %
Investment Grade Credit		Long Credit ☐	10 %
Swap-Based Assets		Long Swap-Based Asset: ☐	10 %
MBS vs. Agency		Long MBS vs. Agency ☐	10 %
Core-Plus Assets	HY	Long High Yield ☐	10 %
	TIPS	Long TIPS ☐	10 %
	EM	Long Emerging Markets ☑	10 %
Euro Treasury Exposure		Long All ☐	10 %
Total Risk Budget (Tracking Error, bp/yr)			60
Maximize		Portfolio Alpha	
Total Portfolio TE (bp/yr)			60
Systematic	55		
Non-Systematic	24		
Portfolio Alpha			34
Information Ratio			0.57

Optimize

Interactive Portfolio Positions Editor

View Asset Correlation Matrix

View Strategy Correlation Matrix

View Pair Wise Combination Graph

Print Summary Report

Last optimization status:
OK

Asset	Active Position	Index %	Total Allocation	Chg vs. Current
USD Cash	0.00%	-	0.00%	-3.00%
Maturity cell 1-3	3.71%	18.04%	21.75%	16.01%
Maturity cell 3-7	0.00%	17.40%	17.40%	5.01%
Maturity cell 7-10	-7.92%	10.96%	3.04%	-24.44%
Maturity cell 10+	4.20%	15.10%	19.30%	11.30%
Investment Grade Credit	0.00%	27.46%	27.46%	8.89%
MBS	6.52%	34.17%	40.69%	18.69%
Agency	-5.05%	12.16%	7.11%	-7.73%
ABS/CMBS	0.14%	4.33%	4.47%	4.47%
High Yield	0.00%	0.00%	0.00%	-5.00%
TIPS	10.66%	0.00%	10.66%	10.66%
Emerging Markets	1.13%	0.00%	1.13%	-3.37%
EUR Trs 1-3	2.27%	0.00%	2.27%	-0.88%
EUR Trs 3-7	2.97%	0.00%	2.97%	-1.23%
EUR Trs 7-10	1.72%	0.00%	1.72%	-0.68%
EUR Trs 10+	1.53%	0.00%	1.53%	-0.61%

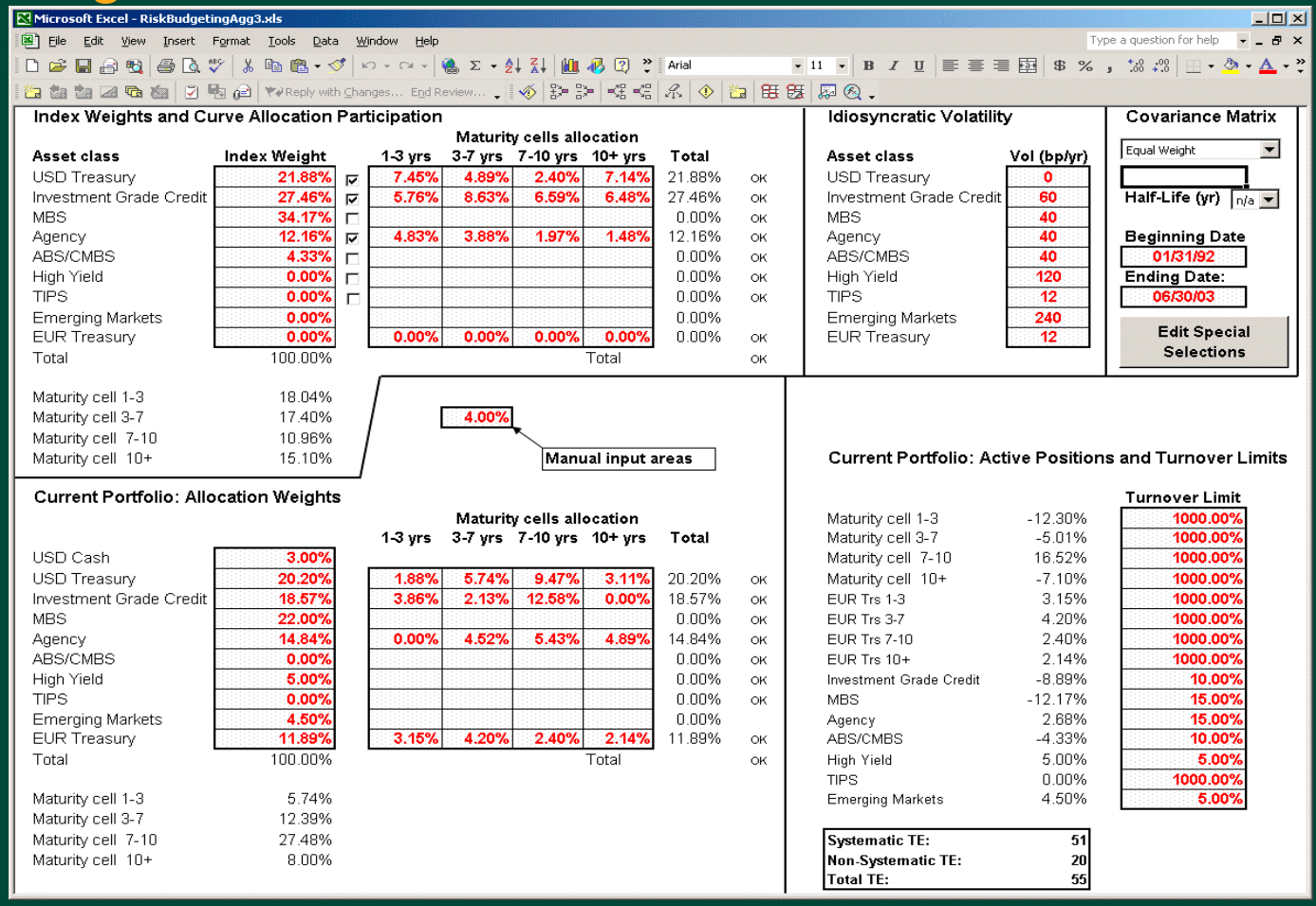
Strategy	Isolated TE (bp/yr)	R-squared	Contrib. to Var.
U.S. Curve Exposure	15.6	29.0%	16.6%
Investment Grade Credit	0.0	0.0%	0.0%
Swap-Based Assets	1.6	16.2%	4.9%
MBS vs. Agency	4.4	17.9%	
Long High Yield	0.0	0.0%	0.0%
Long TIPS	33.3	27.0%	34.1%
Long Emerging Markets	18.9	27.5%	19.6%
Euro Treasury Exposure	24.2	27.2%	24.9%

Broad Asset Allocation	Portfolio	Benchmark	Difference
Treasuries	0.00%	21.88%	-21.88%
Credit	27.46%	27.46%	0.00%
Swaps-based	52.26%	50.66%	1.60%
Out-of-Benchmark Assets	20.28%	0.00%	20.28%

Covariance matrix: Equal Weight 01/31/98 - 06/30/03

LB Risk Budgeting Tool: Additional Options

History used, turnover constraint, idiosyncratic vols, index weights



Microsoft Excel - RiskBudgetingAgg3.xls

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Index Weights and Curve Allocation Participation

Asset class	Index Weight		Maturity cells allocation 1-3 yrs	3-7 yrs	7-10 yrs	10+ yrs	Total	
USD Treasury	21.88%	☑	7.45%	4.89%	2.40%	7.14%	21.88%	OK
Investment Grade Credit	27.46%	☑	5.76%	8.63%	6.59%	6.48%	27.46%	OK
MBS	34.17%	☐					0.00%	OK
Agency	12.16%	☑	4.83%	3.88%	1.97%	1.48%	12.16%	OK
ABS/CMBS	4.33%	☐					0.00%	OK
High Yield	0.00%	☐					0.00%	OK
TIPS	0.00%	☐					0.00%	OK
Emerging Markets	0.00%						0.00%	
EUR Treasury	0.00%		0.00%	0.00%	0.00%	0.00%	0.00%	OK
Total	100.00%					Total		OK

Maturity cell 1-3	18.04%
Maturity cell 3-7	17.40%
Maturity cell 7-10	10.96%
Maturity cell 10+	15.10%

4.00%

Manual input areas

Idiosyncratic Volatility

Asset class	Vol (bp/yr)
USD Treasury	0
Investment Grade Credit	60
MBS	40
Agency	40
ABS/CMBS	40
High Yield	120
TIPS	12
Emerging Markets	240
EUR Treasury	12

Covariance Matrix

Equal Weight

Half-Life (yr) n/a

Beginning Date 01/31/92

Ending Date: 06/30/03

Edit Special Selections

Current Portfolio: Allocation Weights

		Maturity cells allocation 1-3 yrs	3-7 yrs	7-10 yrs	10+ yrs	Total	
USD Cash	3.00%						
USD Treasury	20.20%	1.88%	5.74%	9.47%	3.11%	20.20%	OK
Investment Grade Credit	18.57%	3.86%	2.13%	12.58%	0.00%	18.57%	OK
MBS	22.00%					0.00%	OK
Agency	14.84%	0.00%	4.52%	5.43%	4.89%	14.84%	OK
ABS/CMBS	0.00%					0.00%	OK
High Yield	5.00%					0.00%	OK
TIPS	0.00%					0.00%	OK
Emerging Markets	4.50%					0.00%	
EUR Treasury	11.89%	3.15%	4.20%	2.40%	2.14%	11.89%	OK
Total	100.00%				Total		OK

Maturity cell 1-3	5.74%
Maturity cell 3-7	12.39%
Maturity cell 7-10	27.48%
Maturity cell 10+	8.00%

Current Portfolio: Active Positions and Turnover Limits

		Turnover Limit
Maturity cell 1-3	-12.30%	1000.00%
Maturity cell 3-7	-5.01%	1000.00%
Maturity cell 7-10	16.52%	1000.00%
Maturity cell 10+	-7.10%	1000.00%
EUR Trs 1-3	3.15%	1000.00%
EUR Trs 3-7	4.20%	1000.00%
EUR Trs 7-10	2.40%	1000.00%
EUR Trs 10+	2.14%	1000.00%
Investment Grade Credit	-8.89%	10.00%
MBS	-12.17%	15.00%
Agency	2.68%	15.00%
ABS/CMBS	-4.33%	10.00%
High Yield	5.00%	5.00%
TIPS	0.00%	1000.00%
Emerging Markets	4.50%	5.00%

Systematic TE:	51
Non-Systematic TE:	20
Total TE:	55

Global Risk Model

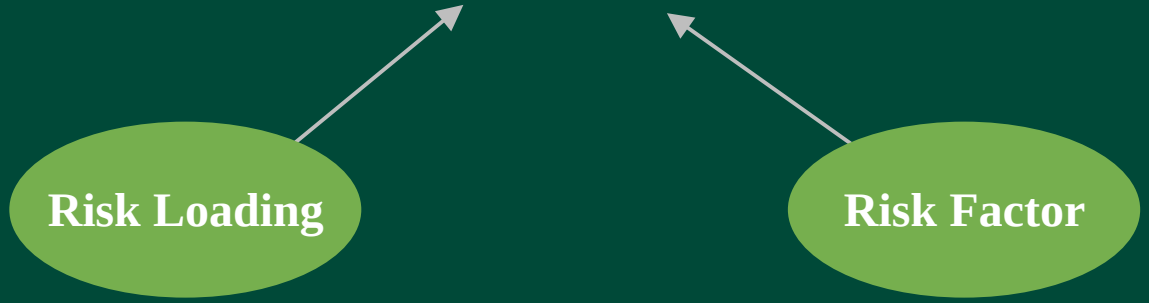
Why Do We Need a Risk Model?

- Quantify the market risk embedded in a portfolio
  - In absolute terms: expected volatility of the portfolio total returns
  - In relative terms: tracking error volatility
- Attributes ex-ante risk to major decisions implemented by fund managers
  - Currency allocation
  - Interest rate management: duration and yield curve exposure
  - Swap spreads
  - Interest rate volatility
  - Credit allocation
  - Name and security selection
- Can be used in
  - Monitoring active risk
  - Portfolio optimisation
  - Risk Budgeting
  - Scenario analysis

Lehman's Model Framework

- The return of any particular fixed income security can be decomposed linearly:

$$R_{i,(t+1)} = \mu_{i,t} + L_{i,t} \cdot f_{(t+1)} + \varepsilon_{i,(t+1)}$$



- This general framework has been used in our risk modeling work since the early 90's and has proved robust, flexible, and intuitive

Categories of Risk factors

Category	Factor	Sensitivity
Currency	Change in spot exchange rate	Market value
Yield curve	Yield changes for key tenors of the respective Treasury par curve	Key rate duration
	Square of yield change	Convexity
Volatility	Change in Swaption volatility/latent factor	Volatility duration
Swap spreads	Changes in swap spreads for key tenors	Spread duration
Spread	Systematic change in spread across an entire sector/quality cell	Spread duration
	Change in spread curve slope	Sprd Durt * Norm Life
	Change in spread level premium	Sprd Durt * Norm OAS Level
	Geographic factors (US vs. Non-US issuers)	Spread duration
Non-systematic spread	Issue/issuer-specific spread change	Spread duration

Indicative Number of Systematic Risk Factors

Factor	All	USD	EUR	GBP	JPY	Other	Core
Currency	18	-	1	1	1	15	8
Curve	58	7	7	7	8	29	23
Volatility	8	6	1	1			3
Swap Spreads	26	6	4	4	7	5	8
IG Spread	148	75	37	24	12		16
HY Spread	18	18					
Totals	276	112	50	37	28	49	58

Yield Curve and Volatility Factors for Major Currencies

Currency	Yield Curve	Swap Spreads	Volatility
USD	6 Months 2, 5, 10, 20, 30 Yrs Convexity	6 Months 2, 5, 10, 20, 30 Yrs	6 Factors: Treasury, Agency, IG Corp, HY Corp, Short & Long MBS
EUR, GBP	6 Months 2, 5, 10, 20, 30 Yrs Convexity	2, 5, 10, 30 Yrs	5 x 5 Swaption
JPY	6 Months, 2, 5, 7, 10, 20, 30 Yrs Convexity	6 Months, 2, 5, 7, 10, 20, 30 Yrs	—

Spread Factors
Dollar Risk Model

<table>
<tr><th>Gov</th><th>Other Spread Markets</th><th>Corporate Credit</th></tr>
<tr><td rowspan="2">Treasury
Agy_farm
Agy_fhlb
Agy_fhlmc
Agy_fnma
Agy_other</td><td>10 MBS buckets
4 CMBS buckets
6 ABS buckets

Non-Corp Aaa/Aa
Non-Corp A
Non-Corp Baa</td><td>24 IG buckets across 3 qualities and 8 sectors:
Banking, Finance, Basic, Energy, Cyclical, Non-Cyclical, Communication, Utility

11 HY buckets, one for each of:
Basic, Cyclical, ConsumerGoods, Communications, Energy, Finance, Medical, Non-Cyclical, Technology, Transport, Utility</td></tr>
<tr><td colspan="2">2 geographic factors</td></tr>
<tr><td colspan="2">2 Spread Slope Factors</td><td>Spread Slope Factor</td></tr>
<tr><td colspan="2">2 Spread Level Factors</td><td>Spread Level Factor</td></tr>
</table>

US MBS Risk Factors (12 Factors)

MBS Volatility Factors

Short volatility

Long volatility

MBS Spread Factors

New discounts

New current coupon

New premiums

Seasoned current coupon

Seasoned premiums

30-year GNMA

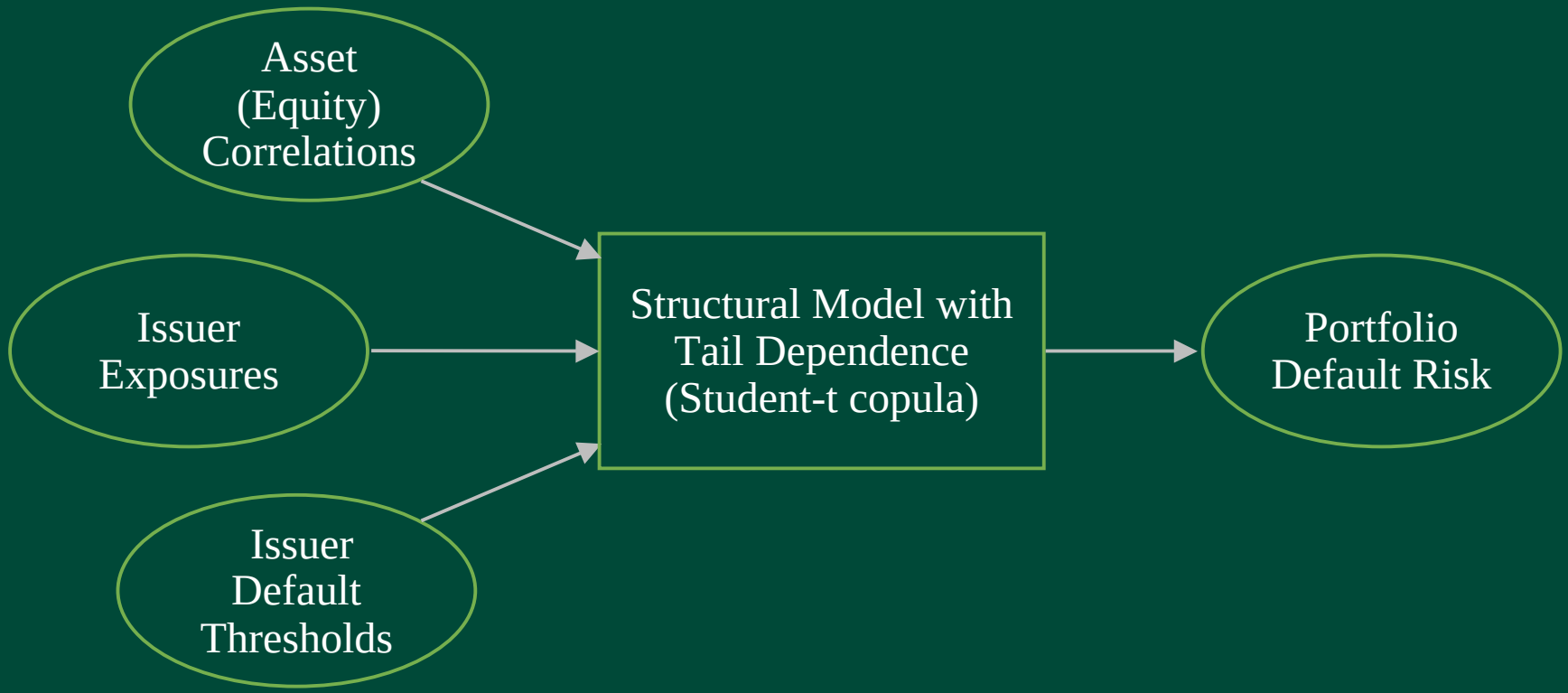
15-year FNMA/FHLMC

15-year GNMA

Balloon FNMA/FHLMC

Default Risk: Portfolio

- Default risk at the portfolio level considers correlations among issuer default events, which make default a systematic risk

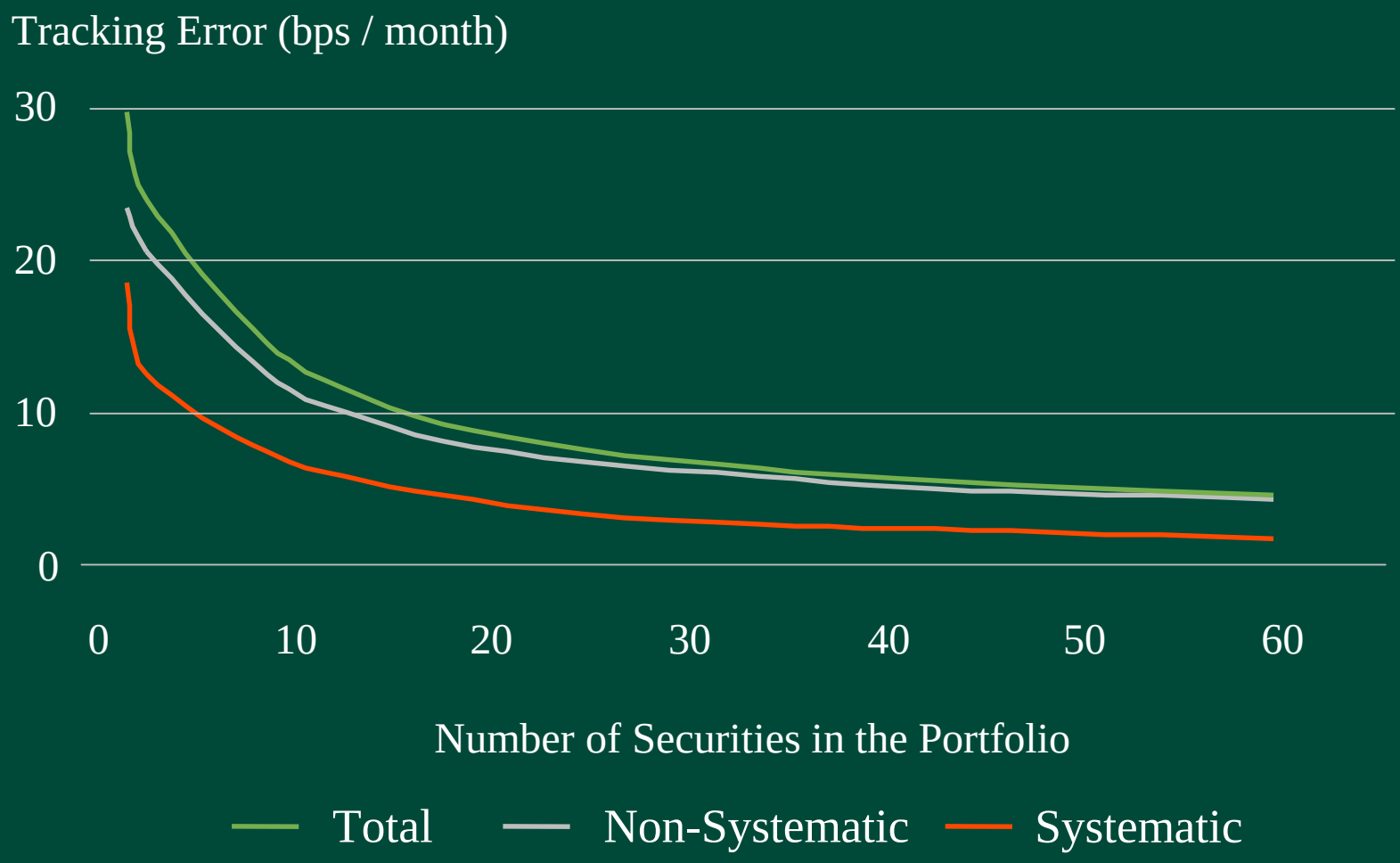


Calculation of Variance due to Special Risk (Issue-Specific Model)

	Portfolio Weights	Benchmark Weights	Contribution to Issue-Specific Risk
Issue 1	w_{P_1}	w_{B_1}	$\left(w_{P_1} - w_{B_1}\right)^2 SD_1^2 \sigma_{\varepsilon_1}^2$
Issue 2	w_{P_2}	w_{B_2}	$\left(w_{P_2} - w_{B_2}\right)^2 SD_2^2 \sigma_{\varepsilon_2}^2$
Issue N	w_{P_N}	w_{B_N}	$\left(w_{P_N} - w_{B_N}\right)^2 SD_N^2 \sigma_{\varepsilon_N}^2$
Total Issue-Specific Risk			$\sum_{i=1}^{N} (w_{P_i} - w_{B_i})^2 SD_i^2 \sigma_{\varepsilon_i}^2$
Total Issuer-Specific Risk			$\sum_{i=1}^{N} \left\{ \sum_{j \in S_i} w_{P_j} SD_j \sigma_{\varepsilon_{i,j}} - \sum_{j \in S_i} w_{B_j} SD_j \sigma_{\varepsilon_{i,j}} \right\}^2$

Risk Model Application: Effect of Diversification on Index Tracking

Portfolio Tracking Error vs. LB Euro Aggregate Index



Risk Model Application: Risk Budgeting Comparing Risk of Diverse Market Exposures

Risk (bp/month) when deviating from the Sterling Aggregate Index

	20% Ovwt Non-Gilt	0.5 yr Duration Extension
Sources of tracking error		
Term structure	1.5	9.8
Non-term structure	3.4	4.5
Swap spreads	3.6	2.3
Credit spreads	3.6	4.4
Non-systematic	11.3	7.2
Total TE	**11.9**	**11.6**

POINT: Tracking Error Report
What are the Sources of Risk?

Global Risk Model Glossary

User-defined Parameters	Portfolio/Benchmark Comparison	Tracking Error	Factor Exposure - Full Details	Portfolio Issue-Specific Risk	Credit Tickers	Warnings & Exclusions

Tracking Error, 10/31/2003

Portfolio : GRMRV | Benchmark : Global Agg

Global Risk Factor	Isolated TEV	Cumulative TEV	Difference in cumulative	Percentage of tracking error variance	Portfolio beta
Global:					

Currency	19.1	19.1	19.1	53.8	1.1
Yield Curve	8.95	22.98	3.88	19.42	0.96
Swap Spreads	0.99	22.73	-0.25	-0.9	1.04
Volatility	0.15	22.74	0.01	0.06	1.05
Investment-Grade Spreads	2.33	22.85	0.11	0.91	1.01
~~ Treasury Spreads	1.14	22.66	-0.09	-0.28	1.44
~~ Credit and Agency Spreads	1.61	22.85	0.2	1.04	1.02
~~ MBS/Securitized	0.98	22.9	0.04	0.16	0.93
~~ CMBS/ABS	0.37	22.85	-0.05	-0.01	1.75
High Yield Spreads	6.97	25.61	2.76	11.82	
Systematic risk	25.61	25.61	0.0	85.1	1.05
Idiosyncratic risk	8.38	26.94	1.34	9.11	
Default risk	6.68	27.76	0.82	5.79	
Total risk (bp/month)		27.76	0.0	100.0	
Portfolio volatility (bp/month)					127.93
Benchmark volatility (bp/month)					119.34

- Upper part of report shows Global Risk Factors
- Lower part shows Risk Factors grouped by currency bloc (not shown)

POINT: Tracking Error Report
What is the Portfolio's Sensitivity to Risk Factors?

Global Risk Model — Glossary

User-defined Parameters | Portfolio/Benchmark Comparison | Tracking Error | Factor Exposure - Full Details | Portfolio Issue-Specific Risk | Credit Tickers | Warnings & Exclusions

Factor Exposure - Full Details, 10/31/2003

Portfolio : GRMRV — Benchmark : Global Agg

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%	37.66	42.2	-4.53	0.0	-0.0		0.0	-0.(
CAD Currency	MV%	2.6	1.8	0.8	2.12	1.69	11.47	0.243	2.5
EUR Currency	MV%	34.17	30.41	3.76	2.97	11.16	21.17	0.628	30.6
GBP Currency	MV%	3.7	4.16	-0.46	2.76	-1.26	17.8	0.49	-2.9
DKK Currency	MV%	0.68	0.53	0.15	3.44	0.52	20.38	0.7	1.3(
SEK Currency	MV%	0.37	0.5	-0.13	3.21	-0.43	20.13	0.646	-1.1
NOK Currency	MV%	1.96	0.13	1.83	3.54	6.47	20.89	0.739	17.5
JPY Currency	MV%	16.52	18.82	-2.31	2.72	-6.29	4.26	0.116	-3.4
KEY RATES AND CONVEXITY:									

USD 6M key rate	KRD (Yr)	0.071	0.064	0.0060	19.67	-0.12	3.62	-0.712	-0.0(
USD 2Y key rate	KRD (Yr)	0.19	0.268	-0.078	32.22	2.53	15.62	-5.032	5.1
USD 5Y key rate	KRD (Yr)	0.411	0.485	-0.074	40.44	2.99	18.08	-7.314	7.0
USD 10Y key rate	KRD (Yr)	0.459	0.56	-0.101	37.35	3.79	17.76	-6.632	8.7
USD 20Y key rate	KRD (Yr)	0.196	0.377	-0.18	31.39	5.66	16.7	-5.241	12.2(
USD 30Y key rate	KRD (Yr)	0.153	0.173	-0.02	29.56	0.6	15.94	-4.713	1.2
USD Convexity	OAC (Yr^2/100)	-0.18	-0.094	-0.086	5.87	-0.51	3.15	0.185	-0.2
CAD 6M key rate	KRD (Yr)	0.0070	0.0010	0.0060	22.81	-0.14	8.01	-1.828	-0.1
CAD 2Y key rate	KRD (Yr)	0.021	0.0090	0.011	32.18	-0.37	12.15	-3.909	-0.5(
CAD 5Y key rate	KRD (Yr)	0.0010	0.025	-0.024	29.89	0.7	13.08	-3.91	1.1
CAD 10Y key rate	KRD (Yr)	0.047	0.038	0.0090	25.32	-0.23	12.14	-3.073	-0.3

- Report lists sensitivities to all risk factors to which portfolio or benchmark are exposed
- The volatility of each risk factor is shown. TE impact of risk factor = Net exposure X Factor volatility

POINT: Issuer Specific Risk
How much Idiosyncratic Risk is There?

- All bonds of a single issuer (grouped by ticker) are grouped together
- Issuers are sorted by idiosyncratic risk exposures

Global Risk Model | **Glossary**

User-defined Parameters | Portfolio/Benchmark Comparison | Tracking Error | Factor Exposure - Full Details | Portfolio Issue-Specific Risk | Credit Tickers | Warnings & Exclusions

Credit Tickers, 10/31/2003

Portfolio : GRMRV | Benchmark : Global Agg

Ticker	Name	Sector	Rating	Currency	# issues in portfolio	Portfolio weight	Benchmark weight	Net weight	Net contribution to OASD	Systematic risk	Idiosyncratic risk
CREDIT											

AWE	AT&T WIRELESS SVCS INC-GLOBAL	Industrial	BAA2	USD	1	1.5	0.06	1.45	0.092	3.84	3.66
NXTL	NEXTEL COMM	Industrial	B2	USD	1	0.28	0.0	0.28	0.018	2.07	2.72
NRUC	NATIONAL RURAL UTILS CFC-GLOBA	MULTIPLE	A1 A2	USD EUR	1	1.13	0.05	1.07	0.134	4.34	2.61
QUS	QWEST SERVICES CORP	Industrial	CAA1	USD	1	0.22	0.0	0.22	0.0080	0.67	2.51
TYC	TYCO INTL GROUP SA	Industrial	BA2	USD	1	0.48	0.0	0.48	0.03	0.85	2.3
THC	TENET HEALTHCARE CORP	Industrial	BA3	USD	1	0.38	0.0	0.38	0.025	0.69	1.73
NSC	NORFOLK SOUTHERN CORP	Industrial	BAA2	USD	1	0.75	0.03	0.71	0.08	2.52	1.69
DT	DEUTSCHE TELEKOM INT FIN-GLOBA	MULTIPLE	BAA3	USD EUR GBP JPY	1	0.83	0.26	0.57	0.038	1.9	1.65
GM	GENERAL MOTORS ACPT CORP	MULTIPLE	BAA2	USD EUR GBP JPY	0	0.0	0.42	-0.42	-0.022	0.56	0.67

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