Quantitative Finance Using R

An Overview

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Introduction

Describe the context within which development is taking place

- How and where R adds value in investing
- Our motivation for writing packages

Show three specific applications using R packages:

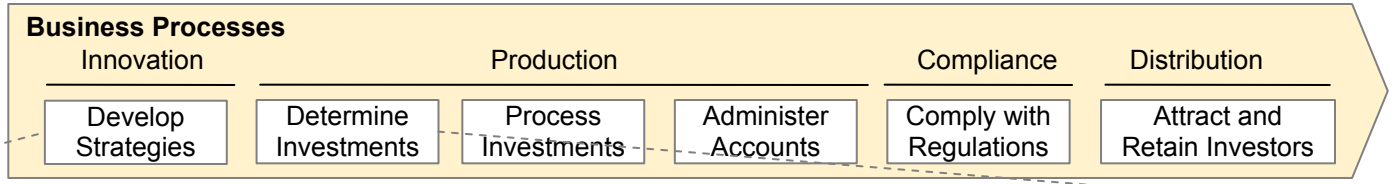
- Performance analysis relative to a peer group
- Strategic allocation of a portfolio
- Backtesting of a trading strategy

Discuss further work

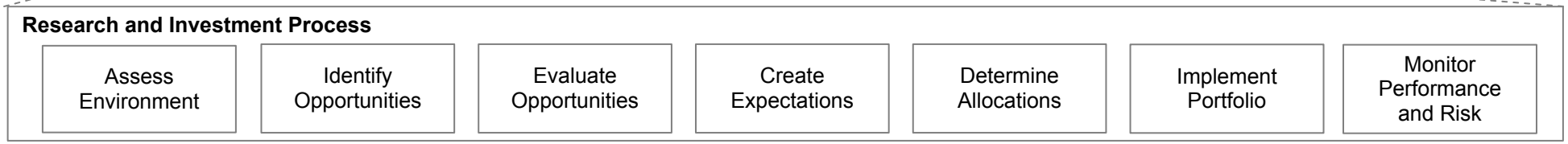
- Google Summer of Code
- Areas of continuing development

Research Process and Capabilities

Business View



Process View



Capabilities View

Strategy Development	Performance Measurement	Performance Attribution	Risk Measurement	Risk Management	Portfolio Construction
What should work?	**What has the strategy achieved?**	**How has the strategy achieved it?**	**What risks are being taken?**	**What can we do about risk?**	**What is the best use of our capital?**
What do we think about the environment? What scenarios or themes will affect performance and risk? Can we effectively tilt our portfolio to capture our views on performance? What is our “neutral” view?	Is performance on track with our expectations? How does performance look in context of risk? How did the strategy compare to its peers? What is a suitable benchmark for performance? How confident are we in our assessment?	How does the strategy generate returns? Are we skilled or lucky? Are we deviating from what we’ve done in the past? How confident are we in our assessments?	What risks does the strategy take? What is its sensitivity to the risks? What risks does the aggregate portfolio contain? What is our exposure to extreme risks? What happens to the strategy/portfolio if...?	What risks does our portfolio contain? What is an appropriate level for each risk? What should we do about them? What should we hedge? What should we use / how much to hedge? How much should we be willing to pay for insurance?	What are our objectives for return and risk? How do we deploy our capital to best meet those objectives? Can we design a portfolio for a particular objective? Is the level of diversification appropriate?

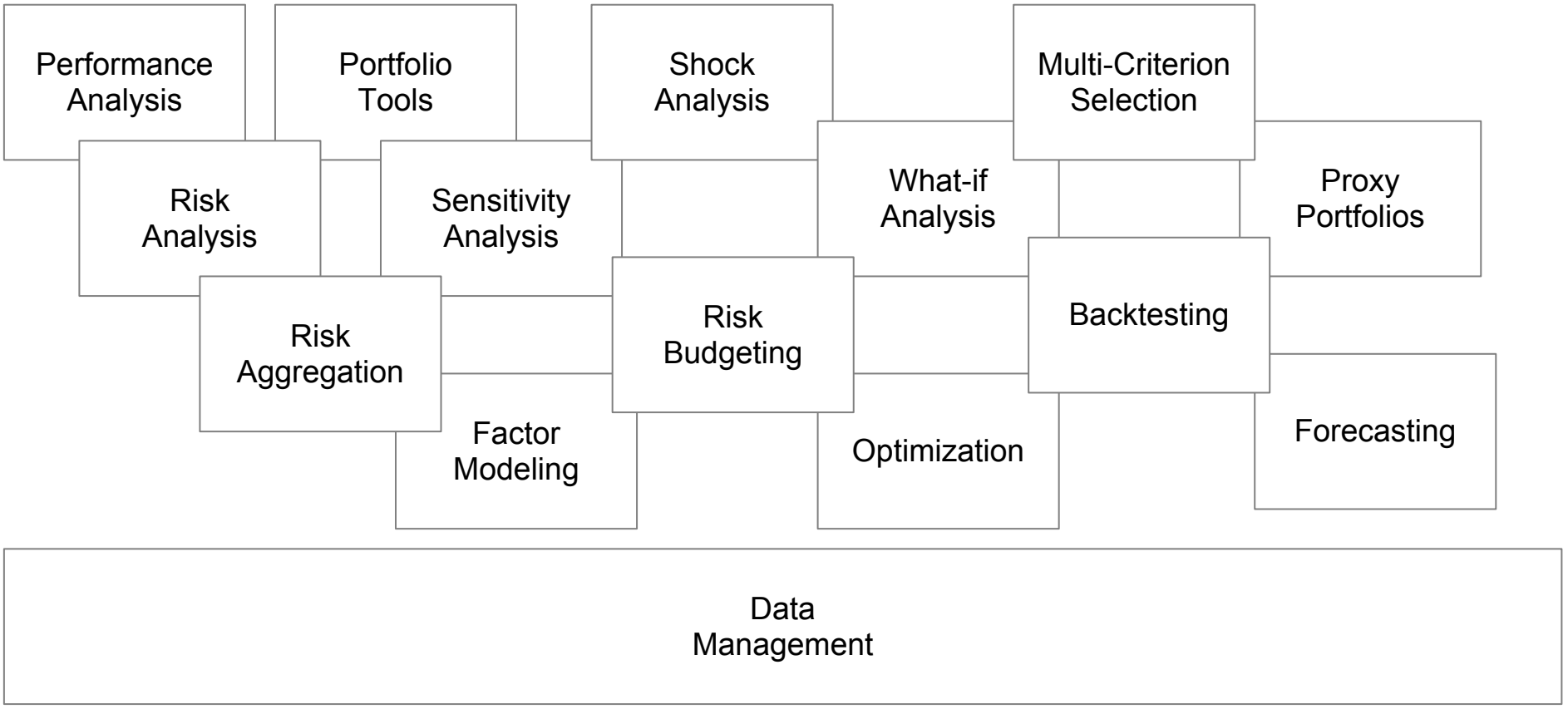
Research Process

Objectives

Make high quality decisions efficiently, effectively.

Decision-focused information
Repeatable decision-making
Accretion of evidence, statistical confidence
Multiple faceted views
Support fast-cycle experimentation

Tools View



Functional Architecture

Functional Groupings

Applications/Reporting	Statementing, Attribution, Risk Analysis, Screening Reporting Tables, Graphics
Portfolio	Profit & Loss, Account Hierarchy Positions Position, Transaction, OMS Connections
Optimization/Sizing	Sizing/Allocation Risk Budgeting, Weighting, Optimization
Modeling/Analytics	Return Forecast, Risk Forecast, Backtesting, Shock Valuation, Signal Generation, Risk Measurement, Simulation Price Transformation, Distribution Fitting
Instrument	Contract Specifications, Corporate Actions Instrument Specifications
Time series	Calendars, Period Aggregation, Date Alignment Timezones, Extended date/time indexing
Data	Real-Time, Historical, Database Connections

Some R packages for Quantitative Research

Application/Reporting	plot.xts, PerformanceAnalytics, quantmod, Rmetrics
Portfolio	fPortfolio, portfolio, backtest, PortfolioAnalytics
Optimization/Sizing	PortfolioAnalytics, fPortfolio, portfolio, BLCOP, ROI, DEoptim,pso, soma, quantstrat
Modeling/Analytics	TTR, PerformanceAnalytics, quantstrat, etc. (most R packages fit here)
Instrument	FinancialInstrument
Time series	xts, zoo, timeSeries, its, irts
Data	RBloomberg, RTAQ, Reuters, InteractiveBrokers, tseries (Rmetrics), quantmod

PerformanceAnalytics

- Focused on returns-based analysis of performance and risk.
- Analysis of return streams, whether distributed normally or not.
- In development since early 2006, packaged and first released to CRAN in 2007
- Collaboration, patches and suggestions from users in industry and academia worldwide
- Contains over 200 functions, including over 30 chart functions and 15 table functions

Over 20,000 lines of code, over 250 pages of documentation and vignettes ...and growing

PortfolioAnalytics

- Provides numerical solutions to portfolios with complex constraints and objectives
- Unifies the interface into different numerical optimizers
- Implements a front end to two analytical solvers: Differential Evolution and Random Portfolios
- Preserves the flexibility to define any kind of objective and constraint
- Work-in-progress, available on R-Forge in the *ReturnAnalytics* project

quantstrat

- Designed and used for 'real' quantitative strategies at all frequencies
- Many strategies may be constructed from all open source components
- Proprietary strategies add custom:
  - Indicators
  - Signal Functions
  - Order Sizing Logic
- R packages blotter and FinancialInstrument provide multi-instrument, multi-currency portfolio P&L support

Package Framework

Values represented as:

Returns	Prices
PerformanceAnalytics FactorAnalytics	quantmod TTR

Positions represented as:

Weights	Transactions
PortfolioAnalytics	quantstrat blotter

Utility

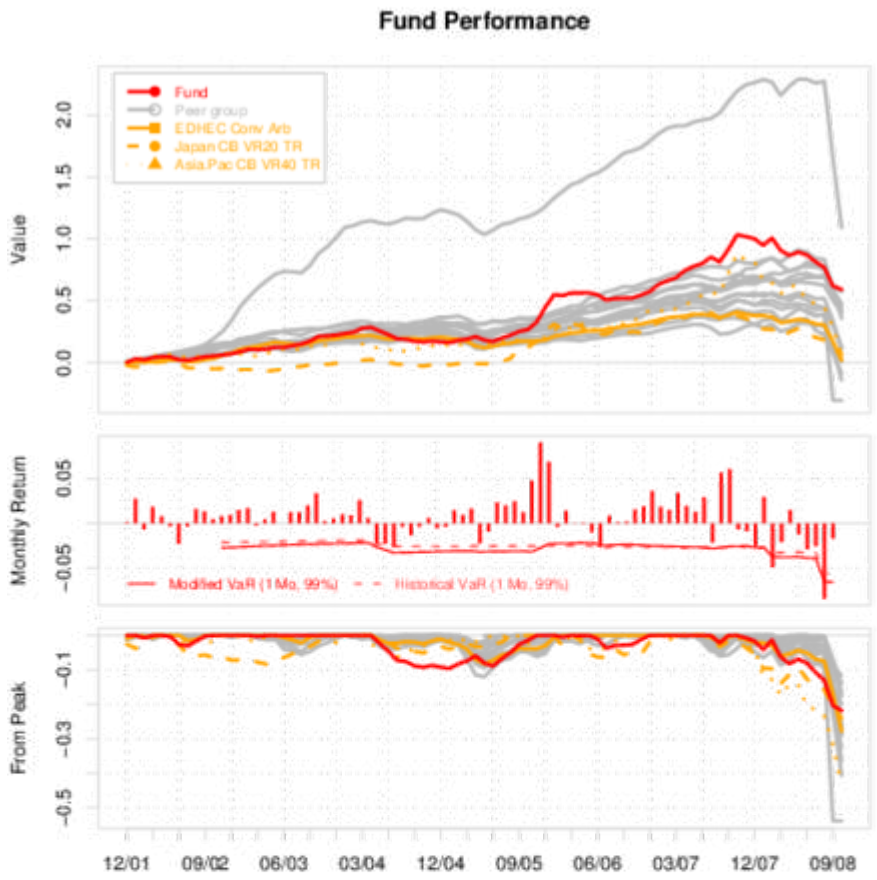
Time Series: xts

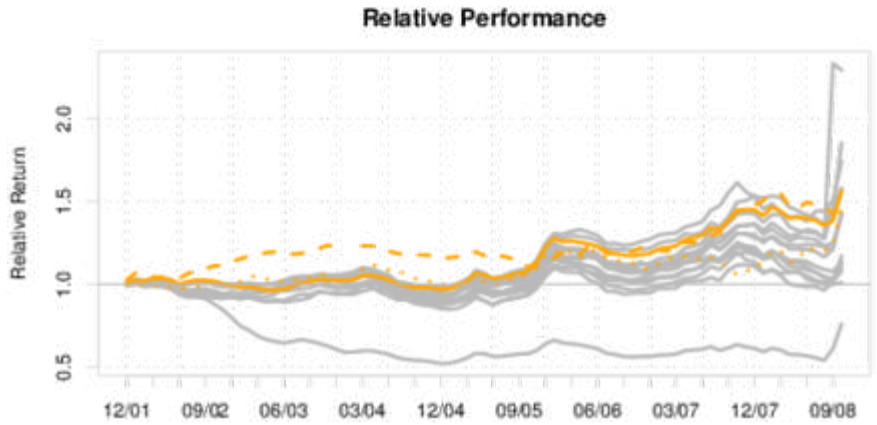
Reference Data: FinancialInstrument

Case Study: Peer Group Analysis

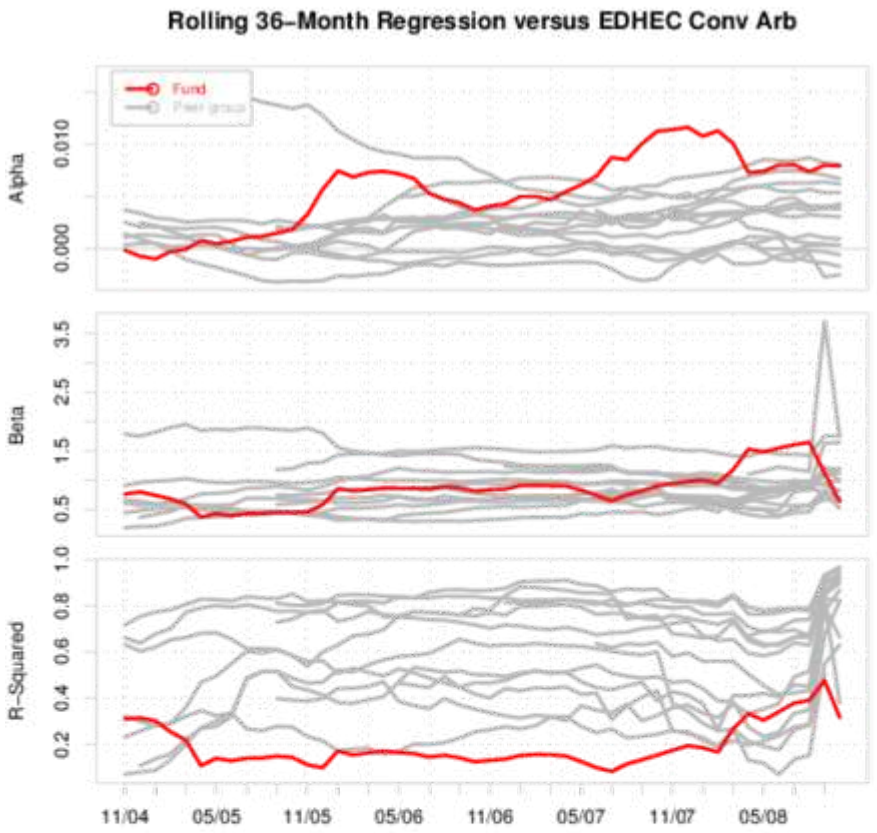
- Accrue evidence to help ask better questions
- Measurement, not prediction
- Consider return and risk together
- Small, biased samples of expensive data
- Comparisons can be tenuous
- Only one of a set of tasks taken to understand a current or potential investment

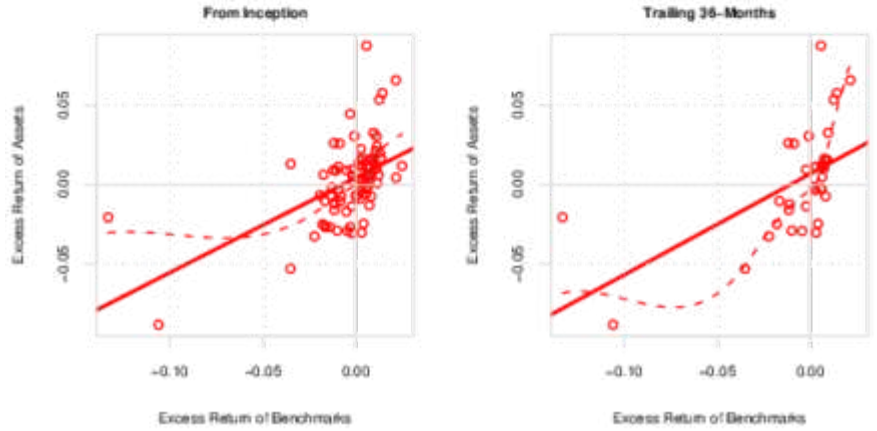
Performance Summary



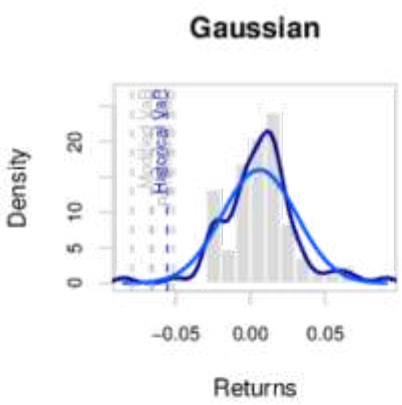


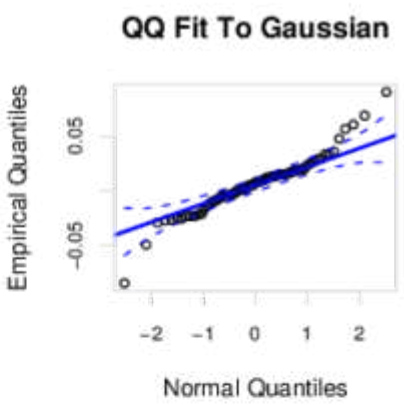
Benchmarking and Regression

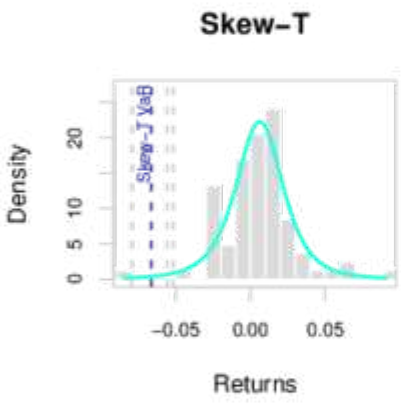


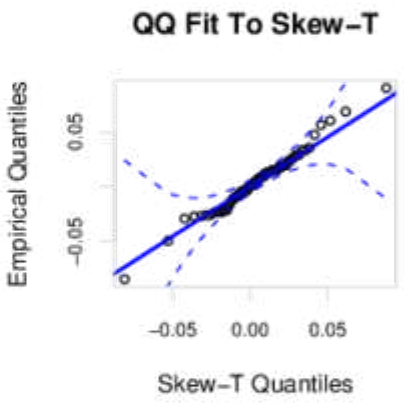


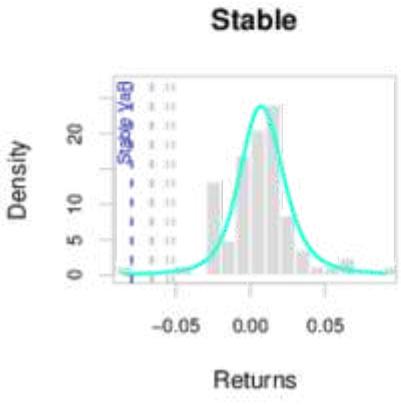
Distributions

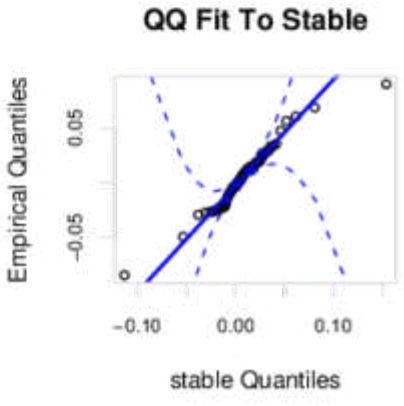




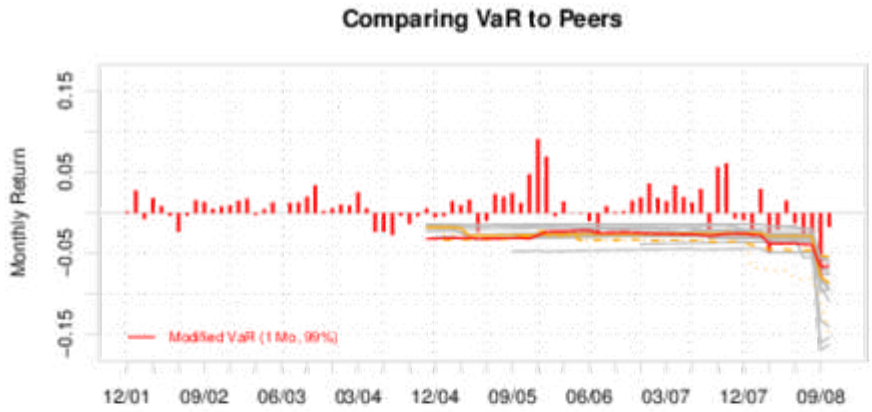


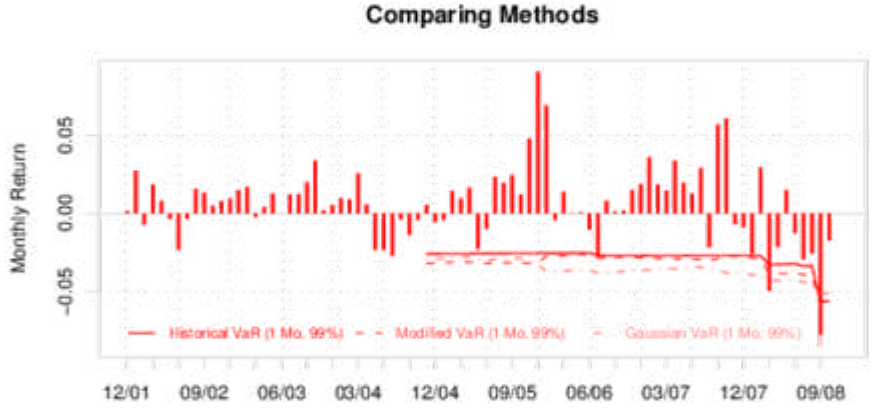


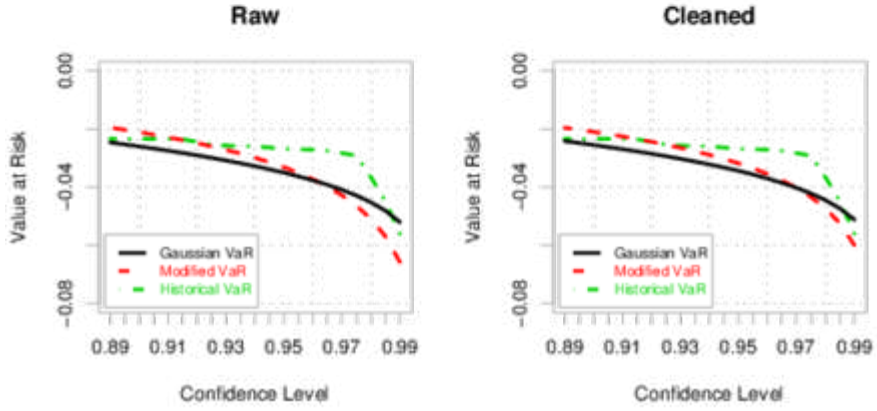




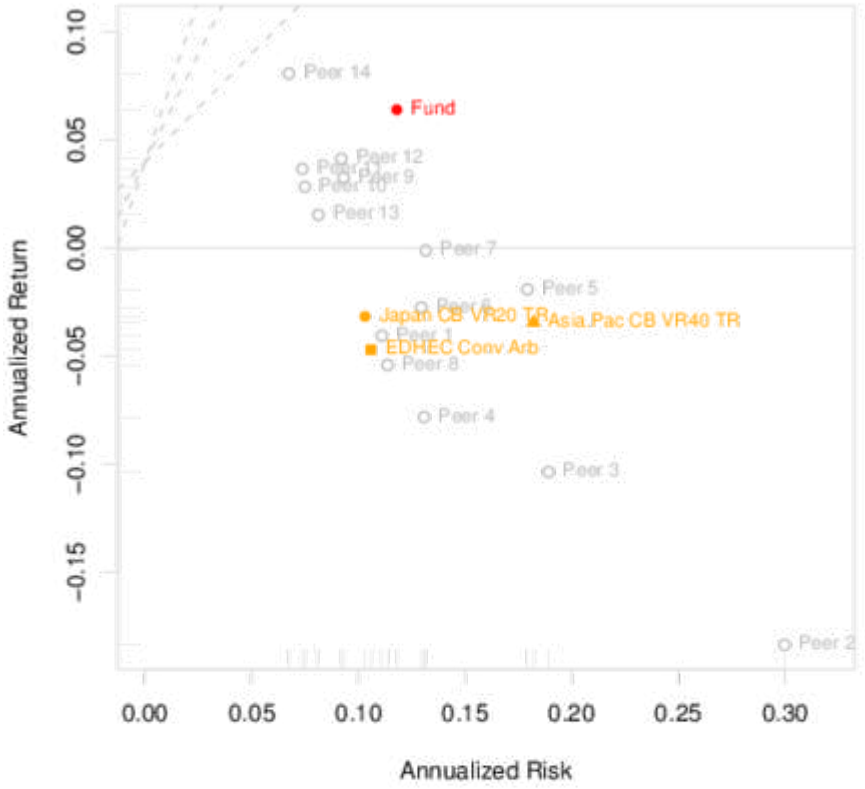
Value at Risk (VaR)

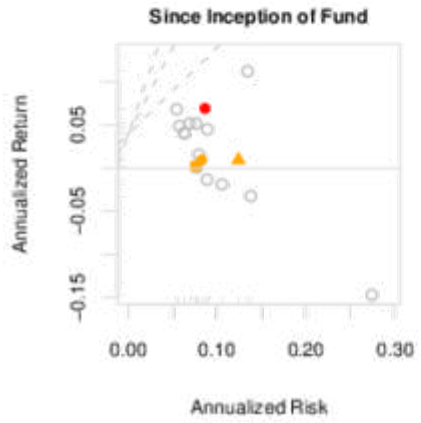


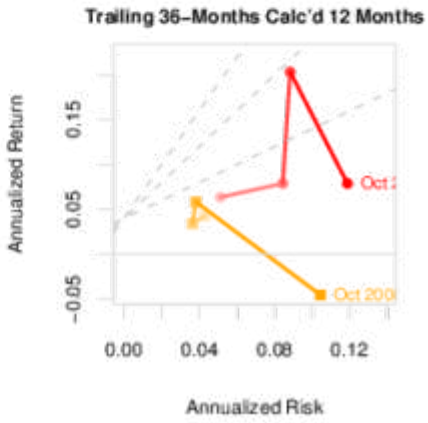




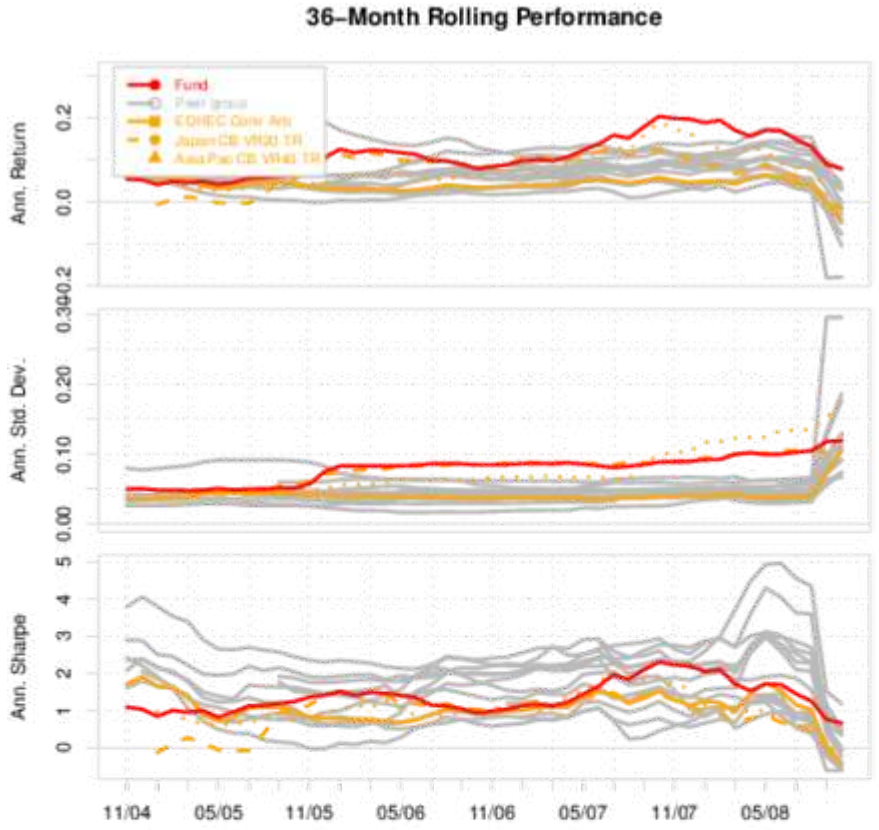
Scatter Plots

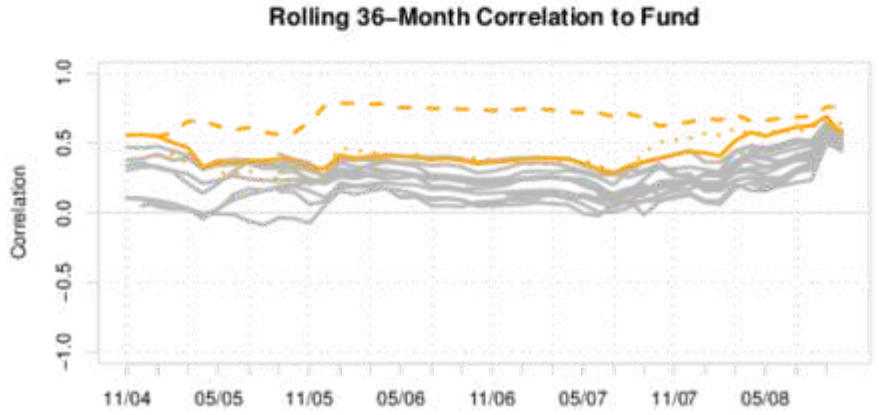






Rolling Performance





Statistics

	Semi Deviation	Gain Deviation	Loss Deviation	Downside Deviation (MAR=10%)	Downside Deviation (rf=4%)	Downside Deviation (0%)	Maximum Drawdown	VaR (99%)	Beyond VaR	Modified VaR (99%)
Japan CB VR20 TR	2.3	1.5	1.4	2.6	2.4	2.2	-24.0	5.2	5.2	5.2
Peer 10	2.4	0.6	2.3	2.3	2.5	2.9	-16.3	3.5	3.5	5.7
Peer 13	2.0	1.1	1.5	2.1	2.1	2.1	-14.7	3.9	3.9	6.1
Peer 11	2.6	0.6	2.5	2.5	2.6	3.0	-14.0	3.9	3.9	6.2
Fund	2.5	1.8	1.7	2.6	2.4	2.4	-21.8	5.2	5.2	6.6
Peer 14	2.0	0.8	2.1	1.9	2.2	2.7	-11.6	3.1	3.1	6.8
Peer 12	2.5	0.8	2.3	2.6	2.7	2.8	-17.6	4.1	4.1	7.3
Peer 9	2.8	1.0	2.3	2.7	2.8	3.0	-20.1	4.7	4.7	7.6
EDHEC Conv Arb	2.9	0.7	2.7	2.6	2.9	3.1	-27.8	3.9	3.9	8.5
Peer 8	2.8	0.7	2.8	2.5	2.9	3.2	-26.6	3.9	3.9	9.1
Peer 4	4.2	0.6	3.7	3.3	3.7	4.3	-32.7	5.9	5.9	9.1
Peer 1	2.7	0.9	2.7	2.5	2.7	3.2	-26.1	4.2	4.2	10.1
Peer 6	4.6	0.6	4.1	4.1	4.5	4.7	-28.6	7.2	7.2	10.9
Peer 7	3.4	1.6	3.8	3.5	3.8	4.3	-29.1	5.5	5.5	12.5
Asia.Pac CB VR40 TR	3.8	2.2	3.1	3.9	3.8	3.9	-43.4	7.9	7.9	13.1
Peer 3	6.4	0.9	5.6	5.5	6.0	6.2	-40.6	9.4	9.4	14.1
Peer 5	5.0	1.7	6.0	5.3	6.5	6.7	-36.5	7.6	7.7	16.0
Peer 2	17.4	0.9	11.9	10.1	11.4	12.2	-53.9	19.3	19.1	16.3

Case Study: Portfolio Optimization

- Discuss the challenges of constructing hedge fund portfolios
- Offer a framework for considering strategic allocation using hedge fund indexes
- Show the relative performance of multiple objectives

Portfolio Issues

Markowitz (1952) described an investor's objectives as:

- maximizing some measure of gain while
- minimizing some measure of risk.

Many approaches follow Markowitz and use mean return and standard deviation of returns for “risk”.

Most investors would prefer:

- to be approximately correct rather than precisely wrong
- to define risk as potential loss rather than volatility
- the flexibility to define any kind of objective and combine constraints
- a framework for considering different sets of portfolio constraints for comparison through time
- to build intuition about optimization through visualization

Portfolio Issues

Real portfolios more often have complex objectives...

Construct a portfolio that:

- maximizes return,
- with per-asset conditional constraints,
- with a specific univariate risk limit,
- while minimizing component risk concentration,
- and limiting drawdowns to a threshold value.

Not a quadratic (or linear, or conical) problem any more.

Use Random Portfolios

Burns (R/Finance 2009) describes Random Portfolios

- From a portfolio seed, generate random permutations of weights that meet your constraints on each asset.
- More from Pat at http://www.portfolioprobe.com/blog/

Sampling can help provide insight into the goals and constraints of the optimization

- Covers the 'edge case'(min/max) constraints well
- Covers the 'interior' portfolios
- Useful for finding the search space for an optimizer
- Allows arbitrary number of samples
- Allows massively parallel execution

Differential Evolution

A very powerful, elegant, population based stochastic function minimizer

- doesn't require a smooth or differentiable function
- Continuous, evolutionary optimization
- Uses real-number parameters
- has shown converging power with difficult, non-convex portfolio problems

DEoptim package implements the algorithms described in:

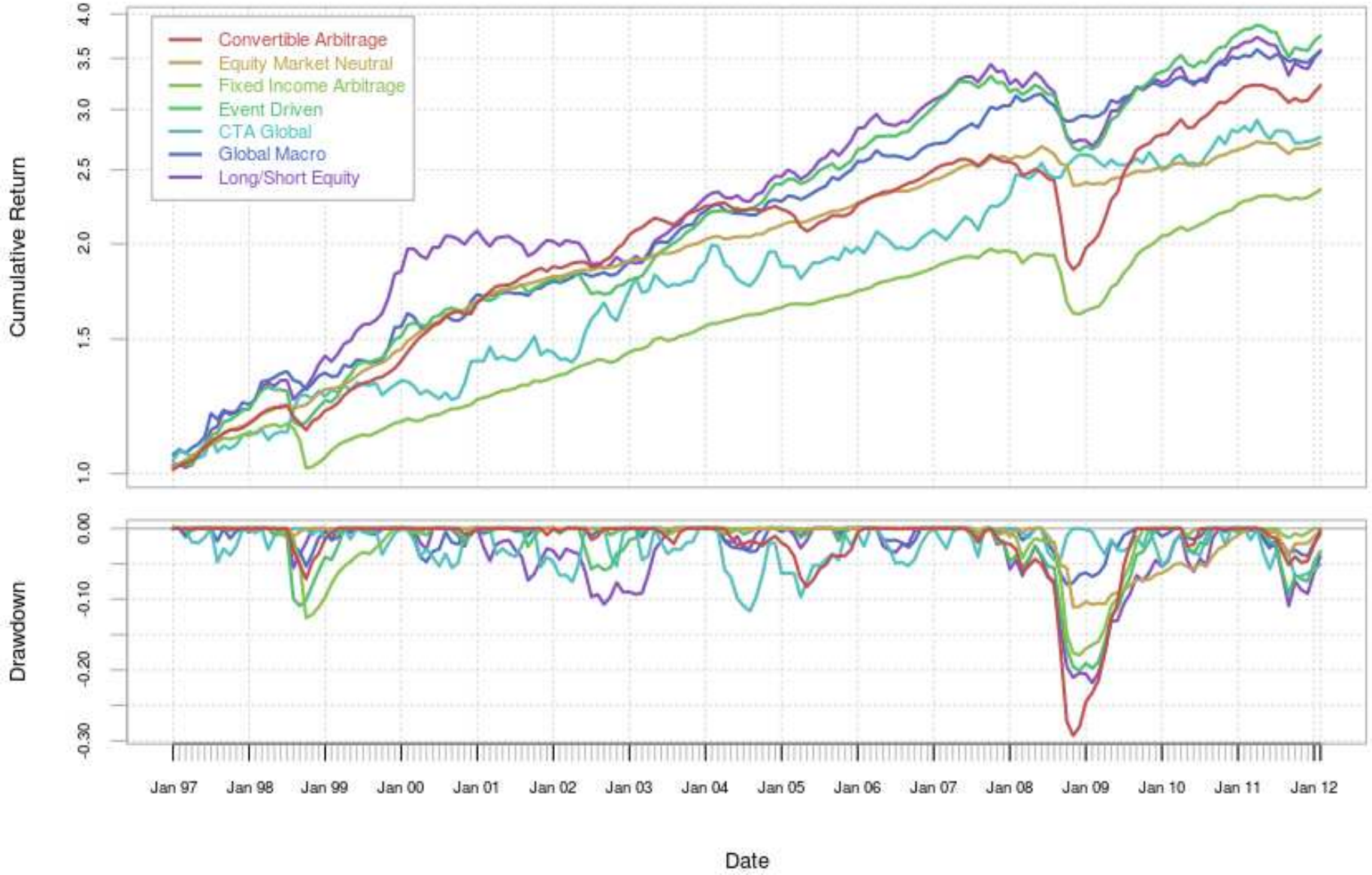
- Differential Evolution - A Practical Approach to Global Optimization by Price, K.V., Storn, R.M., Lampinen J.A, Springer-Verlag, 2005.
- Adaptive Differential Evolution by Zhang, J. and Sanderson, A.C. Springer-Verlag, 2009.
- Thanks to R co-authors David Ardia, Katharine Mullen, and Josh Ulrich

Strategic Allocation

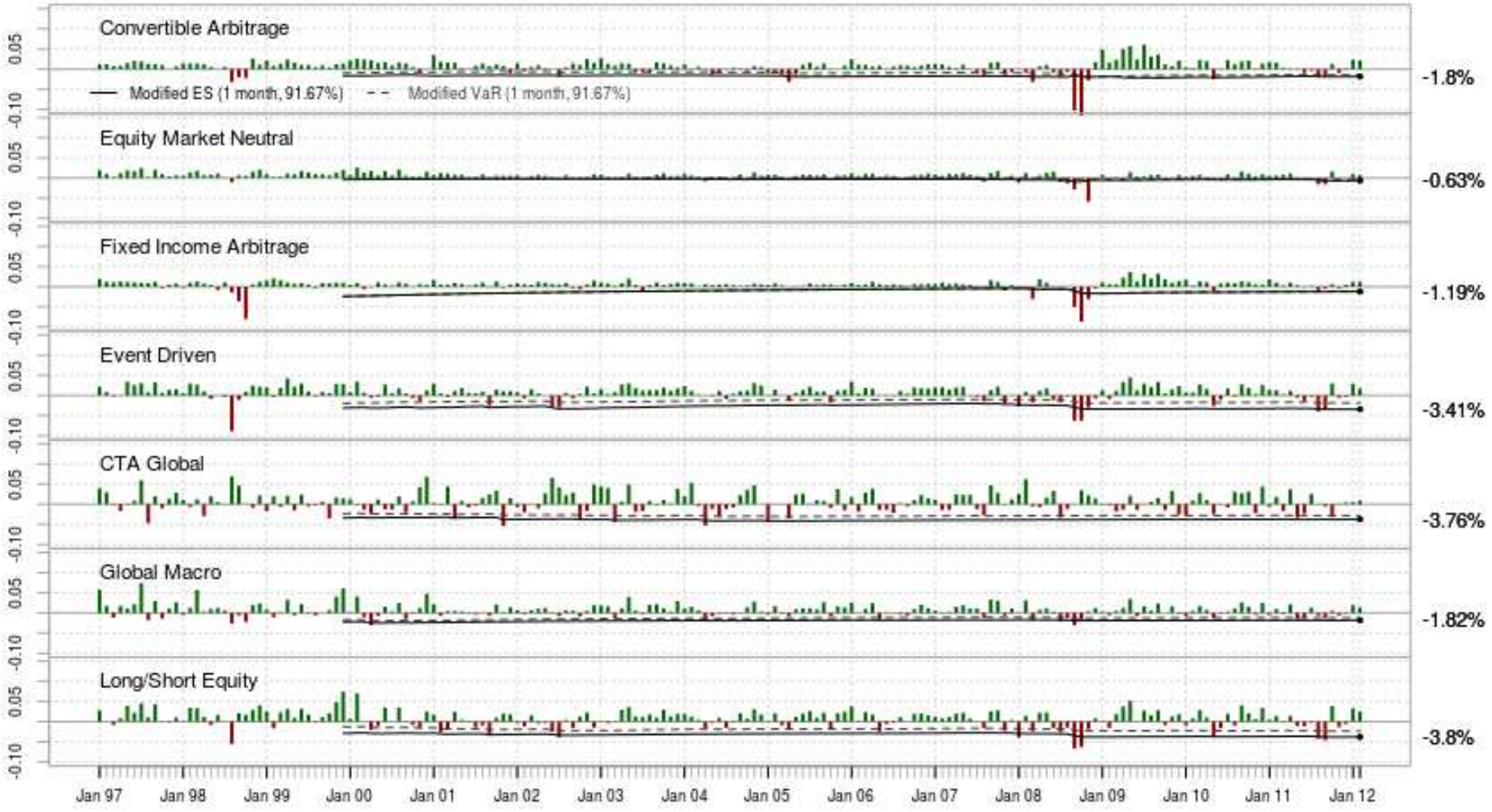
...broadly described as periodically reallocating the portfolio to achieve a long-term goal

- Understand the nature and sources of investment risk within the portfolio
- Manage the resulting balance of risk and return of the portfolio
- Applied within the context of the current economic and market situation
- Think systematically about preferences and constraints

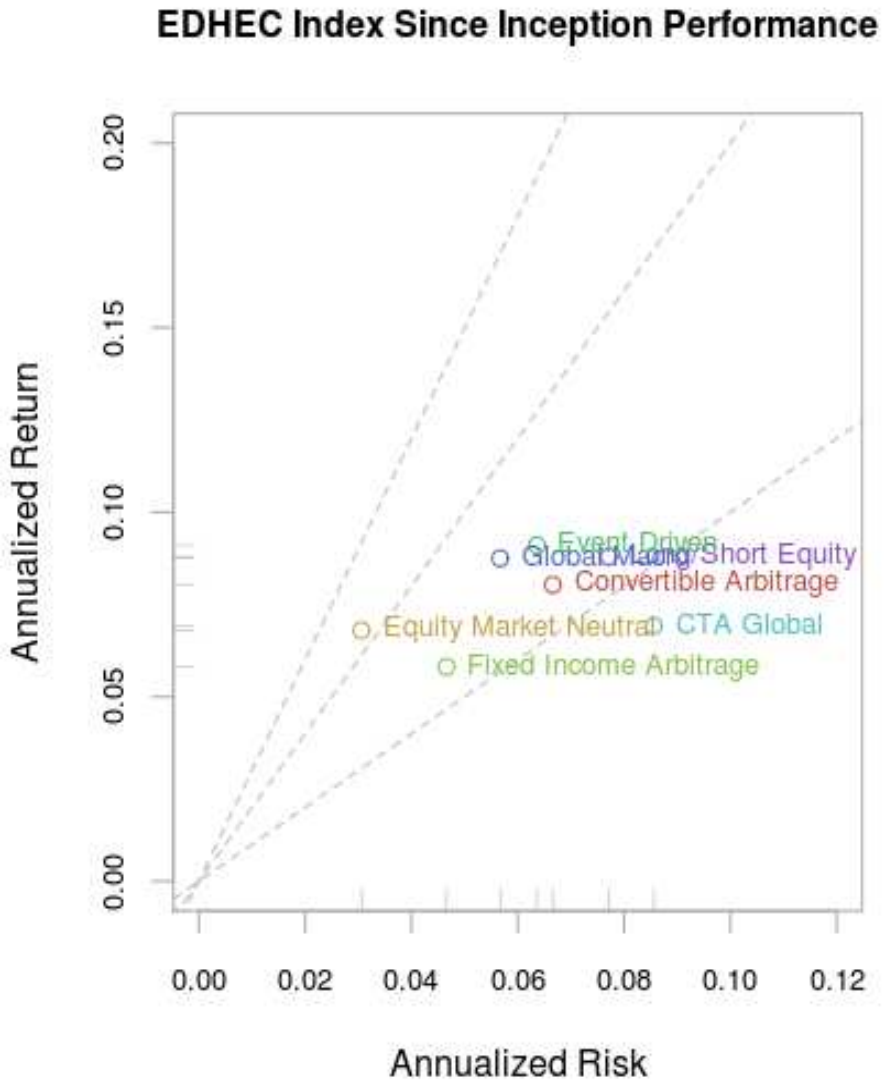
Performance of Indexes

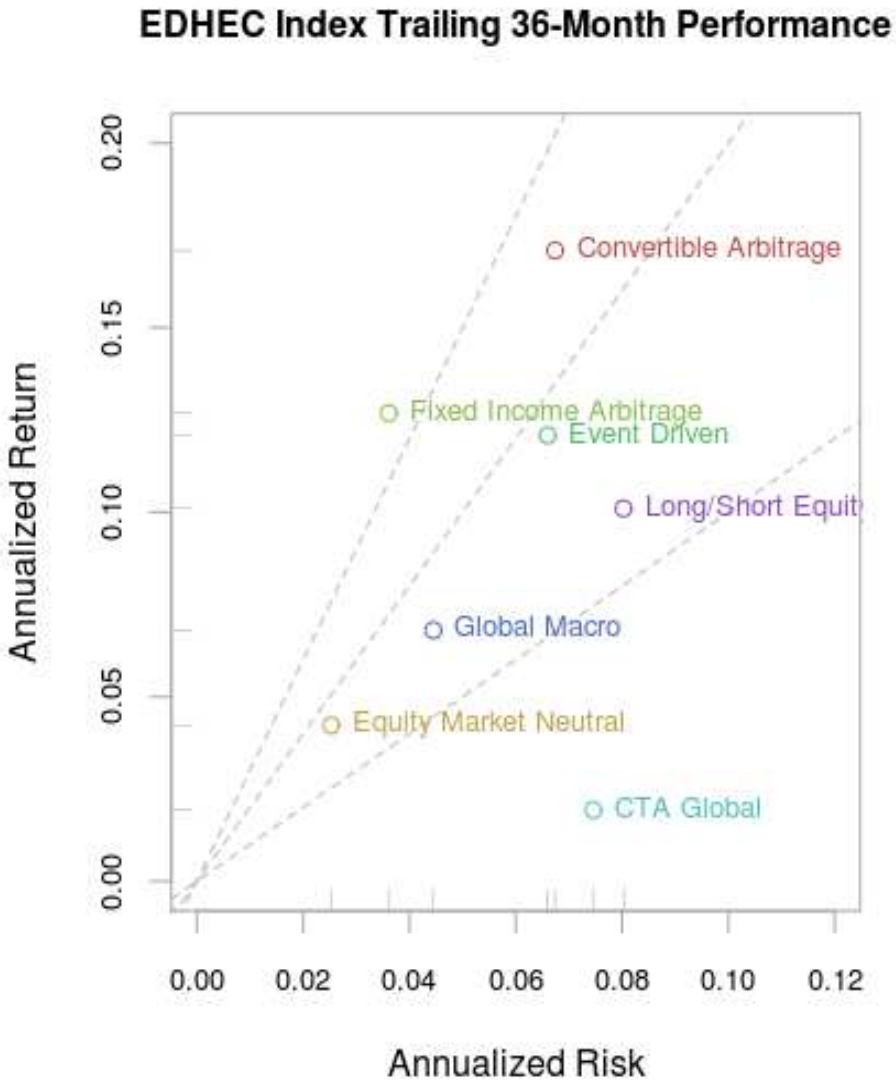


Performance of Indexes



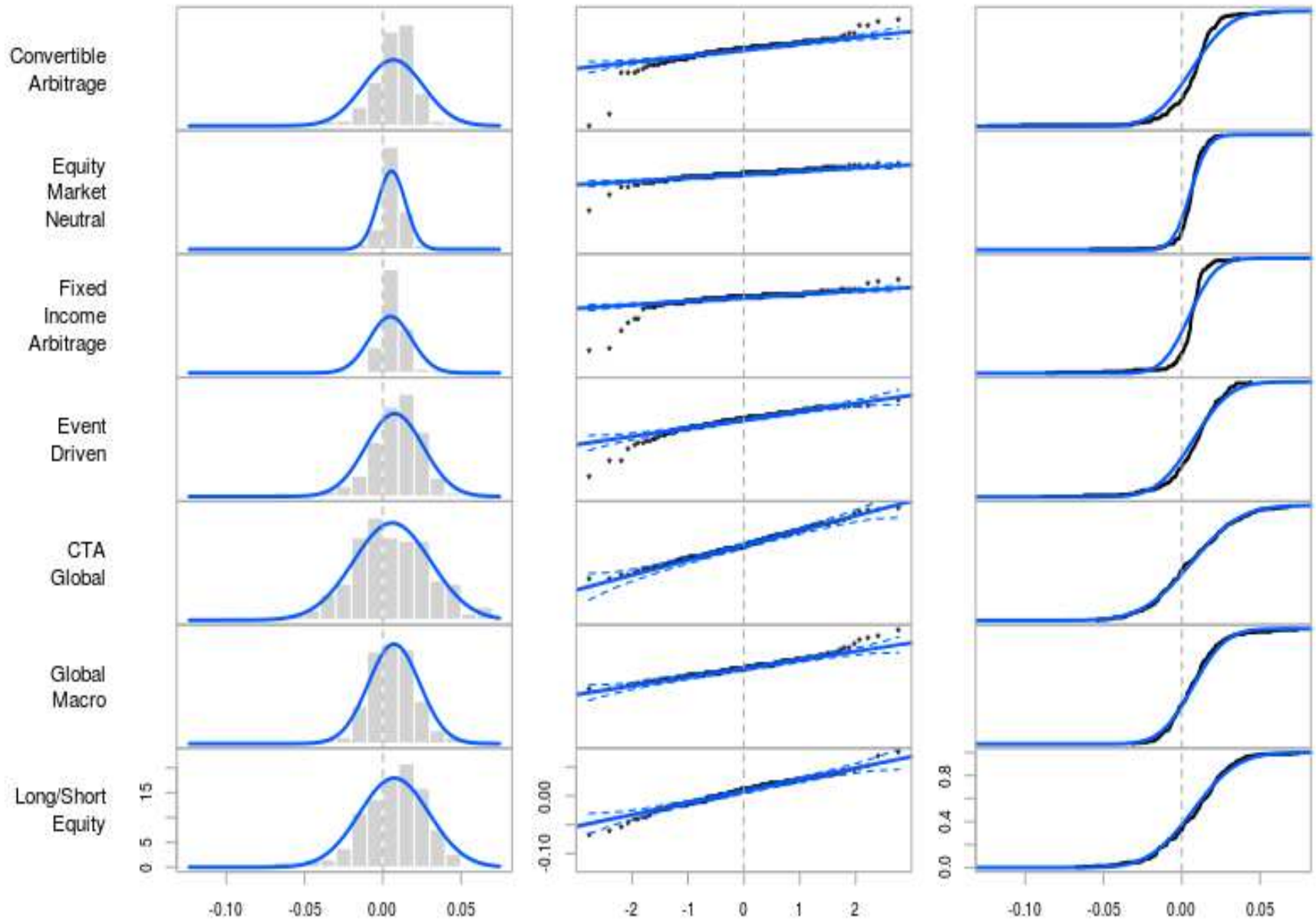
Performance of Indexes





From January 1997 to February 2012

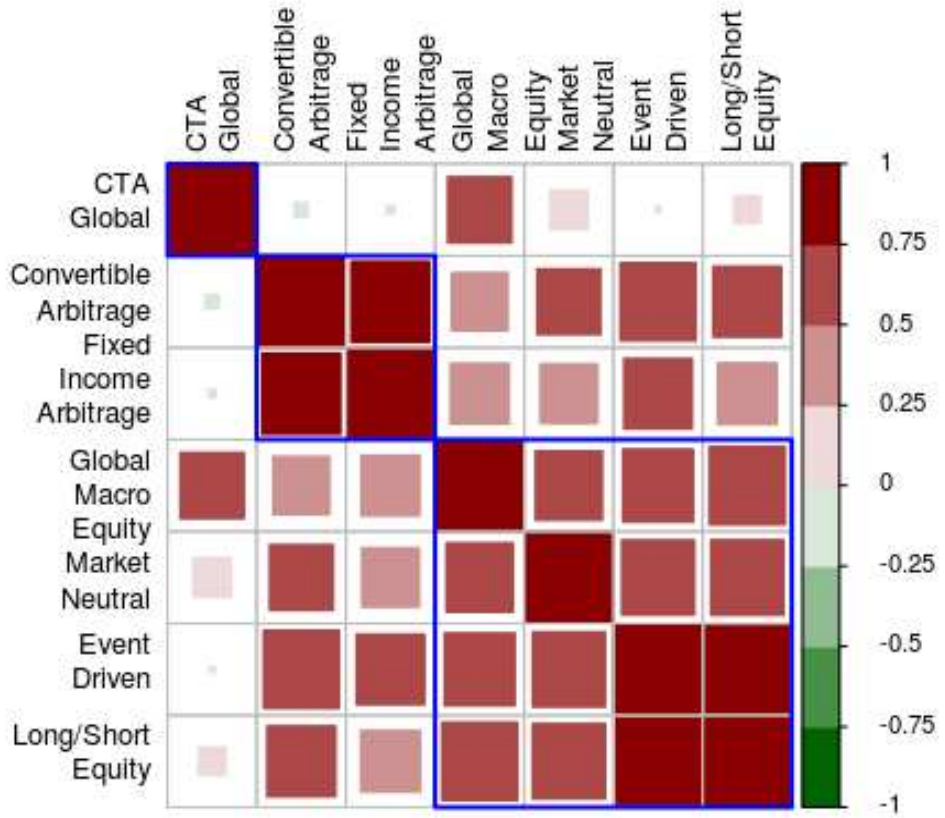
Performance of Indexes



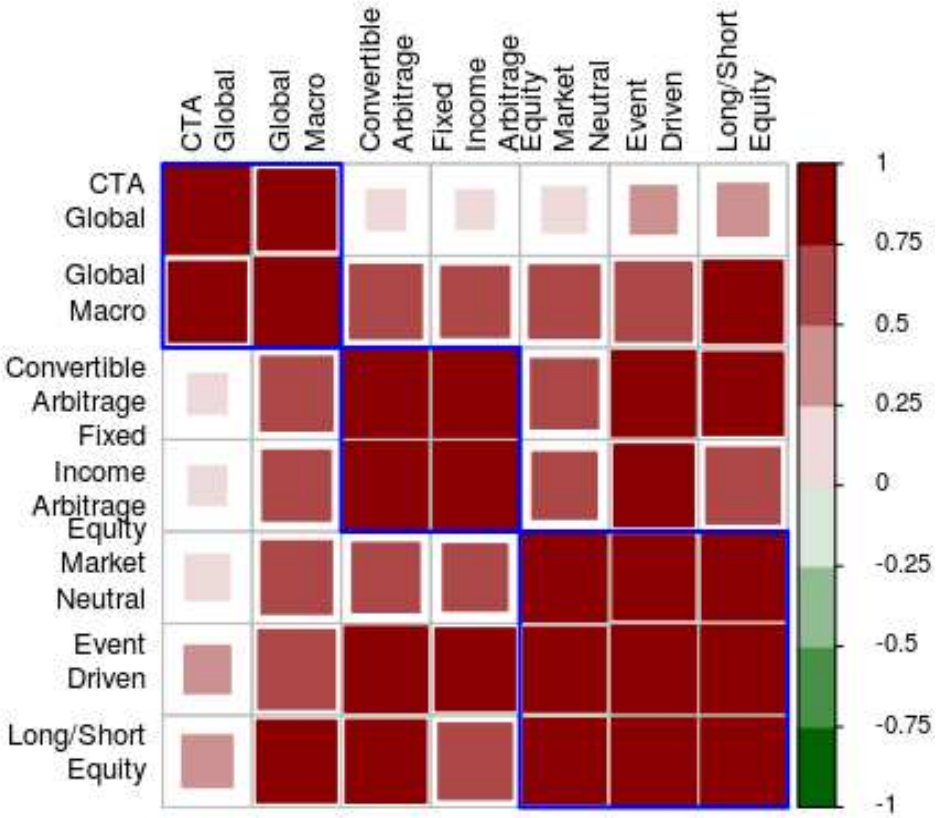
From January 1997 to February 2012

Correlation of Indexes

Since Inception



Trailing 36-Months



uses **corrplot** package

Forecasting: Improving Our Estimates

Returns

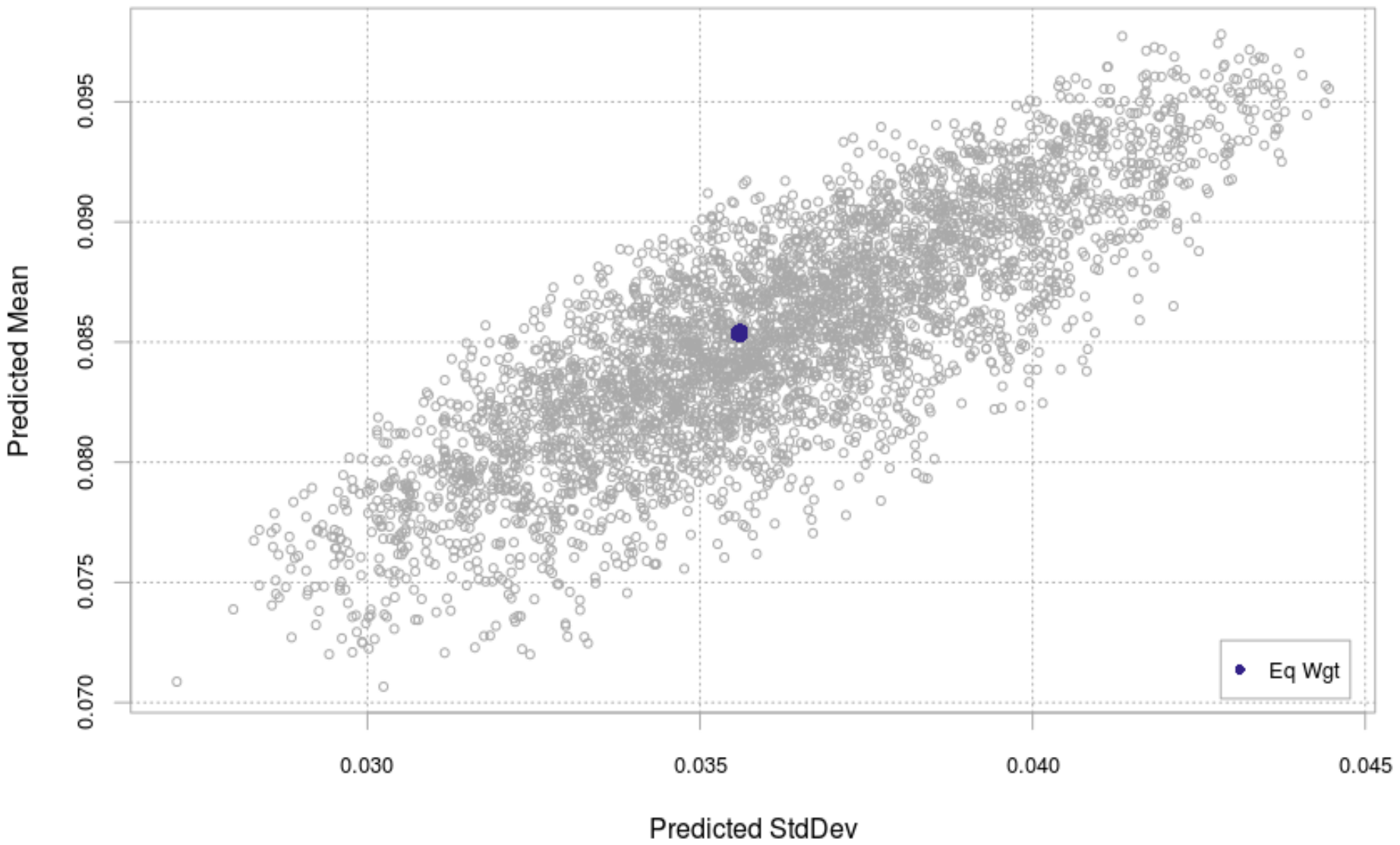
- ARMA(1,1) to try to capture some of the time varying return structure
- Preserves the observed autocorrelation of the series
- Approaches the long-run means of the series near the end, losing time-varying structure
- Merely illustrative of what is possible with a more sophisticated model
- Model specification close to defaults in *rugarch*

Volatility

- Standard GARCH(1,1) framework
- Uses Dynamic Conditional Correlation to capture interdependencies among the series
- Modeled an asymmetric generalized hyperbolic distribution to allow for coskewness and cokurtosis of the return series
- Used *rmgarch*, little tuning of the specification for this example

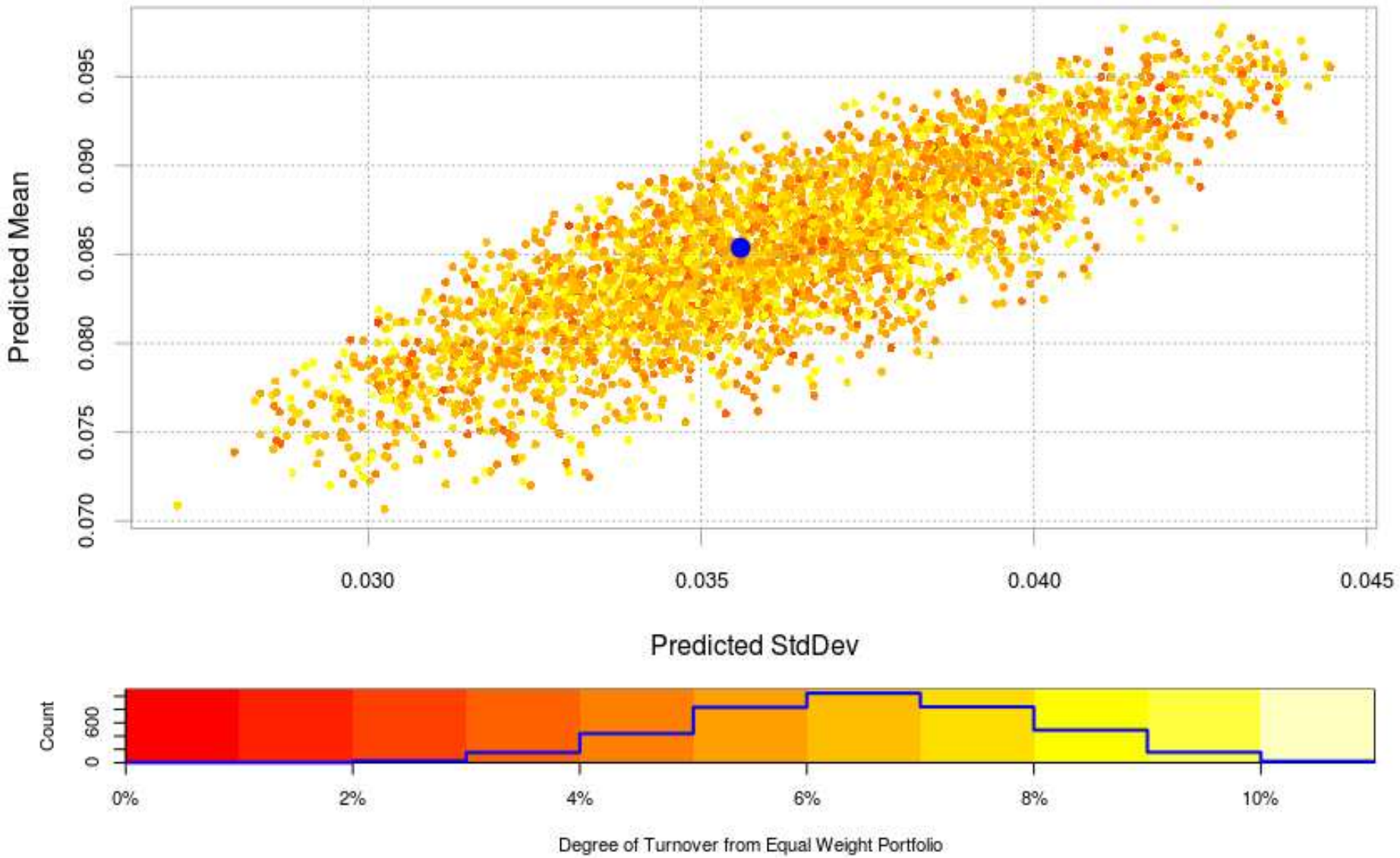
4,000 Random Portfolios

as of 2008-06-30



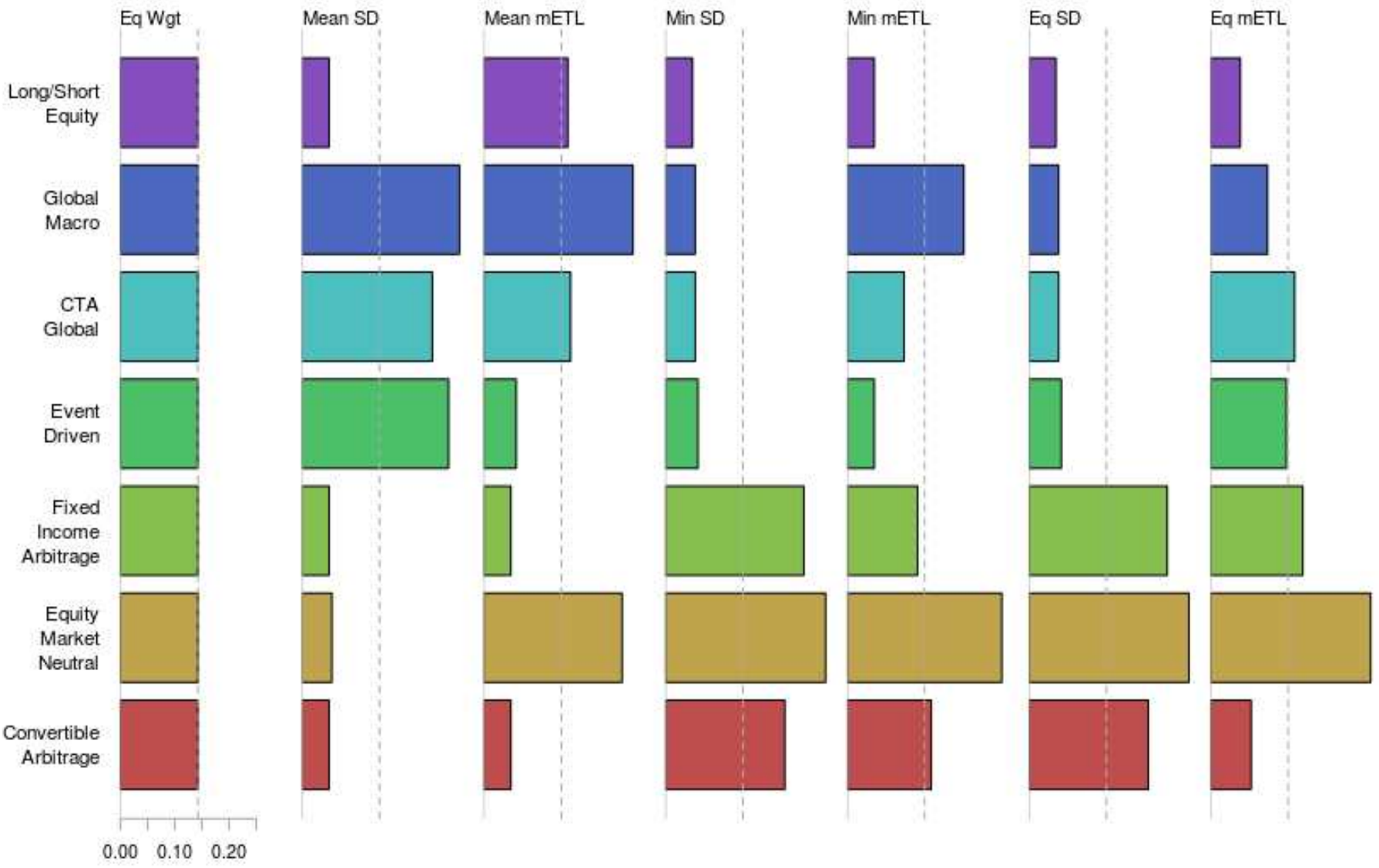
Turnover From Equal Weight

as of 2008-06-30



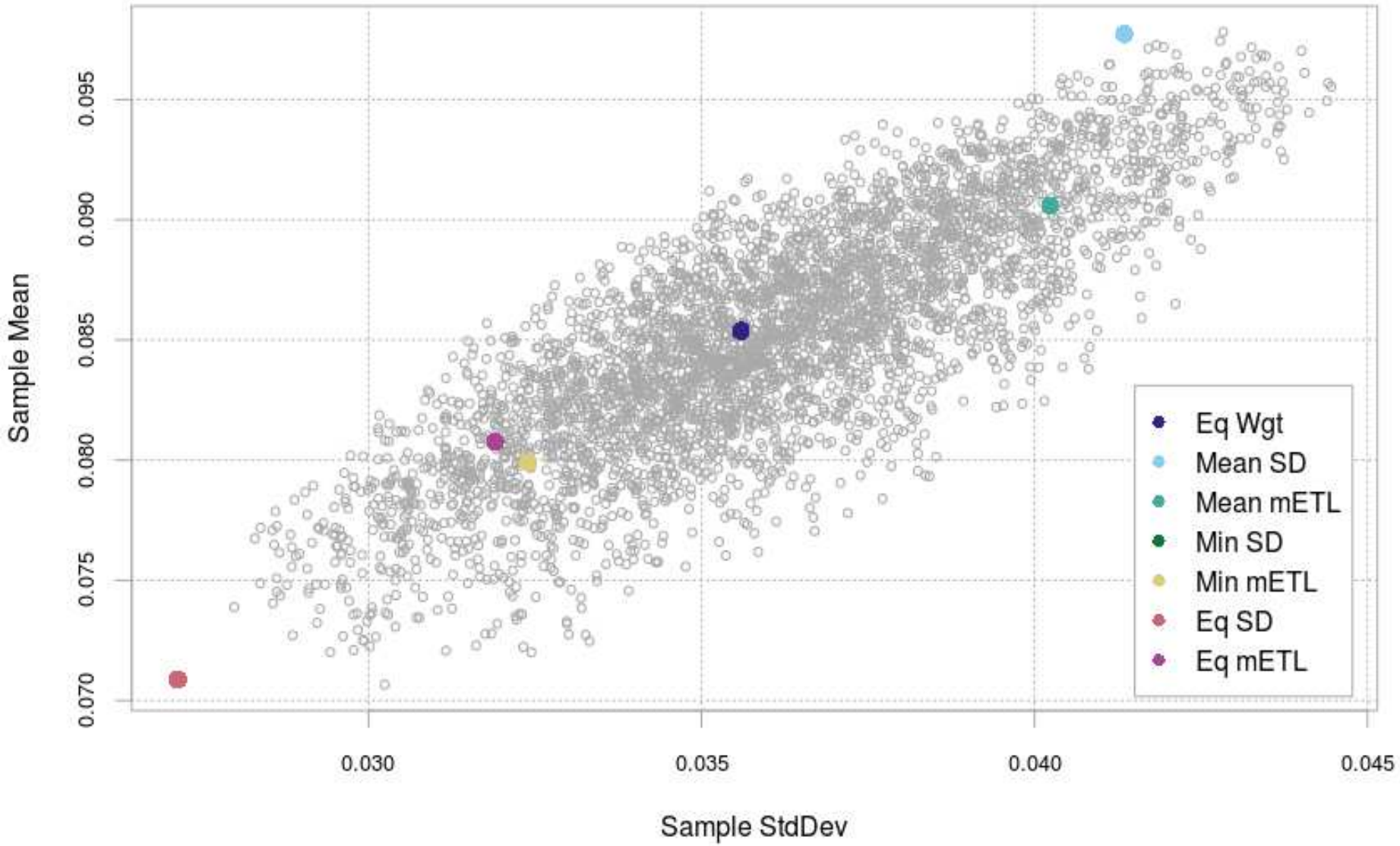
Different Objectives' Portfolio Weights

as of 2008-06-30



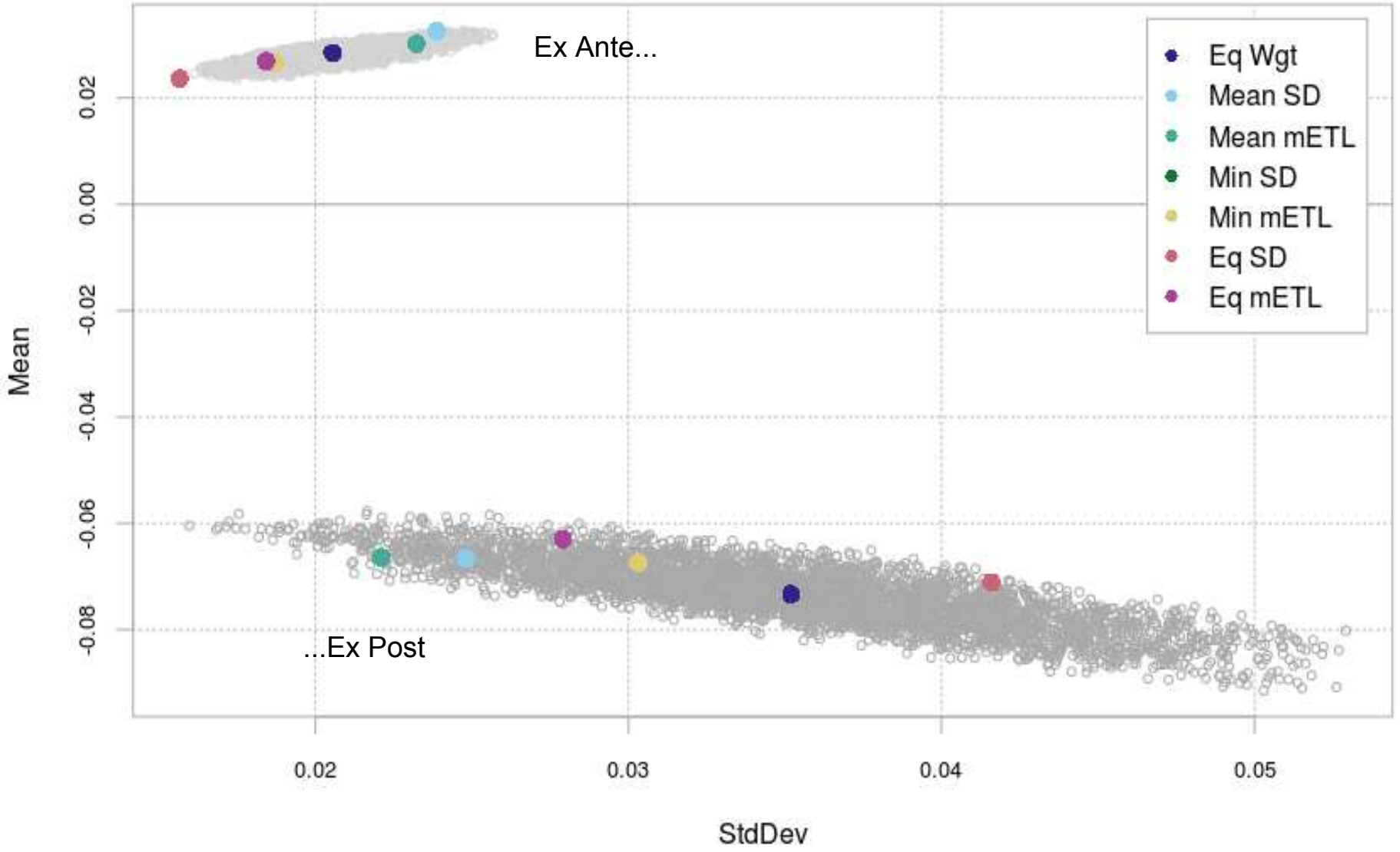
Ex Ante Results

as of 2008-06-30

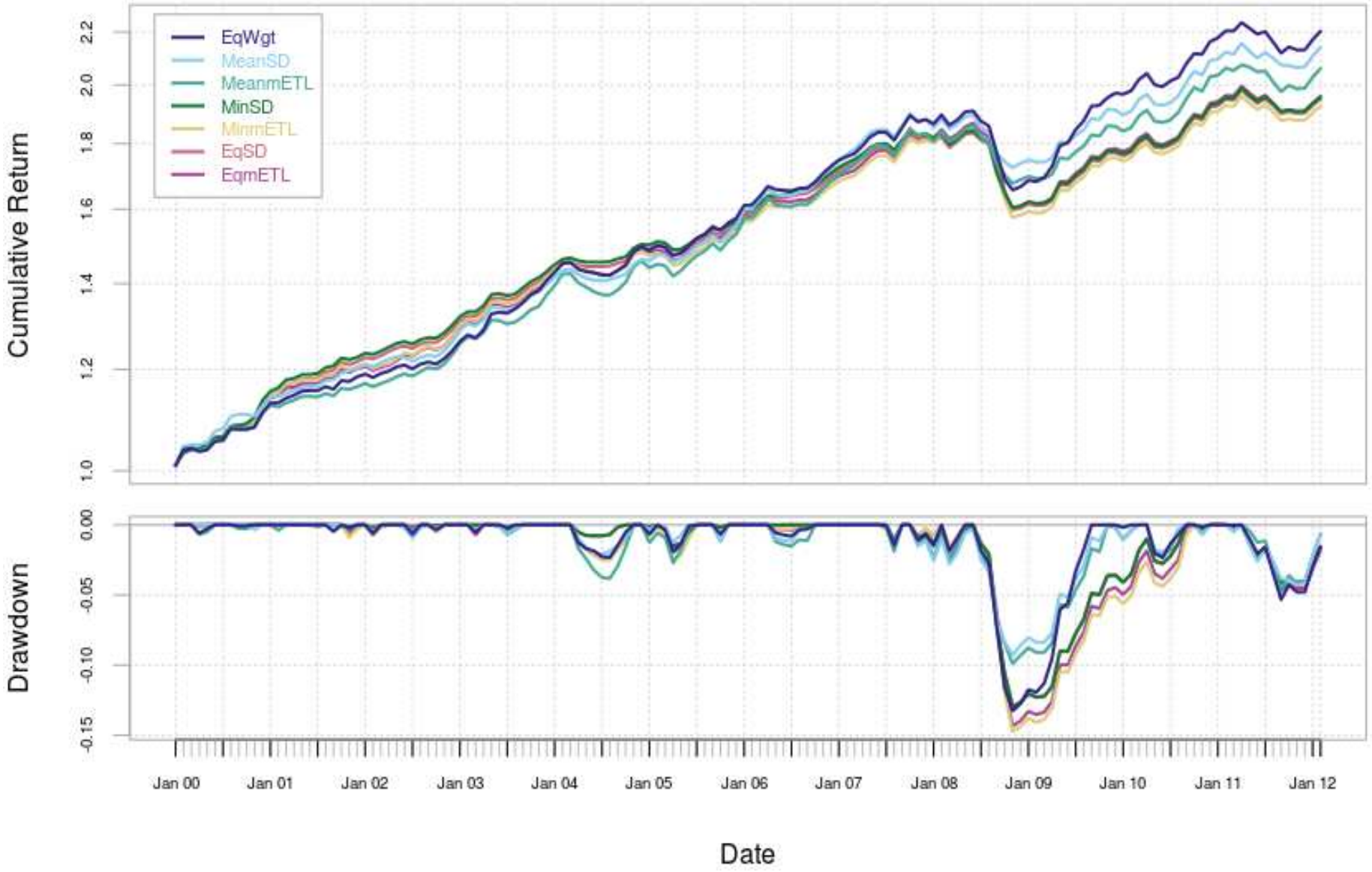


Ex Ante vs. Ex Post Results

2008-06-30 to 2008-09-30



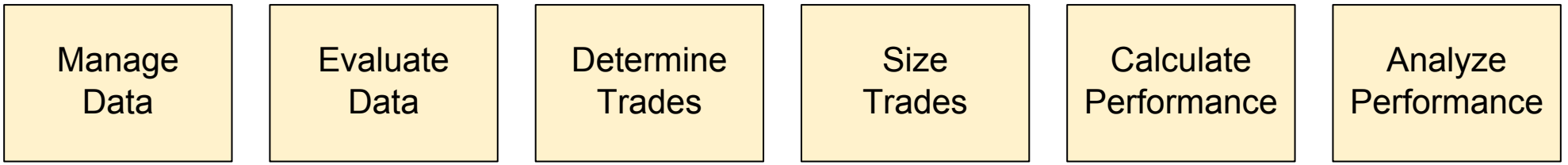
Out of Sample Results



Case Study: Signals Based Trading Strategies

- Generalize and discuss the architectural elements of a trading system
- Describe and implement a simple trend following system
- Discuss the role of the packages used

Trade Simulation Tool Chain



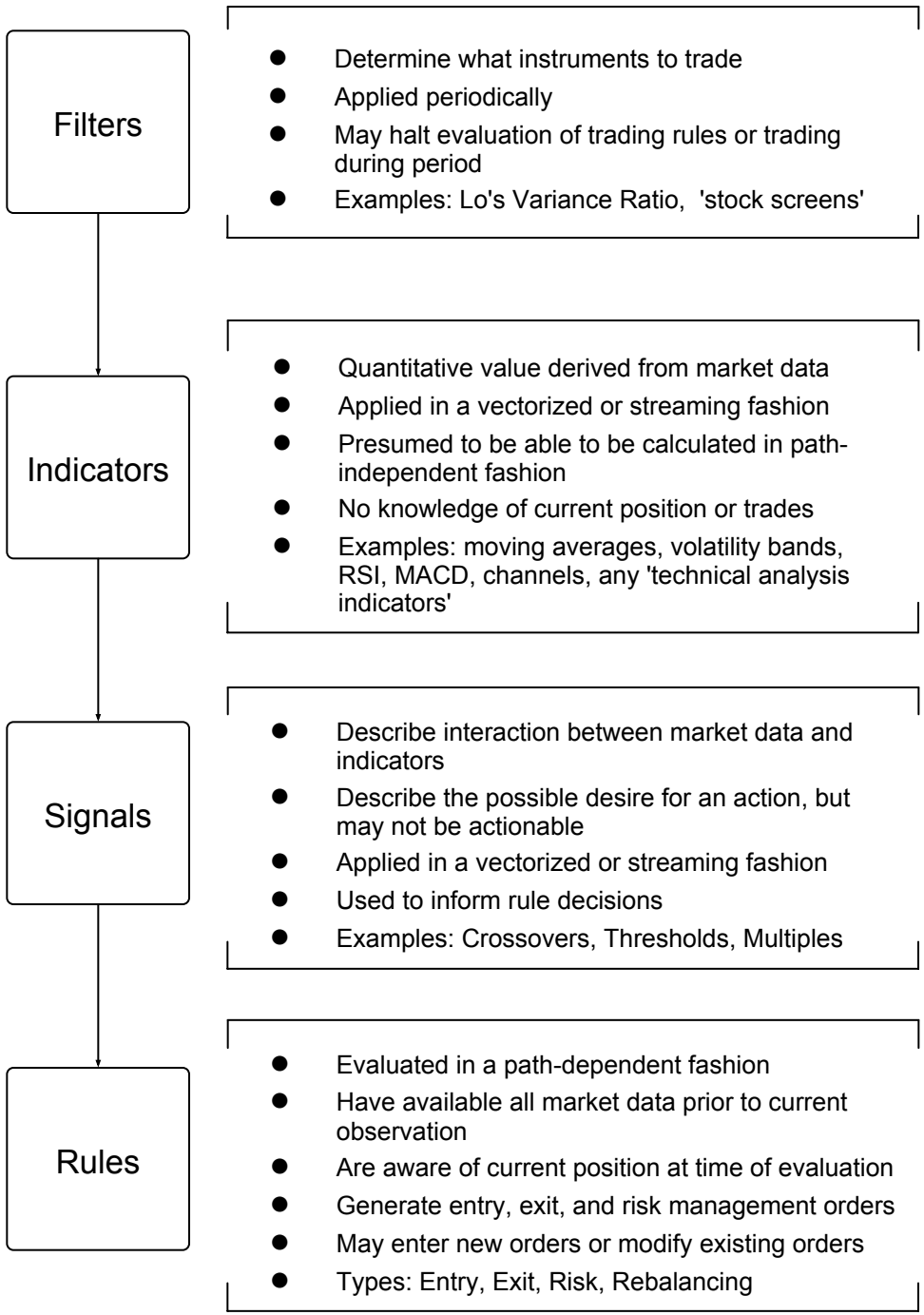
Types of Activities

Manage Data	Evaluate Data	Determine Trades	Size Trades	Calculate Performance	Analyze Performance
Connect to database	Calculate indicators	Estimate pre-trade pricing	Optimize portfolio	Specify contract specs	Calculate returns and risk
Download historical data	Transform prices	Forecast return	Budget risk	Capture trades	Compare to benchmarks
Clean and align data	Estimate volatility	Forecast risk	Calculate target position	Calculate positions	Provide attribution
Graph prices and indicators	Calculate trailing volume	Evaluate rules	Calculate trade size	Calculate P&L	Analyze risk
		Generate signals	Evaluate trading costs	Aggregate portfolio	

Example R Packages

Manage Data	Evaluate Data	Determine Trades	Size Trades	Calculate Performance	Analyze Performance
`quantmod`	`TTR`	`quantstrat`	`lspm`	`blotter`	`PerformanceAnalytics`
`indexing`	`signalextraction`	`quantmod`	`PortfolioAnalytics`	`FinancialInstrument`	
`RTAQ`	`realized`	`Rgarch`			
`xts`		`RQuantLib`			
...	...				

Strategy Specification



- Complete specification of the business logic of the strategy
- Sufficient to
  - Model,
  - Test,
  - and Code
- Describes all required components of the strategy
- Should also define data requirements (e.g. tick, BBO, OHLC bars, etc.)
- Typically defined independently of instruments the strategy may be applied to

About the Faber Example

- A very simple trend following strategy:
  - Faber, Mebane T., "*A Quantitative Approach to Tactical Asset Allocation*." Journal of Risk Management (Spring 2007).
- Buy when monthly price > 10-month SMA.
- Sell and move to cash when monthly price < 10-month SMA.
- 10 years of monthly data, S&P Sector ETFs.
- No shorting, 'sell' goes to cash
- Positions are fixed.

Faber in R Code

```
currency('USD')
symbols = c("XLF", "XLP", "XLE", "XLY", "XLV", "XLI", "XLB", "XLK",
"XLU")
for(symbol in symbols){ stock(symbol, currency="USD",multiplier=1) }
getSymbols(symbols, src='yahoo', index.class=c("POSIXt","POSIXct"),
from='1998-01-01')
for(symbol in symbols) {
    x<-get(symbol)
    x<-to.monthly(x,indexAt='lastof',drop.time=TRUE)
    colnames(x)<-gsub("x",symbol,colnames(x))
    assign(symbol,x)
}
initPortf('faber', symbols=symbols, initDate='1997-12-31')
initAcct('faber', portfolios='faber', initDate='1997-12-31')
initOrders(portfolio='faber', initDate='1997-12-31')
strategy("faber", store=TRUE)
add.indicator(strategy = 'faber', name = " SMA", arguments = list(x =
quote(Cl(mktdata)), n=10), label="SMA10")
add.signal(strategy='faber', name="sigCrossover", arguments = list
(data=quote(mktdata), columns=c("Close","SMA"), relationship="gt"),
label="Cl.gt.SMA")
add.signal(strategy='faber',name="sigCrossover", arguments = list
(data=quote(mktdata), columns=c("Close","SMA"), relationship="lt"),
label="Cl.lt.SMA")
add.rule(strategy='faber', name='ruleSignal', arguments = list
(data=quote(mktdata), sigcol="Cl.gt.SMA", sigval=TRUE, orderqty=100,
ordertype='market', orderside=NULL, threshold=NULL), type='enter')
add.rule(strategy='faber', name='ruleSignal', arguments = list
(data=quote(mktdata), sigcol="Cl.lt.SMA", sigval=TRUE, orderqty='all',
ordertype='market', orderside=NULL, threshold=NULL), type='exit')
out <- applyStrategy(strategy='faber' , portfolios='faber')
updatePortf(Portfolio='faber')
```

Code Color Key:

Financial-Instrument

quantmod

blotter

quantstrat

TTR

xts

No custom code

run

`demo('faber')`

from inside R

Faber Results

For individual positions...

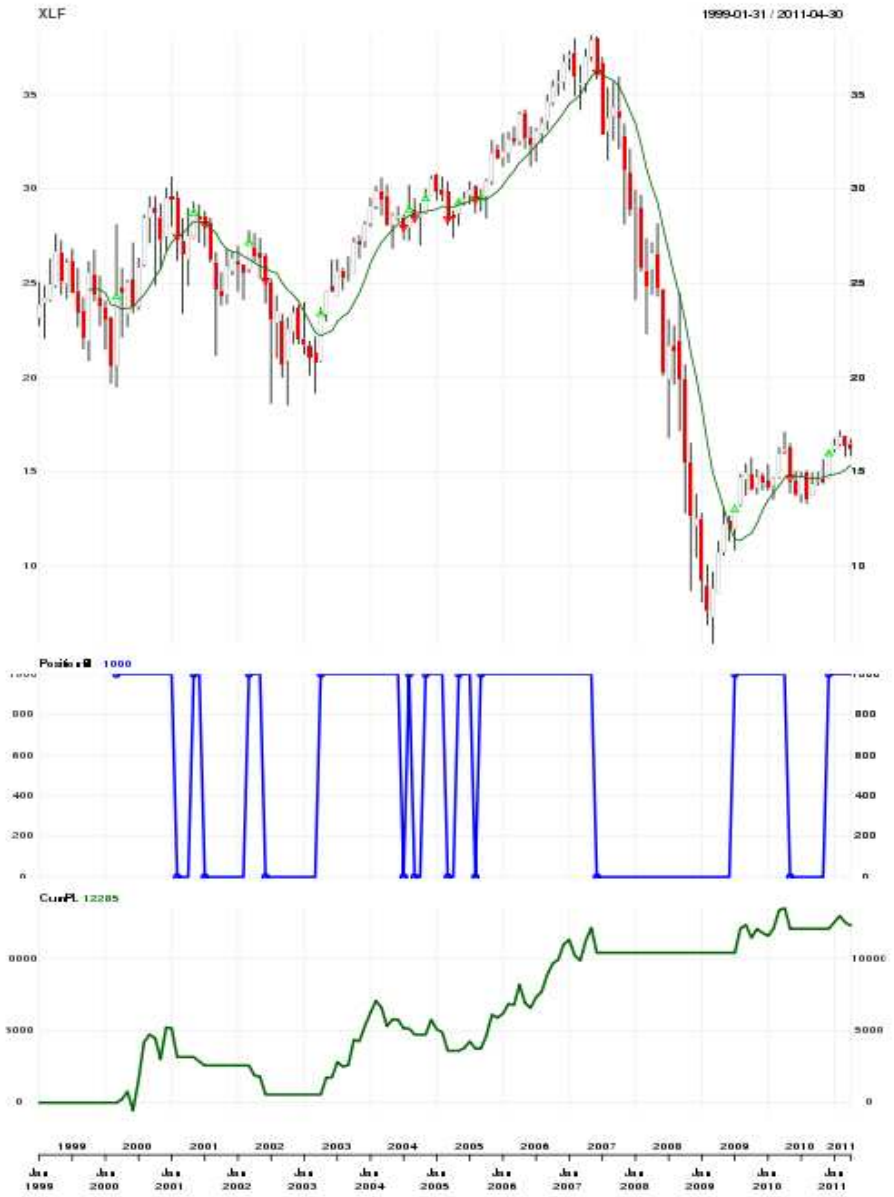
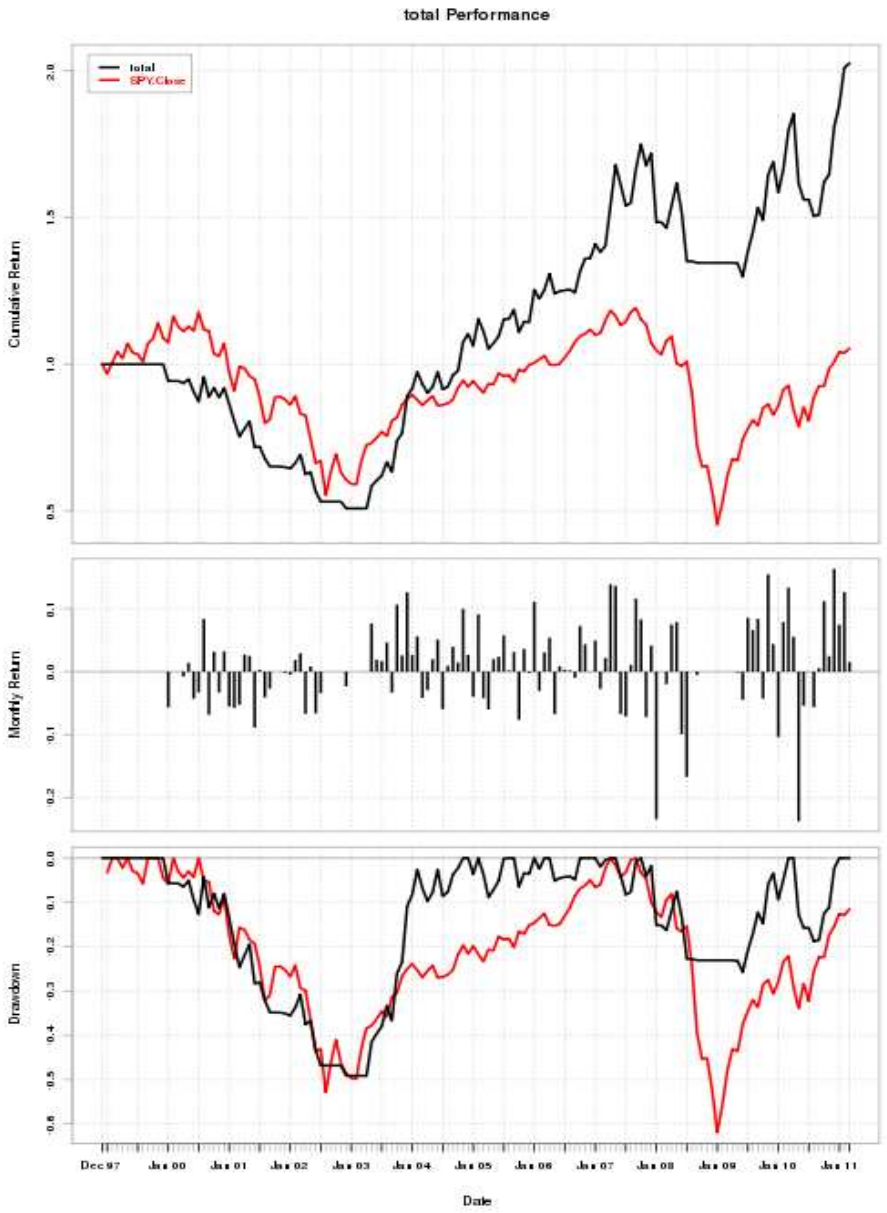


chart.Posn( )

...and the resulting portfolio



charts.PerformanceSummary( )

FURTHER DEVELOPMENT

Google Summer of Code 2012

- Additional Metrics from Bacon (2008) for PerformanceAnalytics
- Portfolio attribution from Cristopherson, Carino, and Ferson (2009)
- Functionality from Attilio Meucci's Factors on Demand and other papers
- Additional closed form optimizer backends for PortfolioAnalytics
- Improvements to xts visualization and subsetting
- Extensions to RTAQ for high frequency time series analysis

Future Development

- FactorAnalytics
  - Lead by Prof. Eric Zivot, recently added to R-Forge
- Possibilities for next summer?
  - Data Envelopment Analysis (DEA) for relative performance measurement
  - Parameter optimization for quantstrat
  - Continued refinement of reporting frameworks
- CRAN releases for
  - PerformanceAnalytics 1.1
  - blotter, FinancialInstrument, quantstrat
  - PortfolioAnalytics
- Future research