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# Trend-following, Risk-Parity and the influence of Correlations

## Risk-Based and Factor Investing Conference
Imperial College Business School

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# Introduction – Motivation

- Trend-following:
  - Long-short systematic strategy
  - Across multiple asset classes
  - Signals: buy rising assets, sell falling assets
  - Weighting scheme: inverse-volatility
- Poor performance during 2009-2013 (following double-digit returns in 2008)
  - The post-crisis period has been characterised by substantial asset co-movement
  - Inverse-volatility weights ignore pairwise correlations
  - Accounting for correlations would require the use of risk-parity
- Extend risk-parity to a long-short framework
  - Significant improvement in the performance of a trend-following strategy
  - Especially during periods of extreme correlation

# Related Literature

- Trend-Following:
  - Covel (2009), Szakmary, Shen & Sharma (2010), Burnside, Eichenbaum & Rebelo (2011), Hurst, Ooi & Pedersen (2012, 2013), Moskowitz, Ooi & Pedersen (2012), Baltas & Kosowski (2013, 2014), Clare, Seaton, Smith & Thomas (2014), Hutchinson & O'Brien (2014)
  - UBS Research Notes:
    1. "*Trend-following meets Risk-Parity*", December 2, 2013

- Risk Parity & Low-Risk investing:
  - Maillard, Roncalli & Teiletche (2010), Bhansali (2011), Inker (2011), Lee (2011), Menchero & Davis (2011), Anderson, Bianchi & Goldberg (2012), Asness, Frazzini & Pedersen (2012), Bhansali, Davis, Rennison, Hsu & Li (2012), Clare, Seaton, Smith & Thomas (2012), Leote de Carvalho, Lu & Moulin (2012), Lohre, Neugebauer & Zimmer (2012), Steiner (2012), Bernandi, Leippold & Lohre (2013), Fisher, Maymin & Maymin (2013), Lohre, Opfer & Orszag (2013), Jurczenko, Michel & Teiletche (2015)
  - Ang, Hodrick, Xing & Zhang (2006, 2009), Baker, Bradley & Wurgler (2011), Frazzini & Pedersen (2014).
  - UBS Research Notes:
    1. "*Low-Risk Investing*", *September 23, 2011*
    2. "*Understanding Risk Parity*", February 7, 2013
    3. "*Risk Parity with Different Risk Measures*", July 10, 2013
    4. "*Risk-Parity versus Mean-Variance*", May 16, 2014
    5. "*Correlation, De-correlation and Risk-Parity*", 27 June 2014

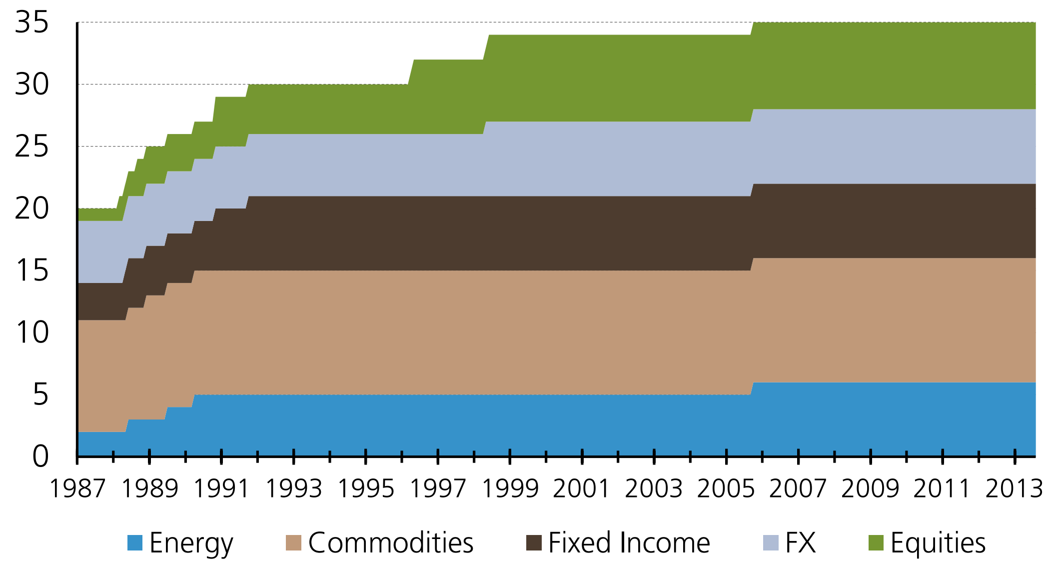
- Volatility Targeting:
  - Hallerbach (2012, 2014), Daniel & Moskowitz (2013), Barroso & Santa-Clara (2014).
  - UBS Research Notes:
    1. "*Understanding Volatility Targeting*", October 4, 2011
    2. "*Beyond Volatility Targeting*", June 18, 2012
    3. "*Extending Volatility Targeting*", September 2, 2013

# Data Description

- Futures Data
  - Source: **Bloomberg** [see the Appendix A for details on the construction of continuous series]
  - Daily closing futures prices for 35 assets over the period January 1987 – December 2013:

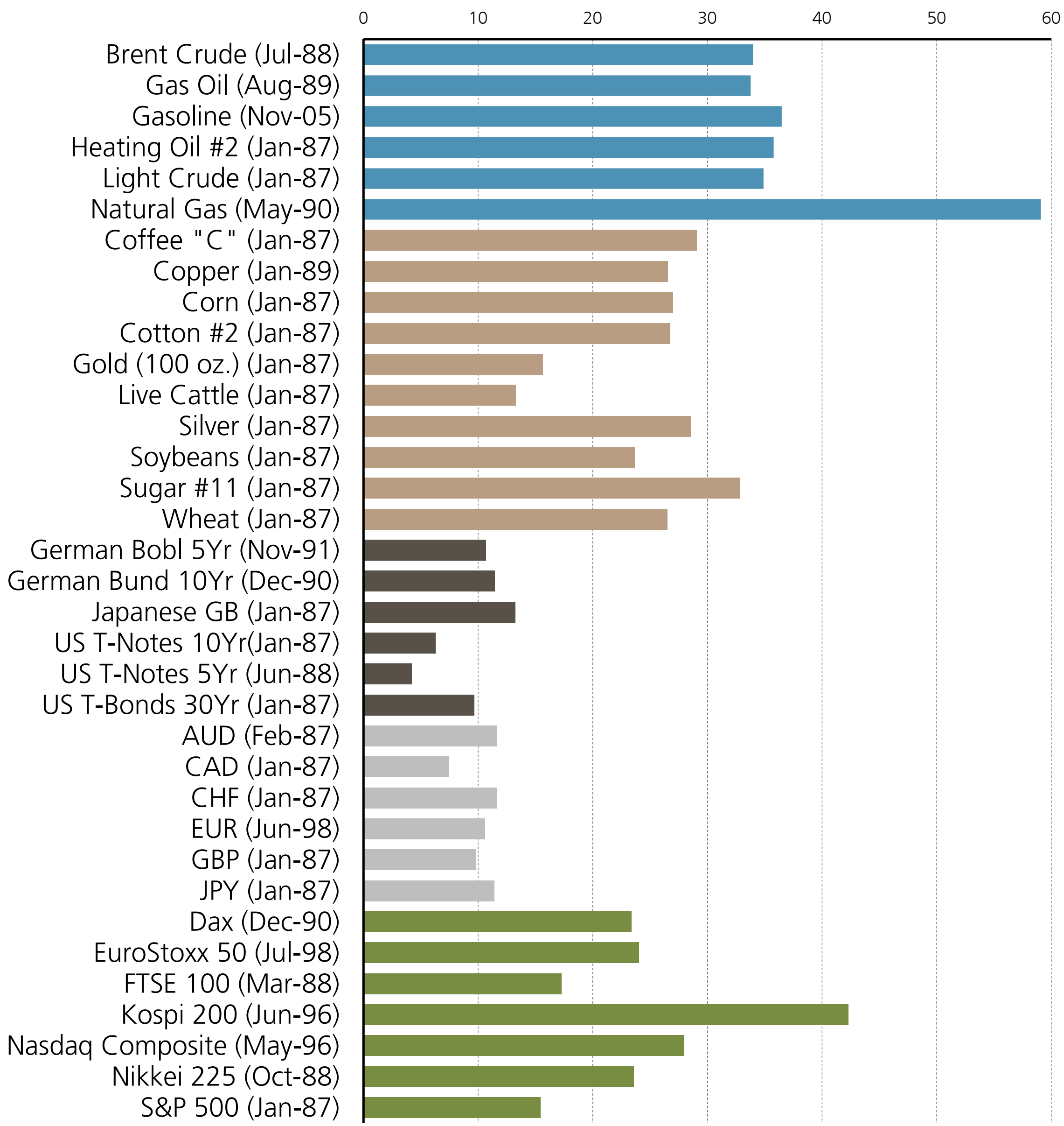
- 6 Energy contracts:
  Brent Crude Oil, Gas Oil, Gasoline,
  Heating Oil #2, Light Crude Oil, Natural Gas
- 10 Commodity contracts:
  Metals: Cooper, Gold, Silver
  Meat: Live Cattle
  Grains: Corn, Soybeans, Wheat
  Softs: Coffee "C", Cotton #2, Sugar
- 7 Equity contracts:
  DAX, Eurostoxx 50, FTSE 100, KOSPI 200,
  NASDAQ Composite, Nikkei 225, S&P500.
- 6 Currency contracts:
  AUD, CAD, CHF, EUR, GBP, JPY.
- 6 Government Bond contracts:
  US T-Note 5Yr, US T-Note 10Yr, US T-Bond 30Yr,
  German Bobl (5Yr), German Bund (10Yr), JGB 10Yr.

Number of available contracts




Source: Bloomberg

# Unconditional Asset Volatilities



Source: UBS Quantitative Research

- Large cross-sectional dispersion of volatilities…
- Must be taken into account when constructing a cross-asset portfolio.

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# Trend-Following Strategies

- Trend-Following ($TF$) strategy:
  - Assume $N_t$ available assets at the end of month $t$.
  - Look-back 12 months
  - Buy/sell signal = sign of past return.
  - Hold the portfolio for 1 month and rebalance:

$$r_{t,t+1}^{TF} = \sum_{i=1}^{N_t} \underbrace{sign\left(r_{t-12,t}^{i}\right) \cdot w_t^{i,Gross}}_{w_t^{i,Net}} \cdot r_{t,t+1}^{i}$$

where $\sum_{i=1}^{N_t} w_t^{i,Gross} = \sum_{i=1}^{N_t} \left| w_t^{i,Net} \right| = 100\%$ and $\sum_{i=1}^{N_t} w_t^{Net,i} \leq 100\%$.

- Constant-Volatility Trend-Following ($CV\!:\!TF$) strategy:
  - Assuming a desirable target level of volatility $\sigma_{TGT}$ (10% for our purposes):

$$r_{t,t+1}^{CV:TF} = \frac{\sigma_{TGT}}{\sigma_t^{TF}} \sum_{i=1}^{N_t} w_t^{i,Net} \cdot r_{t,t+1}^{i}$$

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# Trend-Following Strategies … picking the weights

- Volatility Parity Trend-Following ($VP\!:TF$) strategy:
  - Standard approach: inverse-volatility weighted portfolio, aka "volatility-parity":

$$w_t^{i,Gross,VP} = \frac{\left(\sigma_t^i\right)^{-1}}{\sum_{j=1}^{N_t}\left(\sigma_t^j\right)^{-1}}, \forall i$$

$$\Rightarrow \quad r_{t,t+1}^{VP:TF} = \frac{\sigma_{TGT}}{\sigma_t^{TF}} \sum_{i=1}^{N_t} sign\left(r_{t-12,t}^i\right) \cdot \frac{\left(\sigma_t^i\right)^{-1}}{\sum_{j=1}^{N_t}\left(\sigma_t^j\right)^{-1}} \cdot r_{t,t+1}^i$$

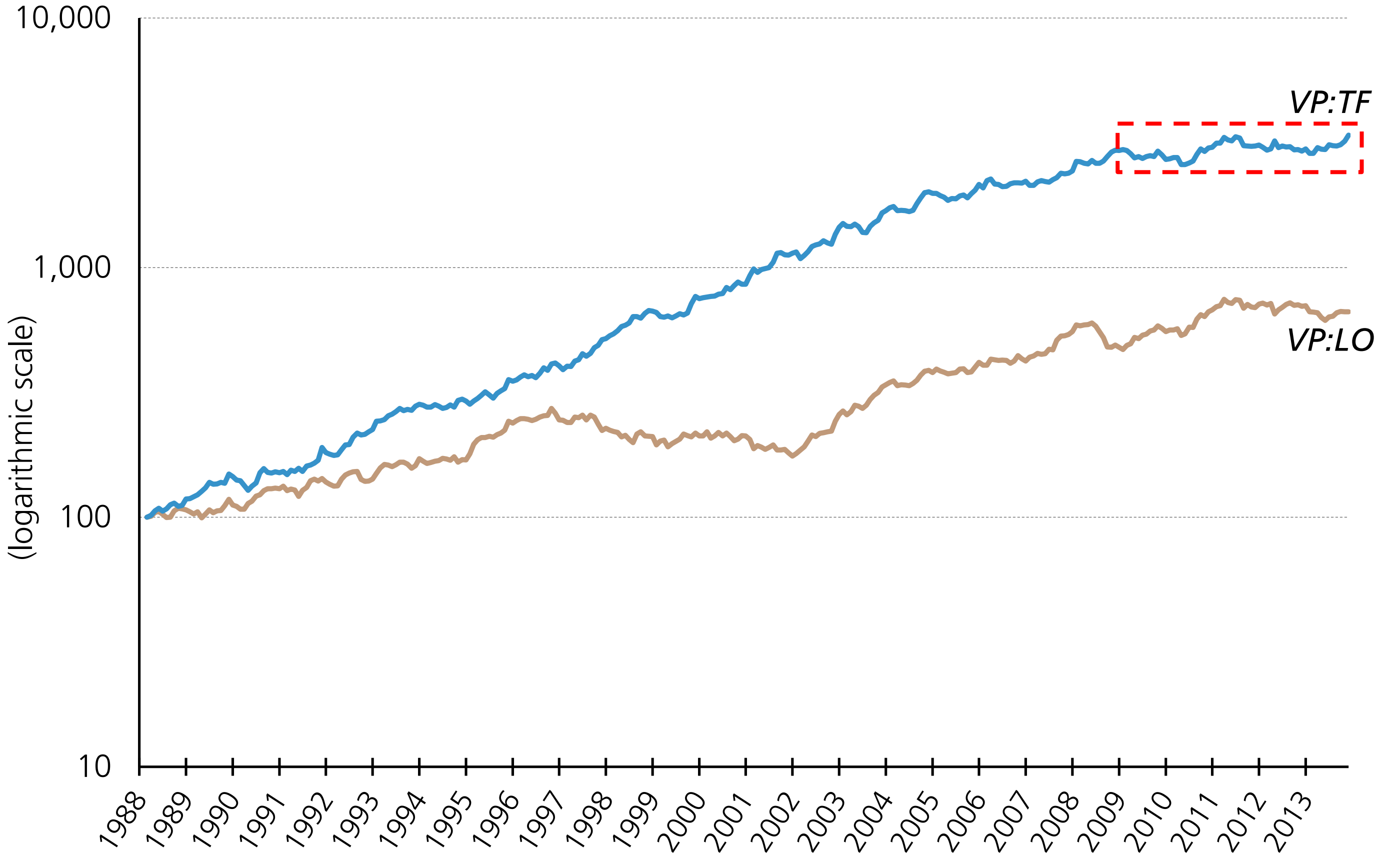
  - All assets enter the portfolio with the same volatility (hence "volatility-parity")
  - However, the portfolio construction ignores all pairwise correlations

- Benchmark: Volatility Parity Long-Only ($VP\!:LO$) strategy:

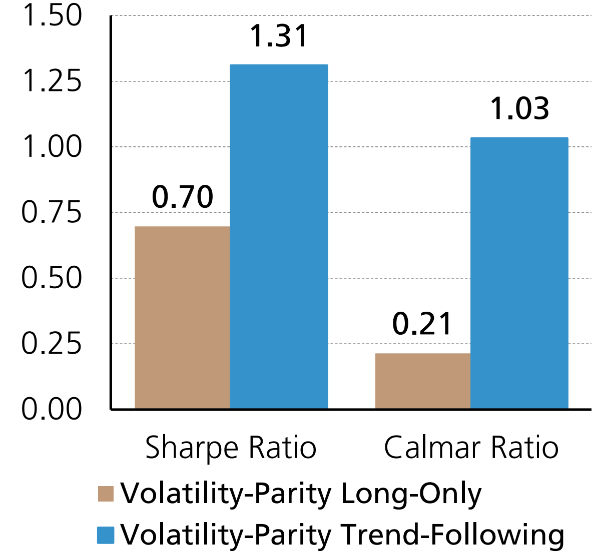
$$r_{t,t+1}^{VP:LO} = \frac{\sigma_{TGT}}{\sigma_t^{LO}} \sum_{i=1}^{N_t} (+1) \cdot \frac{\left(\sigma_t^i\right)^{-1}}{\sum_{j=1}^{N_t}\left(\sigma_t^j\right)^{-1}} \cdot r_{t,t+1}^i$$

# Cumulative Returns [Apr. 1988 – Dec.2013]

- Target volatility level $\sigma_{TGT} = 10\%$




Source: UBS Quantitative Research




Source: UBS Quantitative Research

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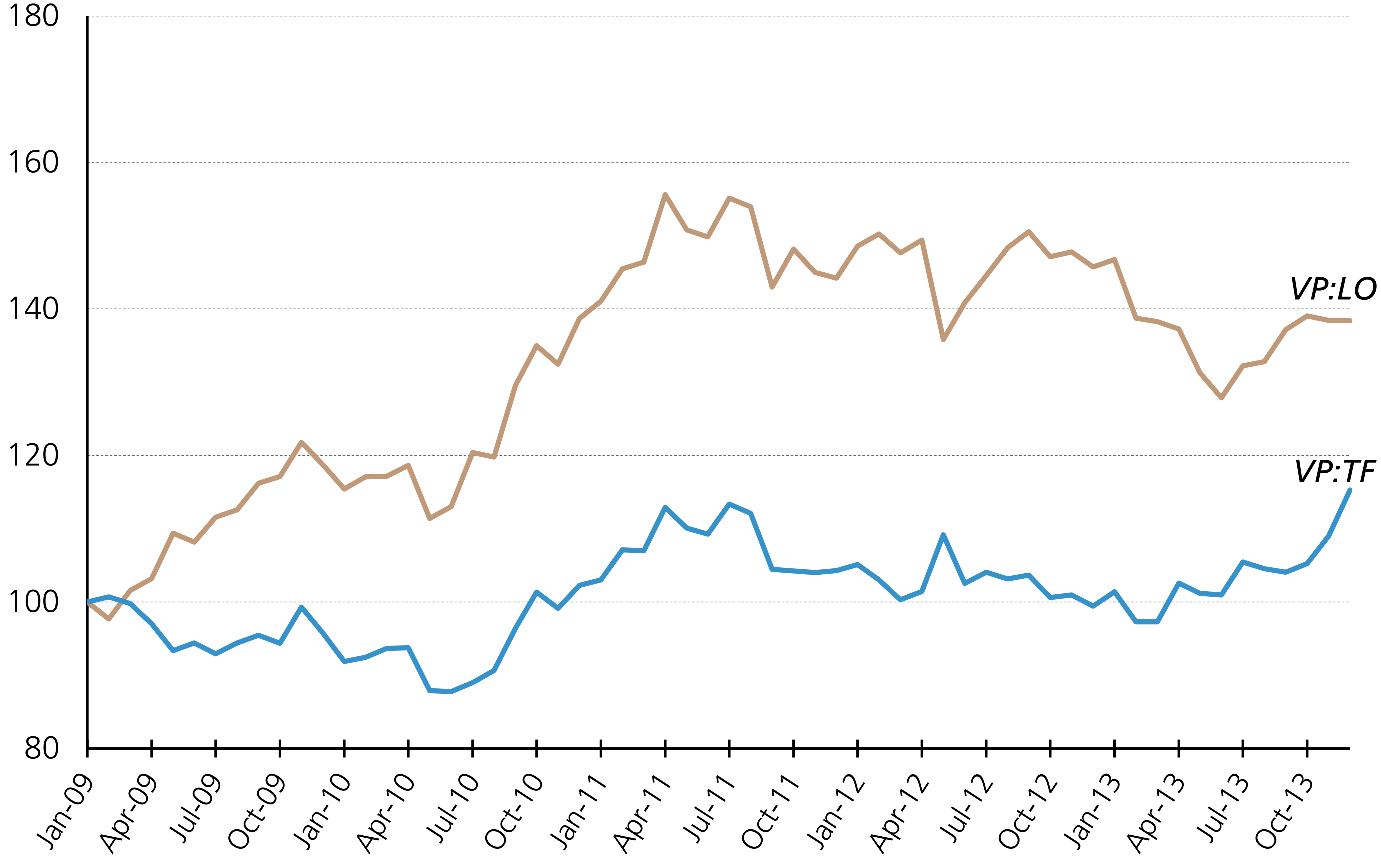
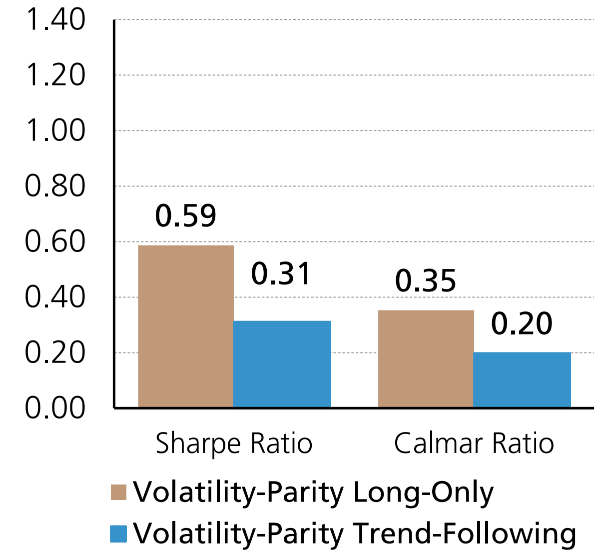
# Cumulative Returns [Jan. 2009 – Dec.2013]

- And then trend-following stopped working…




Source: UBS Quantitative Research




Source: UBS Quantitative Research

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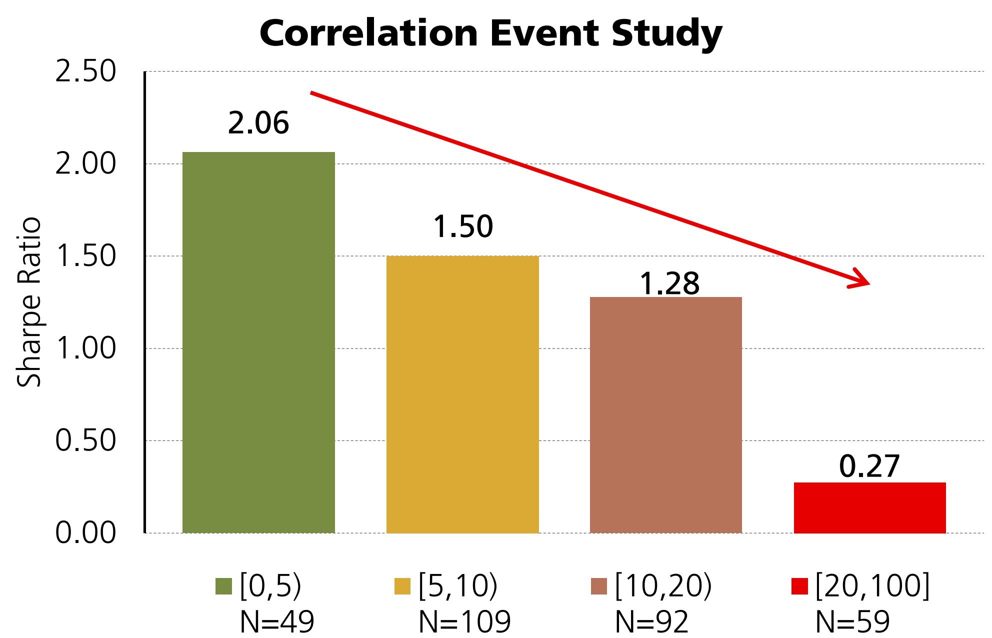
# Correlation Event Study – Do correlations matter?

- Split months in correlation buckets and estimate Sharpe ratio per correlation regime



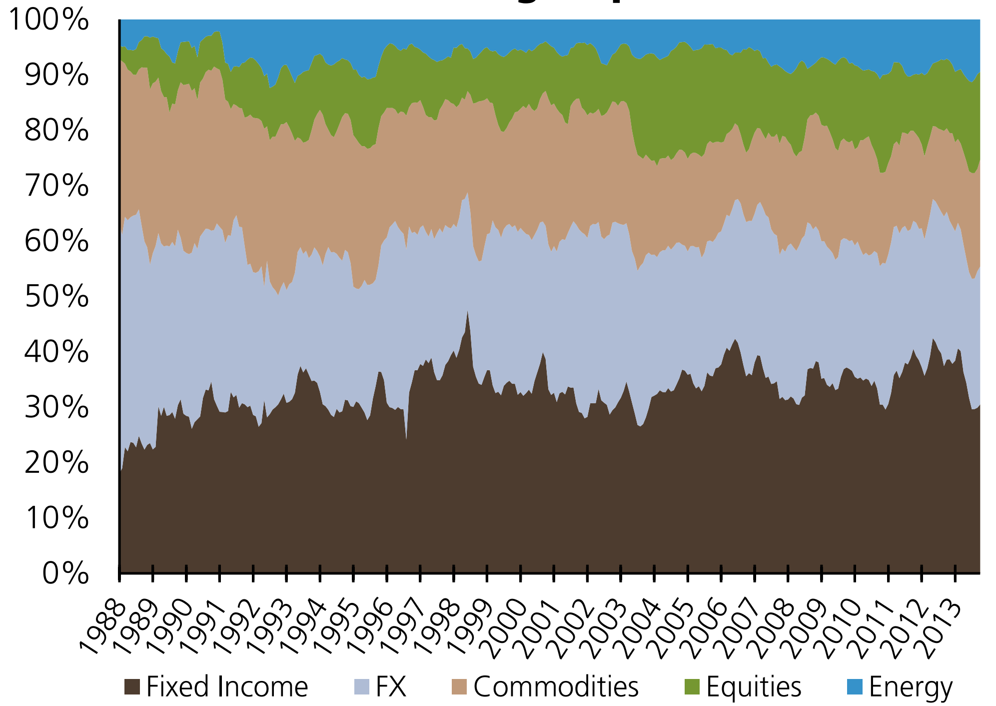

Source: UBS Quantitative Research

- Could this be due to the recent increases in correlations? "Risk On – Risk Off"…?
- *Volatility-Parity* ignores the effect of pairwise correlations, hence "*Naïve Risk Parity*"

# Volatility Parity ignores the Pairwise Correlations

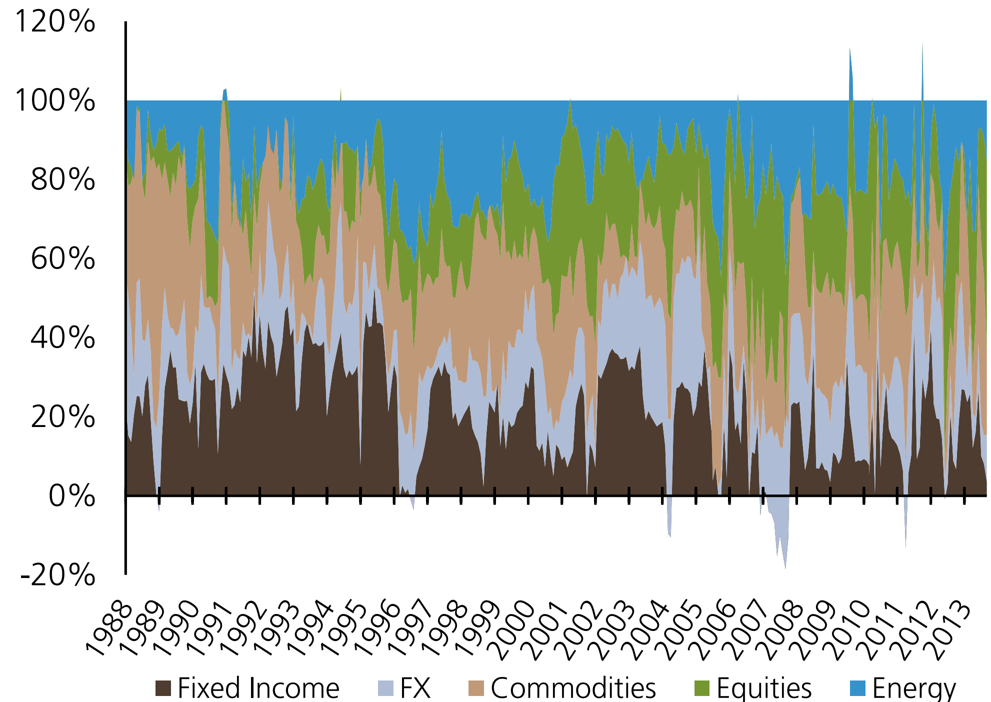
- Let's look into *gross weight allocation* and respective *risk allocation* per asset class

**Sum of Gross Weights per asset class**




Source: UBS Quantitative Research

**Percentage contribution to risk per asset class**




Source: UBS Quantitative Research

- There in No Equal Contribution to Risk
- …clearly due to asset pairwise correlations not being equal

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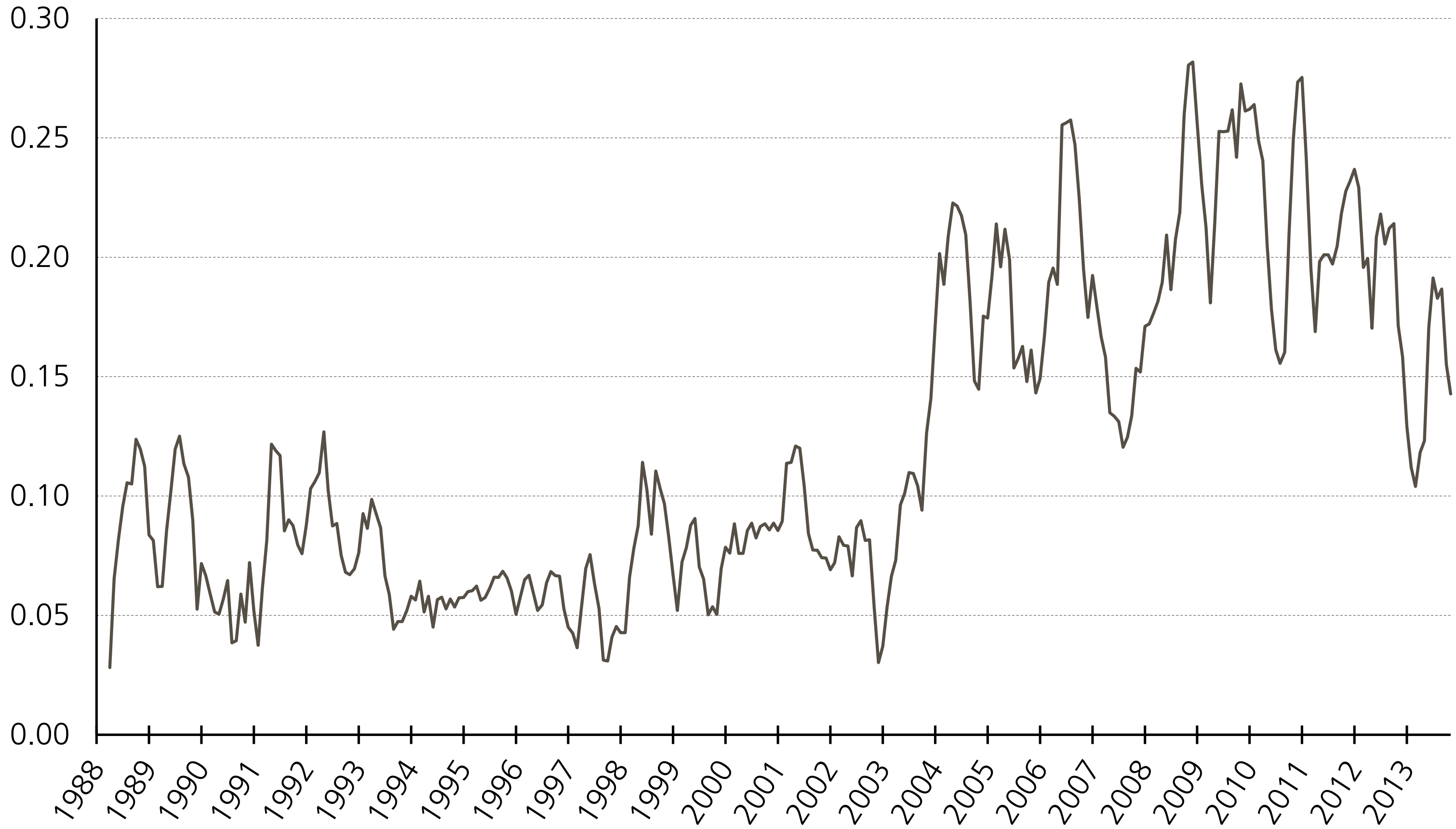
# Volatility Parity ignores the Pairwise Correlations

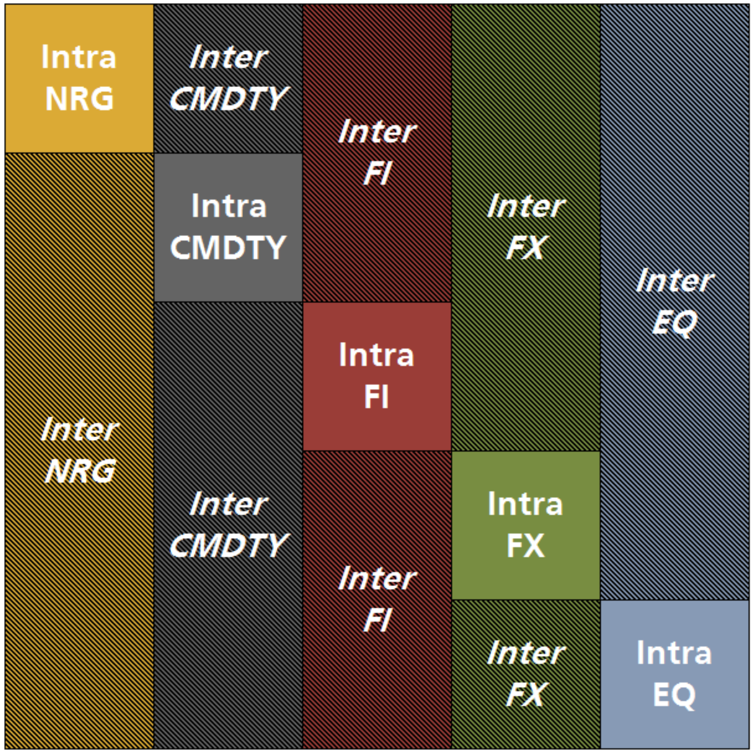
- We next plot 90-day rolling estimates of average pairwise correlation over time.




Source: UBS Quantitative Research

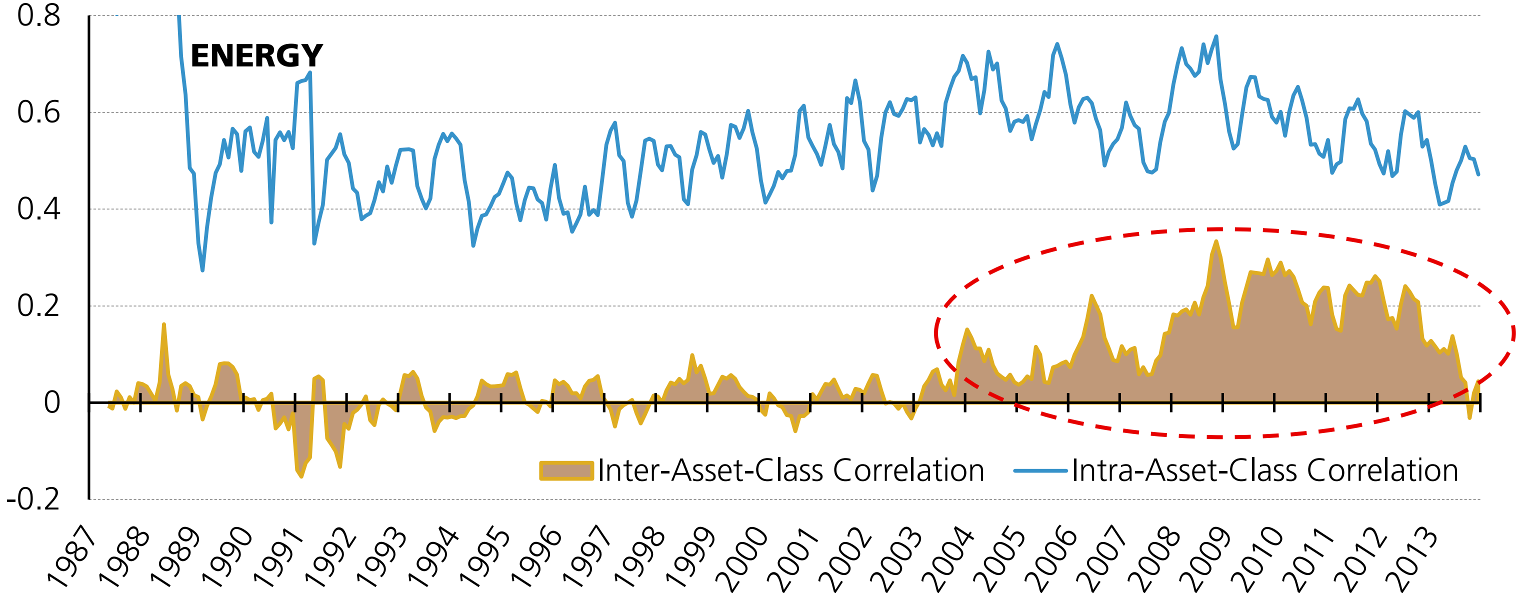
# Volatility Parity ignores the Pairwise Correlations

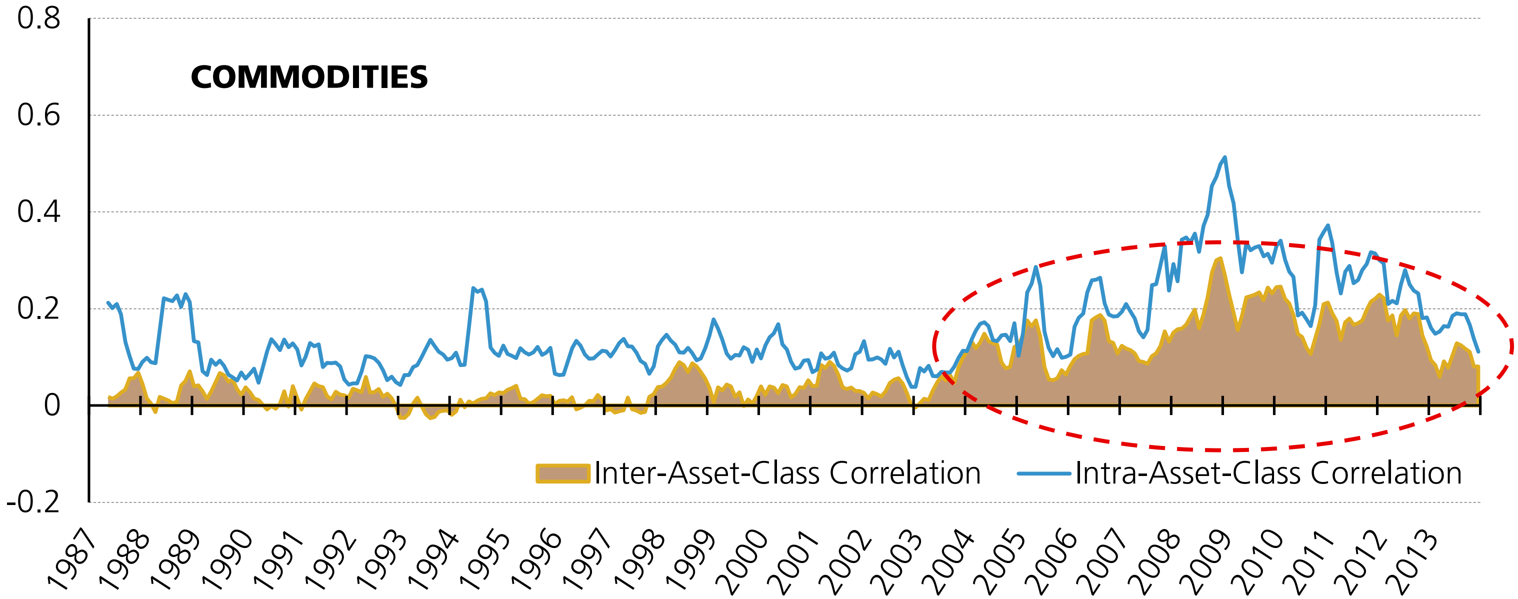
- We next plot 90-day rolling estimates of intra and inter asset-class correlations over time.




Source: UBS Quantitative Research

# Intra and Inter Asset-Class Correlations




Source: UBS Quantitative Research

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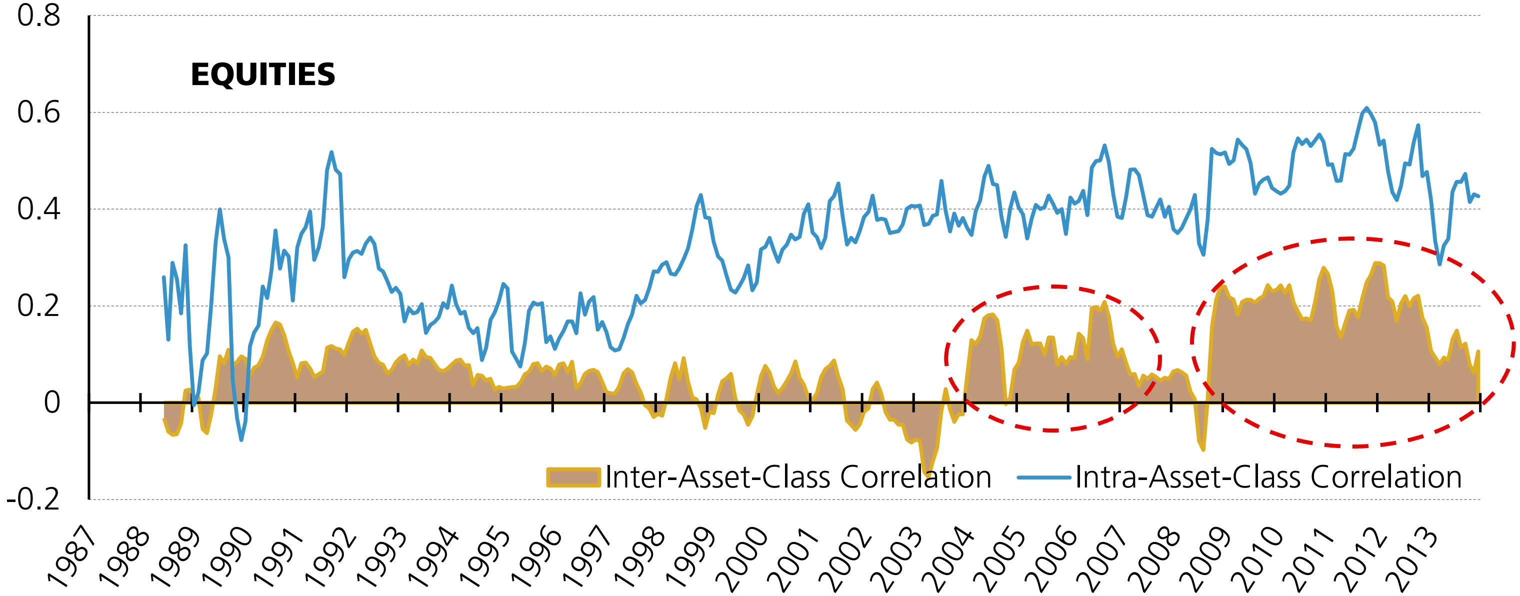
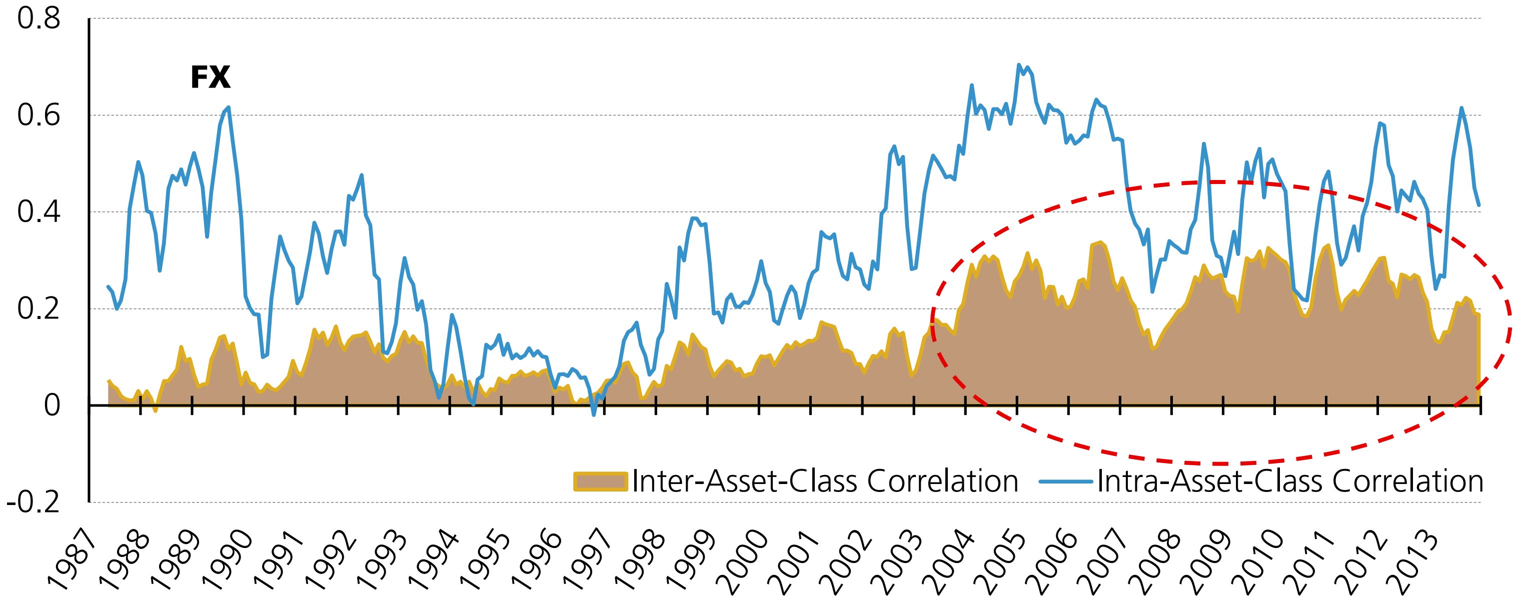
# Intra and Inter Asset-Class Correlations




Source: UBS Quantitative Research

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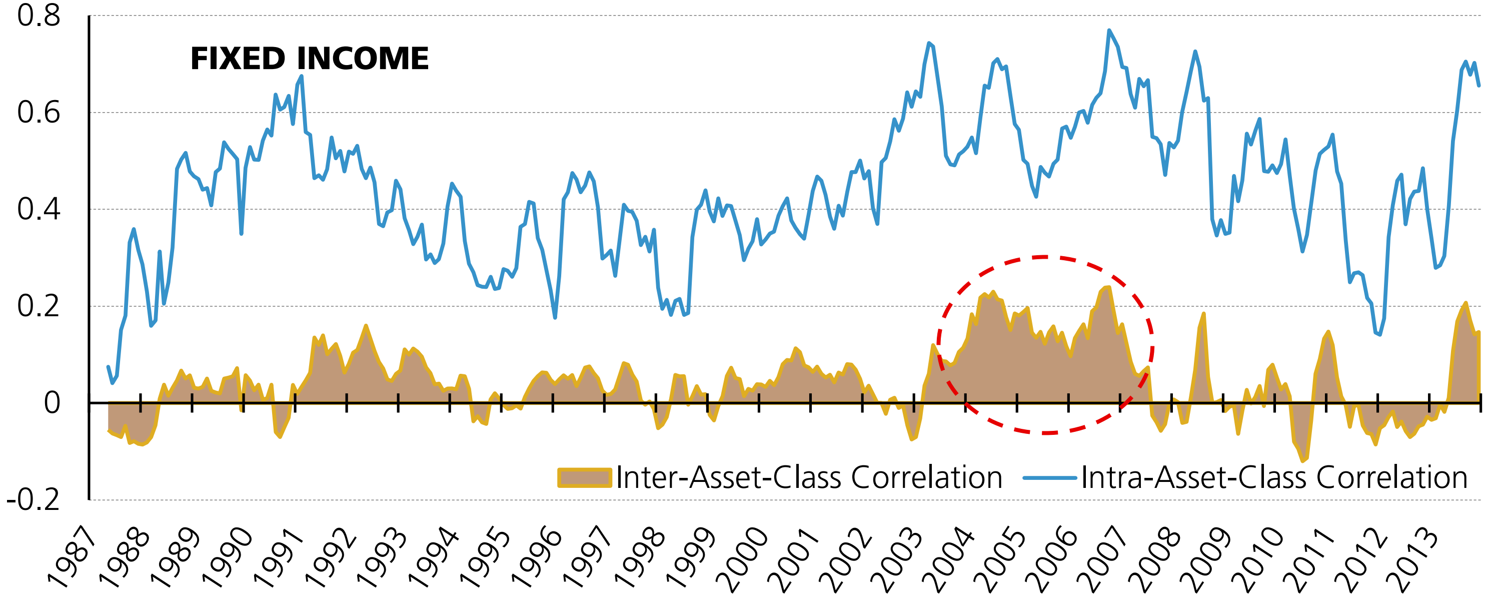
# Intra and Inter Asset-Class Correlations




Source: UBS Quantitative Research

- The degree of co-movement has dramatically increased post-2004
- However, fixed income assets have been become de-correlated after 2007
- Two rough clusters: Fixed Income and non-Fixed Income → "*Risk on/Risk off*"
- Pairwise correlations are ignored by a Volatility-Parity allocation.
- How to account for such information in portfolio construction?..."True Risk Parity"

# Risk-Parity (aka Equal Risk Contribution - ERC)

- Define Marginal Contribution to Risk (*MCR*): $MCR_i = \frac{\partial \sigma_P}{\partial w_i}$, where $\sigma_P$ denotes portfolio volatility
- It can be trivially shown that:

$$\sum_{j=1}^{N} w_j \cdot MCR_j = \sigma_P$$

❖ Contrast this with: $\sum_{j=1}^{N} w_j \cdot \sigma_j \geq \sigma_P$

- <u>RP Objective</u>: equate the weighted *MCR*'s:

$$\boxed{w_i^{RP} \cdot MCR_i = constant, \forall i}$$

- Optimisation:

| |
|---|
| Maximise: $\sum_{i=1}^{N} \log(w_i)$ |
| Subject to: $\sigma_P(\boldsymbol{w}) = \sqrt{\boldsymbol{w}' \cdot \boldsymbol{\Sigma} \cdot \boldsymbol{w}} \leq \sigma_{TGT}$ |

- Initial weights: $w_i^{RP,init} = w_i^{VP} = \frac{(\sigma_i)^{-1}}{\sum_{j=1}^{N} (\sigma_j)^{-1}}, \forall i$
- Post-optimisation rescaling of weights is permitted so to get weights in [0,1].
- Logarithmic weights are also used by Kaya (2012), Kaya and Lee (2012) and Roncalli (2014).

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Note: For comparison between VP and RP see Appendix B.

# Risk-Parity

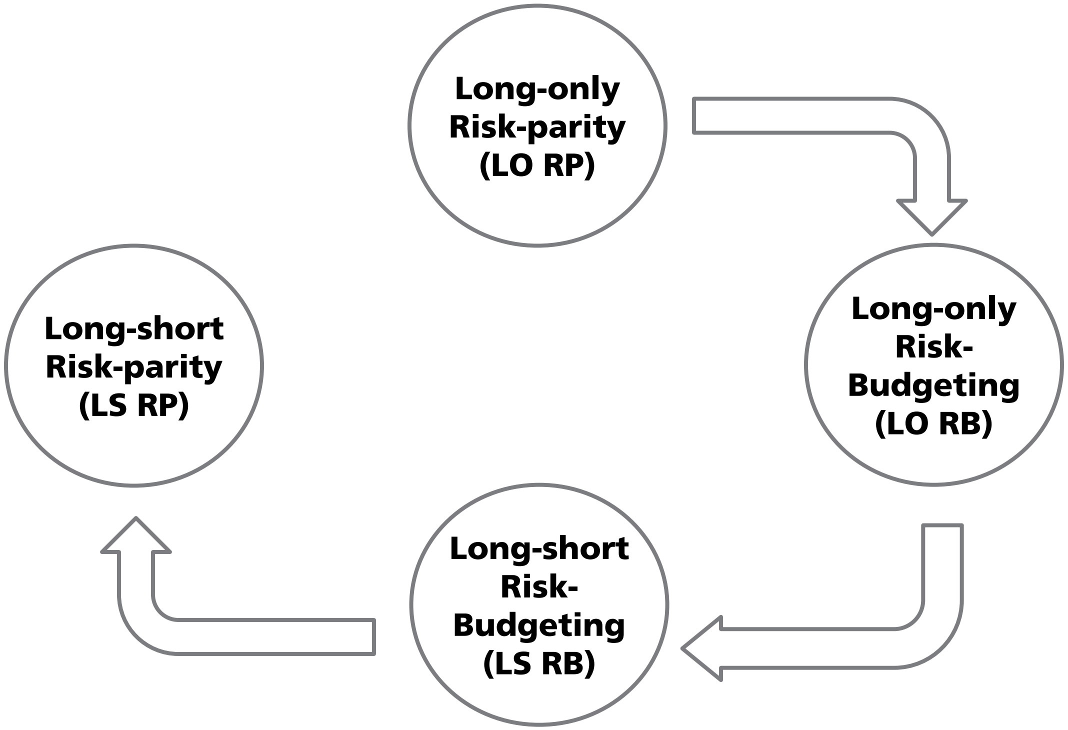
- Advantages:
  - Attractive risk-return profile
  - True equal distribution of risk across portfolio constituents
  - Robust against parameter estimation error (acts like shrinkage)
  - Naturally constrained (the optimisation does not allow negative weights or position flips)
  - Lower turnover than minimum-variance or mean-variance portfolios

- Criticisms:
  - No information about expected returns is used
  - Substantial leverage for low-volatility assets (e.g. bonds)
  - Does not offer guidance as to which assets should be included in the portfolio; whatever enters the optimisation will bear a non-zero weight.
  - Highly correlated assets will bear a larger aggregate weight than what a single asset would bear ("identical asset problem")

# Extending Risk-Parity to a Long-Short Framework

- The risk-parity formulation that has been presented only applies to long-only portfolio
  - ❖ If anything, $\log(w_i)$ can only be defined for positive weights.

- How to go from long-only risk-parity to a long-short one:
  1. Start with **long-only risk-parity**
  2. Introduce/extend to long-only risk-budgeting
  3. Extend long-only risk-budgeting to long-short risk-budgeting
  4. Simplify long-short risk-budgeting down to **long-short risk-parity**



# Long-Only Risk-Budgeting

- Risk-parity equates the weighted marginal contribution to risk from all assets
- **Risk-budgeting** (RB) allocates weights so that the assets contribute an amount to the overall portfolio volatility that is **proportional** to a certain **positive asset-specific score,** $s_i$
- From RP objective:

$$\boxed{w_i^{RP} \cdot MCR_i = constant, \forall i}$$

- To RB objective:

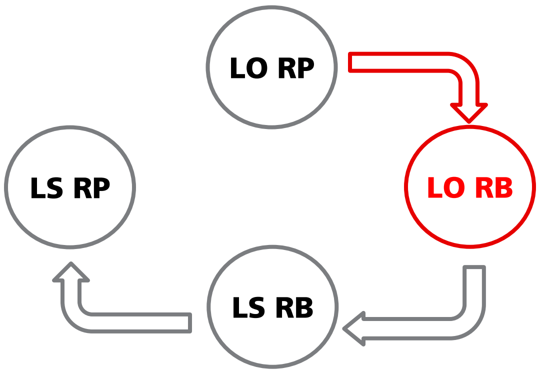
$$\boxed{w_i^{RB} \cdot MCR_i \propto s_i, \forall i}$$

- Optimisation (also shown in Kaya and Lee, 2012):

Maximise: $\sum_{i=1}^{N} s_i \cdot log(w_i)$

Subject to: $\sigma_P(\boldsymbol{w}) = \sqrt{\boldsymbol{w}' \cdot \boldsymbol{\Sigma} \cdot \boldsymbol{w}} \leq \sigma_{TGT}$

- Initial weights: $w_i^{RB,init} = \dfrac{s_i \cdot (\sigma_i)^{-1}}{\sum_{j=1}^{N} s_j \cdot (\sigma_j)^{-1}}, \forall i$

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# Long-Short Risk-Budgeting

- Can we allow for negative asset-specific scores?
  - ❖ Positive scores → Long positions
  - ❖ Negative scores → Short positions
- The resulting net weights <u>must</u> agree with the asset-specific scores in their sign:

$$sign\left(w_i^{Net,RB}\right) = sign(s_i), \qquad \forall i$$

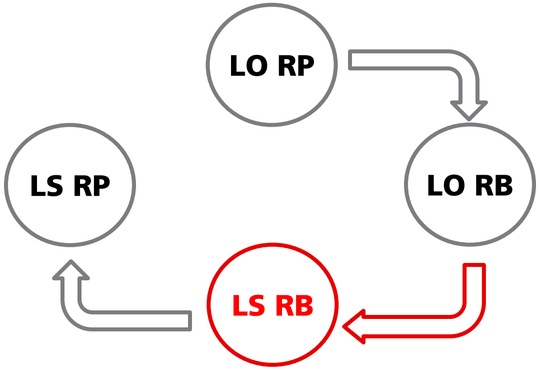
- The RB objective becomes:

$$\boxed{w_i^{Net,RB} \cdot MCR_i \propto |s_i|, \forall i}$$

- Optimisation:

$$\boxed{\begin{array}{l} \text{Maximise: } \sum_{i=1}^{N} |s_i| \cdot log(|w_i|) \\ \text{Subject to: } \sigma_P(\boldsymbol{w}) = \sqrt{\boldsymbol{w}' \cdot \boldsymbol{\Sigma} \cdot \boldsymbol{w}} \leq \sigma_{TGT} \end{array}}$$

- Initial weights: $w_i^{Net,RB,init} = \dfrac{s_i \cdot (\sigma_i)^{-1}}{\sum_{j=1}^{N} |s_j| \cdot (\sigma_j)^{-1}}$



# Long-Short Risk-Parity and Trend-Following

- Notice that if all asset-specific scores are equal in absolute value, we are back to risk-parity:

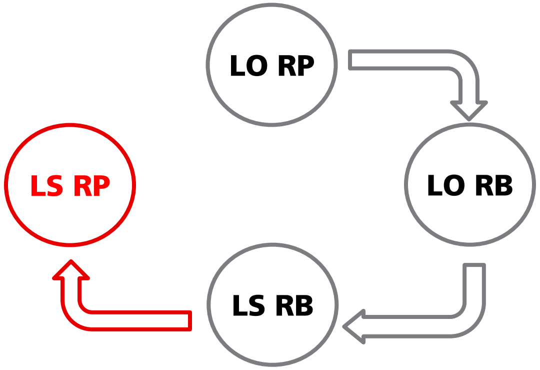
$$if\ |s_i| = |s_j|, \forall i,j$$
$$\Rightarrow \text{Long–Short Risk–Budgeting: } w_i^{Net,RB} \cdot MCR_i \propto 1$$
$$\Rightarrow w_i^{Net,RB} \cdot MCR_i = constant, \forall i \Rightarrow \text{Risk} - \text{Parity}$$

- However, this framework now allows for long and short positions!
- Trend-following signal: $s_i = sign\left(ret_i^{12M}\right) = \pm 1 \Rightarrow |s_i| = |s_j|, \forall i,j$
- Long-Short risk-budgeting optimisation boils down to a long-short risk-parity optimisation.
- Optimisation:

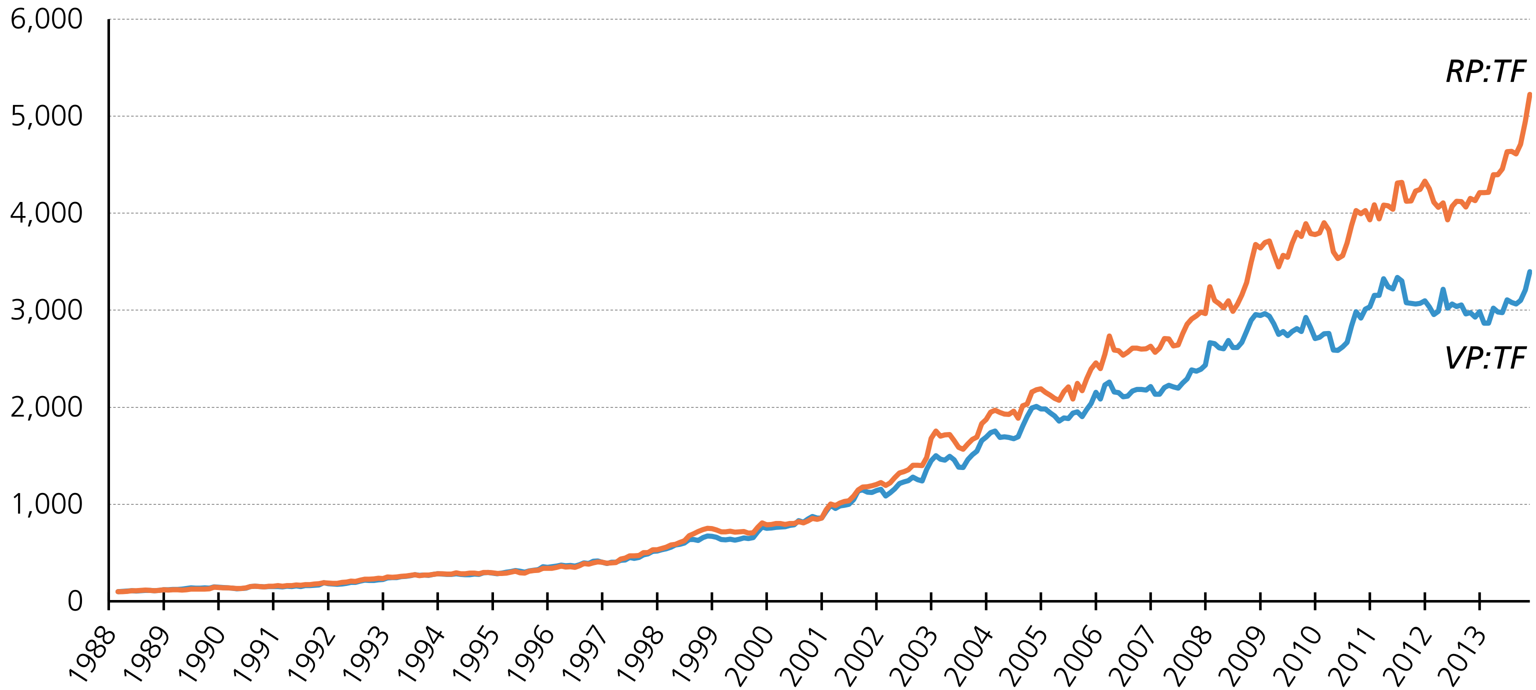
| |
|---|
| Maximise: $\sum_{i=1}^{N} log(\lvert w_i \rvert)$ |
| Subject to: $\sigma_P(\boldsymbol{w}) = \sqrt{\boldsymbol{w}' \cdot \boldsymbol{\Sigma} \cdot \boldsymbol{w}} \leq \sigma_{TGT}$ |

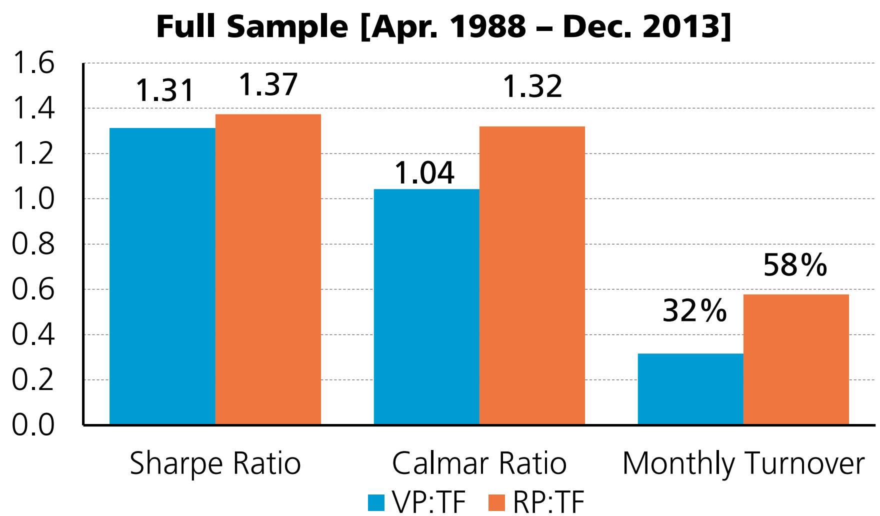
- Initial weights: $w_i^{Net,RP,init} = sign\left(ret_i^{12M}\right) \cdot \frac{(\sigma_i)^{-1}}{\sum_{j=1}^{N}(\sigma_j)^{-1}}$
- Risk-Parity Trend-Following ($RP\!:\!TF$) strategy:

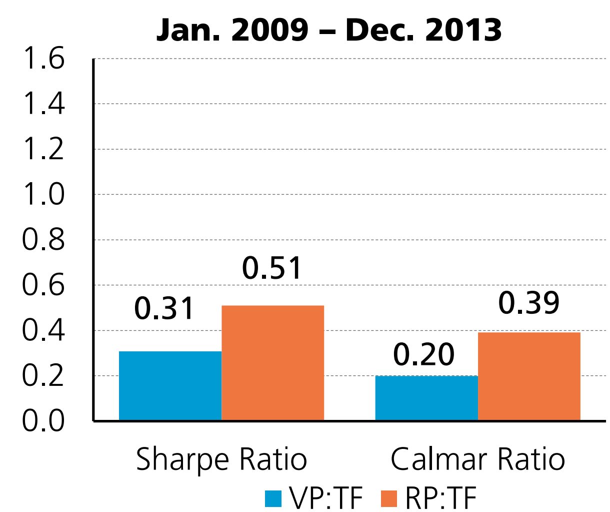
$$r_{t,t+1}^{RP:TF} = \frac{\sigma_{TGT}}{\sigma_t^{TF}} \sum_{i=1}^{N_t} w_t^{i,Net,RP} \cdot r_{t,t+1}^{i}$$



# Trend-following: Performance Statistics

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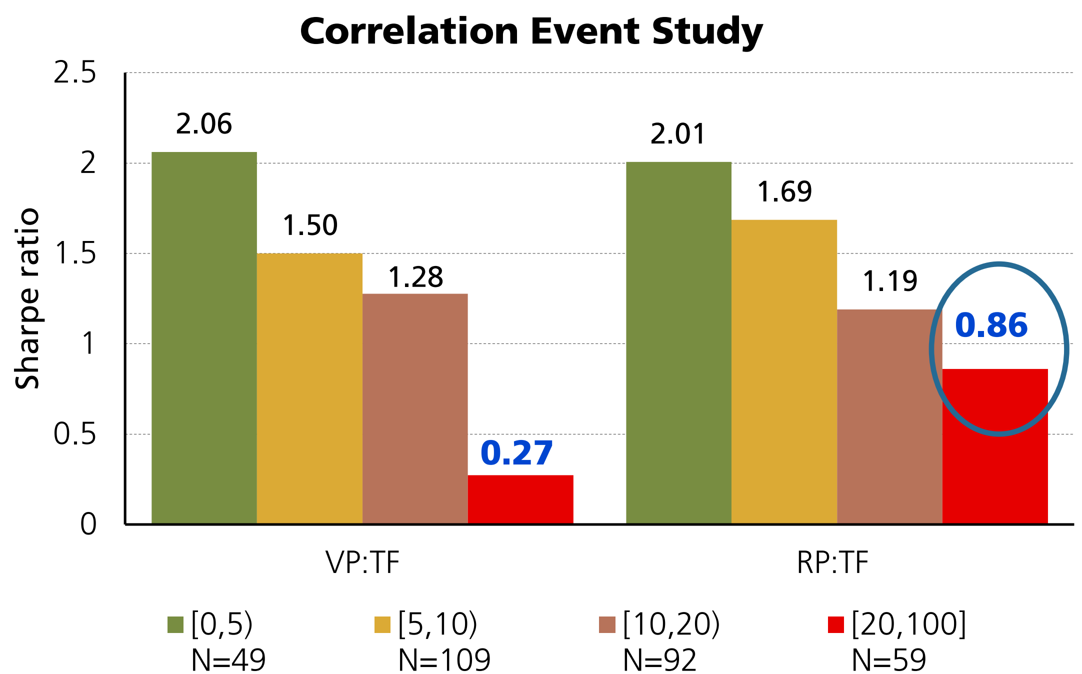
Note: For rolling Sharpe ratio see Appendix C.

Source: UBS Quantitative Research

# Correlation Event Study – Revisited

- How do RP portfolios perform in extreme-correlation regimes?



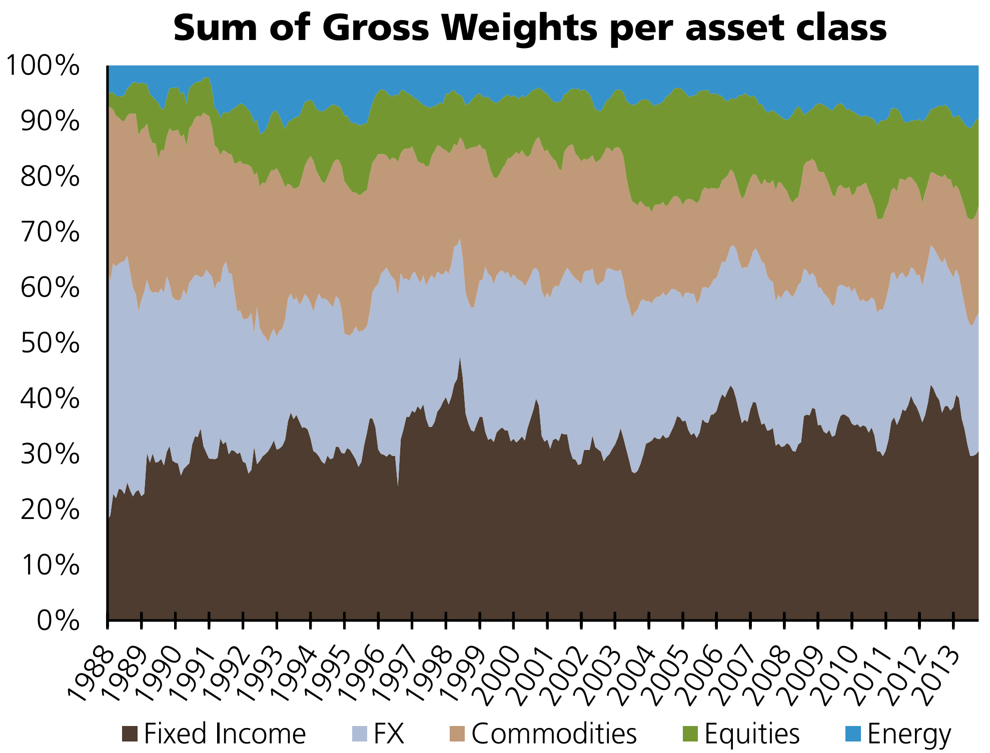

Source: UBS Quantitative Research.
For illustrative purposes only

- RP constitutes a genuine improvement to naïve VP, especially in periods of high correlations.
- *Word of Caution*: In an environment that markets do not trend at all, a more sophisticated weighting scheme like Risk-Parity can only do so much.

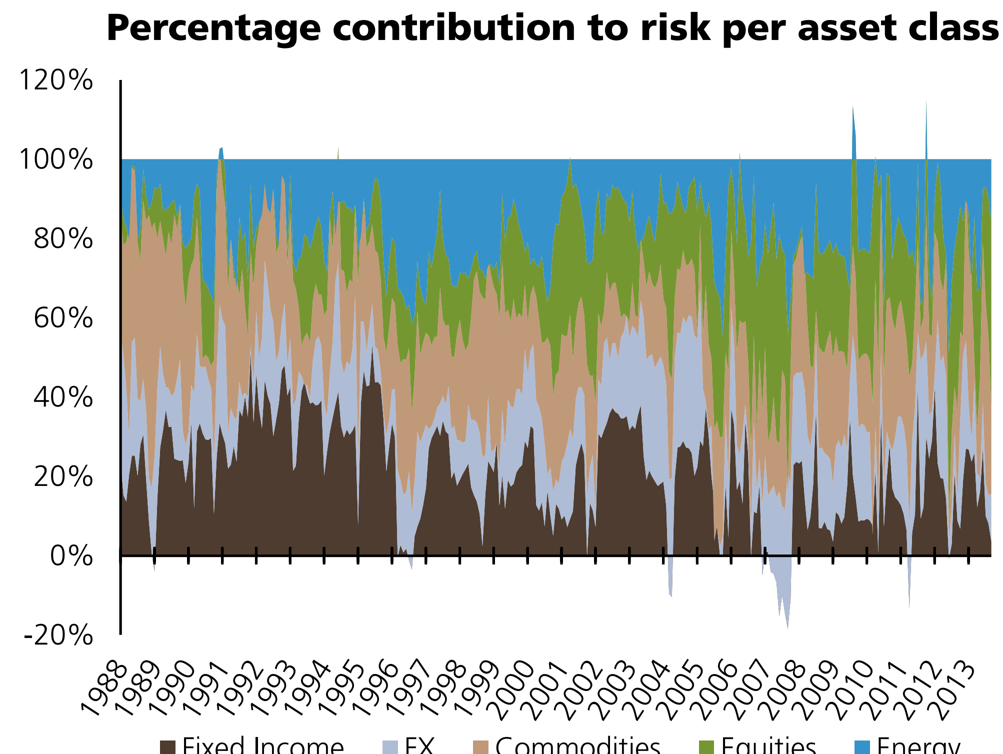
# From VP to RP – Weight vs. Risk Allocation

- *Gross weight allocation* and respective *risk allocation* per asset class.

- From Volatility-Parity…




Source: UBS Quantitative Research




Source: UBS Quantitative Research

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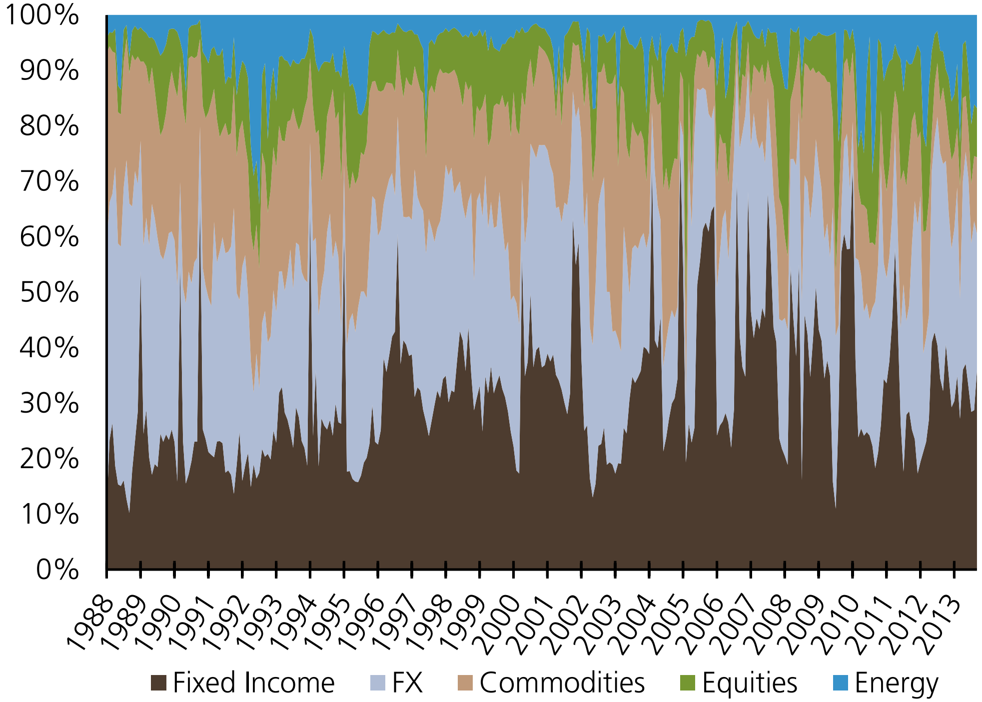
# From VP to RP – Weight vs. Risk Allocation

- *Gross weight allocation* and respective *risk allocation* per asset class.

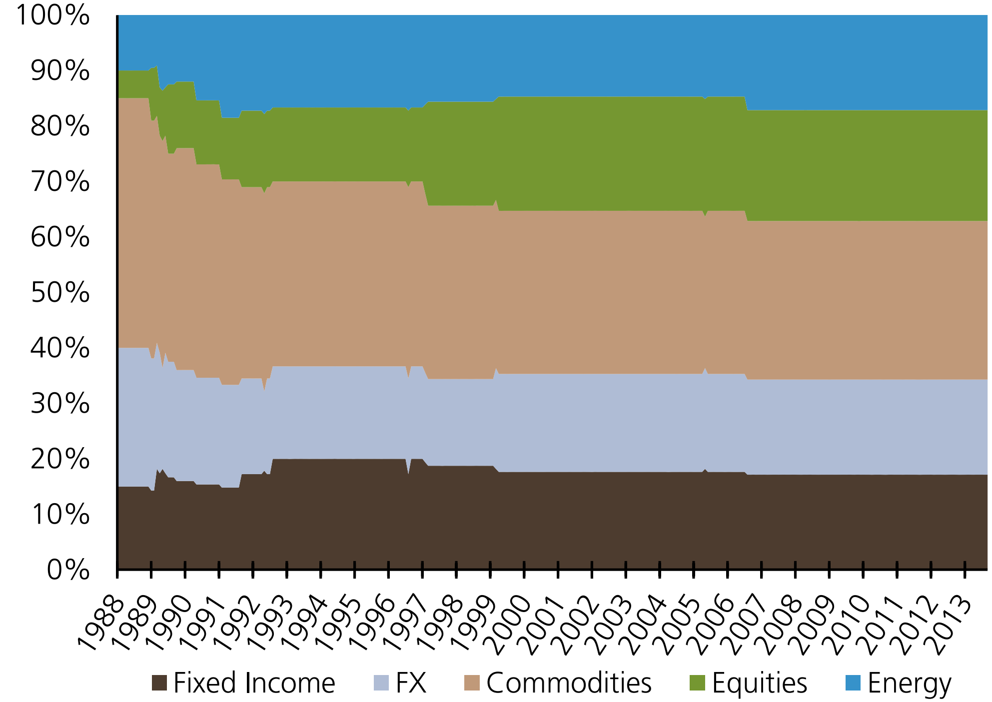
- From Volatility-Parity…to *Risk-Parity*

**Sum of Gross Weights per asset class**




Source: UBS Quantitative Research

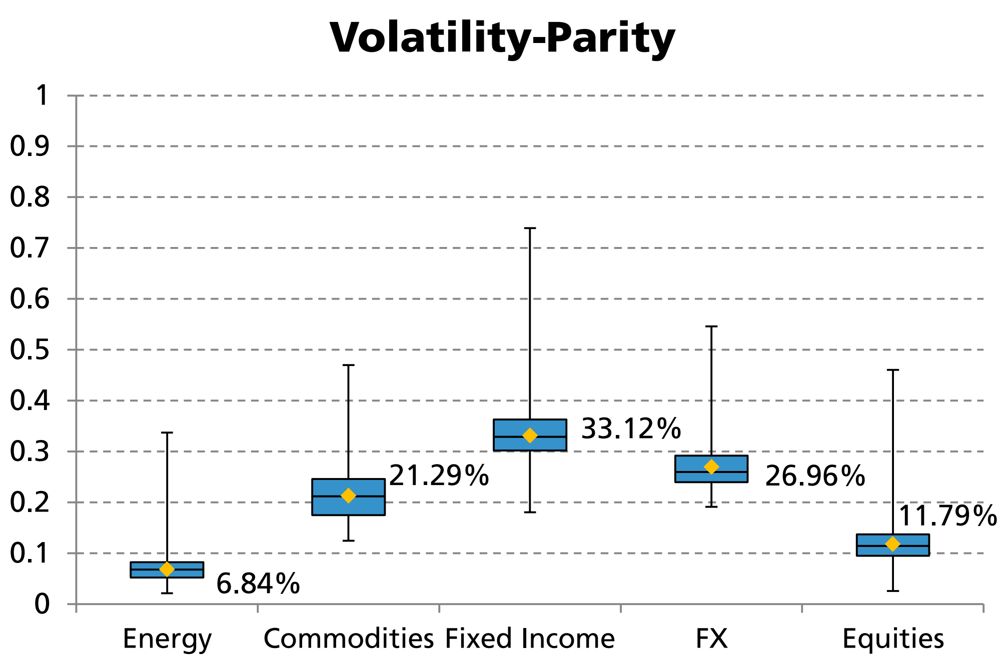
**Percentage contribution to risk per asset class**



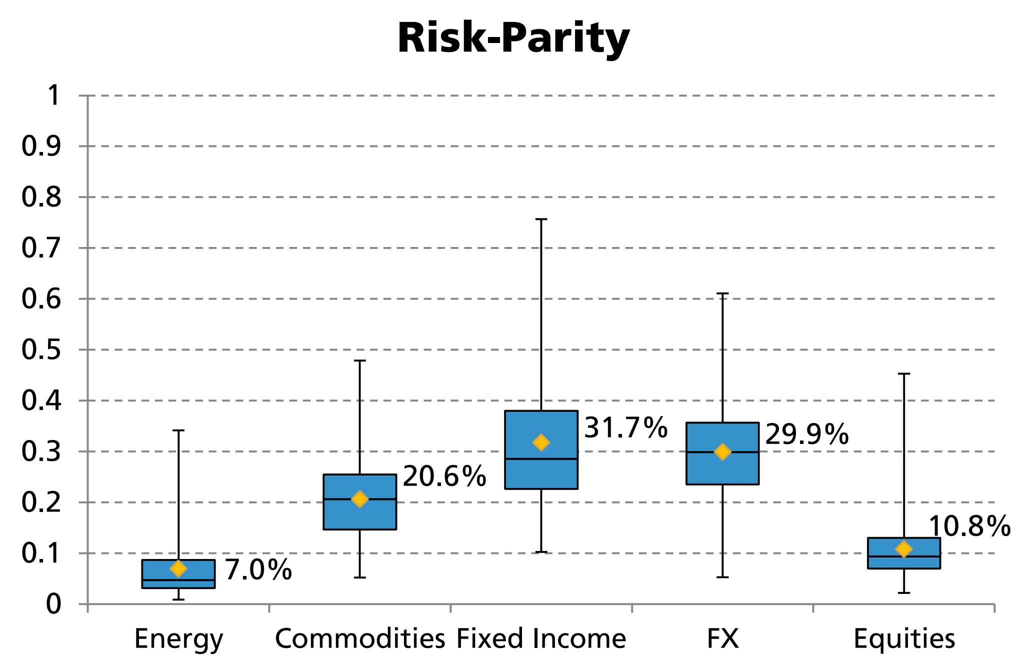

Source: UBS Quantitative Research

- *Equal Risk Contribution* across assets and consequently asset classes.

# From VP to RP – Unconditional Weight Distribution




Source: UBS Quantitative Research




Source: UBS Quantitative Research

- Similar distribution, but RP has larger interquartile ranges
- … →larger turnover, but this was expected
- The two weighting schemes are only different because of correlations.

# Concluding Remarks

- One reason for the underperformance of trend-following strategies in the post-crisis period has been the substantial co-movement of assets and asset classes
- Trend-following can benefit significantly from a risk-parity allocation, especially in periods of substantial co-movement.
- Risk-parity is generally considered a long-only allocation scheme
- We extend risk-parity to a long-short framework and show that it can significantly improve the risk-adjusted performance of trend-following in periods of high correlation.

# Appendix A - Working with Futures Contracts

- Building continuous futures price-series:
  - Futures contracts are short-lived instruments, only active until the delivery date.
  - In theory, unfunded investments; in practice, initial margin payment is required.
  - We use Bloomberg's custom-made continuous *generic* price-series using *backwards-ratio price adjustment*, so that no "price jump" (fictitious return) occurs on a roll-over day.
  - Screen <GFUT> in Bloomberg provides a number of choices regarding the construction of the generic futures series.
- Construction of “excess” returns:
  - Assume a “front” futures contract priced at $F_{t,T}$ at the end of month $t$ maturing at $T$.
  - Assume the contract is *not* within its delivery month, i.e. $t < t + 1 < T$.
  - At the end of month $t + 1$, it is priced at $F_{t+1,T}$.
  - Entering the contract at time $t$ involves initial margin of $M_t$, which, in turn, grows at $r_t^f$
  - The excess return of the futures contracts in $[t, t + 1]$ is (assuming no variation margin):

$$r_{t,t+1}^{xs} = \frac{\left[M_t\left(1 + r_t^f\right) + \left(F_{t+1,T} - F_{t,T}\right)\right] - M_t}{M_t} - r_t^f = \frac{F_{t+1,T} - F_{t,T}}{M_t}$$

  - For a "*fully-collateralised*" position, $M_t = F_{t,T}$:

$$r_{t,t+1} \equiv r_{t,t+1}^{xs,fc} = \frac{F_{t+1,T} - F_{t,T}}{F_{t,T}}$$

  - We use this formula to calculate monthly holding returns for the strategy backtesting.

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# Appendix B: Volatility-Parity versus Risk-Parity

- Volatility-parity weights:

$$w_i^{VP} \propto \frac{1}{\sigma_i}$$

- Risk-parity weights are such that: $w_i^{RP} \cdot MCR_i = constant, \forall i$

  It can be shown that: $MCR_i = \frac{\partial \sigma_P(\boldsymbol{w})}{\partial w_i} = \sigma_i \cdot \rho_{i,P}(\boldsymbol{w})$

  $\rho_{i,P}(\boldsymbol{w})$: correlation of asset $i$ with the overall portfolio.

$$\Rightarrow \quad w_i^{RP} \propto \frac{1}{MCR_i} = \frac{1}{\sigma_i} \cdot \frac{1}{\rho_{i,P}(\boldsymbol{w}^{RP})}$$

  <u>Caution:</u> the above result is not a closed-form solution…

- Risk-parity over-weights:
  - *Low-volatility* assets
  - *De-correlated* assets (i.e. assets with lower correlation with the rest of the universe)

# Appendix B: Volatility-Parity versus Risk-Parity

- Divide by parts:

$$\frac{w_i^{RP}}{w_i^{VP}} \propto \frac{1}{\rho_{i,P}(\boldsymbol{w}^{RP})}$$

<u>Caution:</u> this result is a proportionality statement → qualitative conclusions only

- When an asset correlates more with the universe, its RP weight falls relative to $\frac{1}{\sigma}$

- When an assets de-correlates, its RP weight increases relative to $\frac{1}{\sigma}$

- Using the weight normalisation (sum of weights is 100%), we deduce the following illustrative comparison:

$$\underbrace{w_i^{VP} = \frac{(\sigma_i)^{-1}}{\sum_{j=1}^{N}(\sigma_j)^{-1}}}_{Closed-form\ Solution} \quad \text{vs.} \quad \underbrace{w_i^{RP} = \frac{(MCR_i)^{-1}}{\sum_{j=1}^{N}(MCR_j)^{-1}}}_{\substack{non-closed-form\ expression \\ \to Numerical\ Solution}}$$

- The two weighting schemes are identical if all correlations are equal [see next page]

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# Appendix B: Volatility-Parity versus Risk-Parity

- The Marginal Contribution to Risk ($MCR$) is defined as the change in portfolio volatility $\sigma_P(\boldsymbol{w})$ for a marginal change in the weight of each asset $i$, $w_i$:

$$MCR_i = \frac{\partial \sigma_P(\boldsymbol{w})}{\partial w_i} = \frac{(\boldsymbol{\Sigma} \cdot \boldsymbol{w})_i}{\sigma_P(\boldsymbol{w})} \quad \textbf{(1)}$$

- If the pairwise correlation is constant across all pairs and equal to $\bar{\rho}$ then (1) simplifies to:

$$MCR_i(\bar{\rho}) = \frac{\sigma_i}{\sigma_P(\boldsymbol{w})}\left[w_i \cdot \sigma_i \cdot (1-\bar{\rho}) + \bar{\rho}\sum_{j=1}^{N} w_j \cdot \sigma_j\right] \quad \textbf{(2)}$$

- The Risk-Parity objective is:

$$w_i^{RP} \cdot MCR_i = constant, \forall i \Leftrightarrow w_i^{RP} \cdot MCR_i = w_j^{RP} \cdot MCR_j, \forall i,j \quad \textbf{(3)}$$

- Combining (2) – for $i$ and $j$ – and (3) leads to:

$$\underbrace{\left(w_i \cdot \sigma_i - w_j \cdot \sigma_j\right)}_{A} \cdot \underbrace{\left[\left(w_i \cdot \sigma_i + w_j \cdot \sigma_j\right)(1-\bar{\rho}) + \bar{\rho}\sum_{m=1}^{N} w_m \cdot \sigma_m\right]}_{B} = 0, \forall i,j \quad \textbf{(4)}$$

- Under reasonable assumptions for $B$ (…) the solution to (4) is $A = 0$, hence:

$$\frac{w_i}{w_j} = \frac{1/\sigma_i}{1/\sigma_j}, \forall i,j \Leftrightarrow \boldsymbol{Volatility\ Parity}$$

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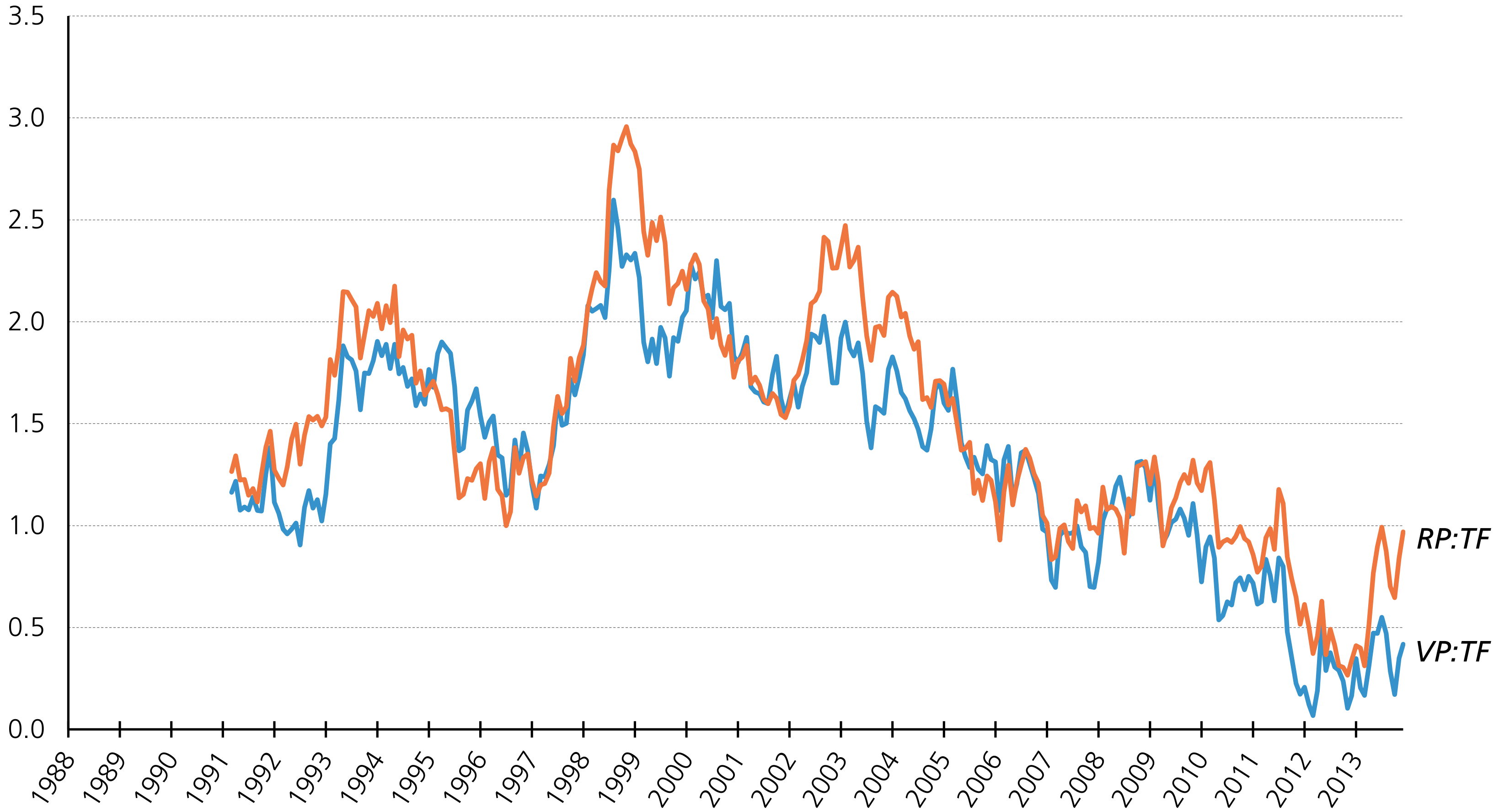
# Appendix C: 36-month Rolling Sharpe Ratio




Source: UBS Quantitative Research

- The picture is similar (in terms of RP relative benefit) for long-only strategies.

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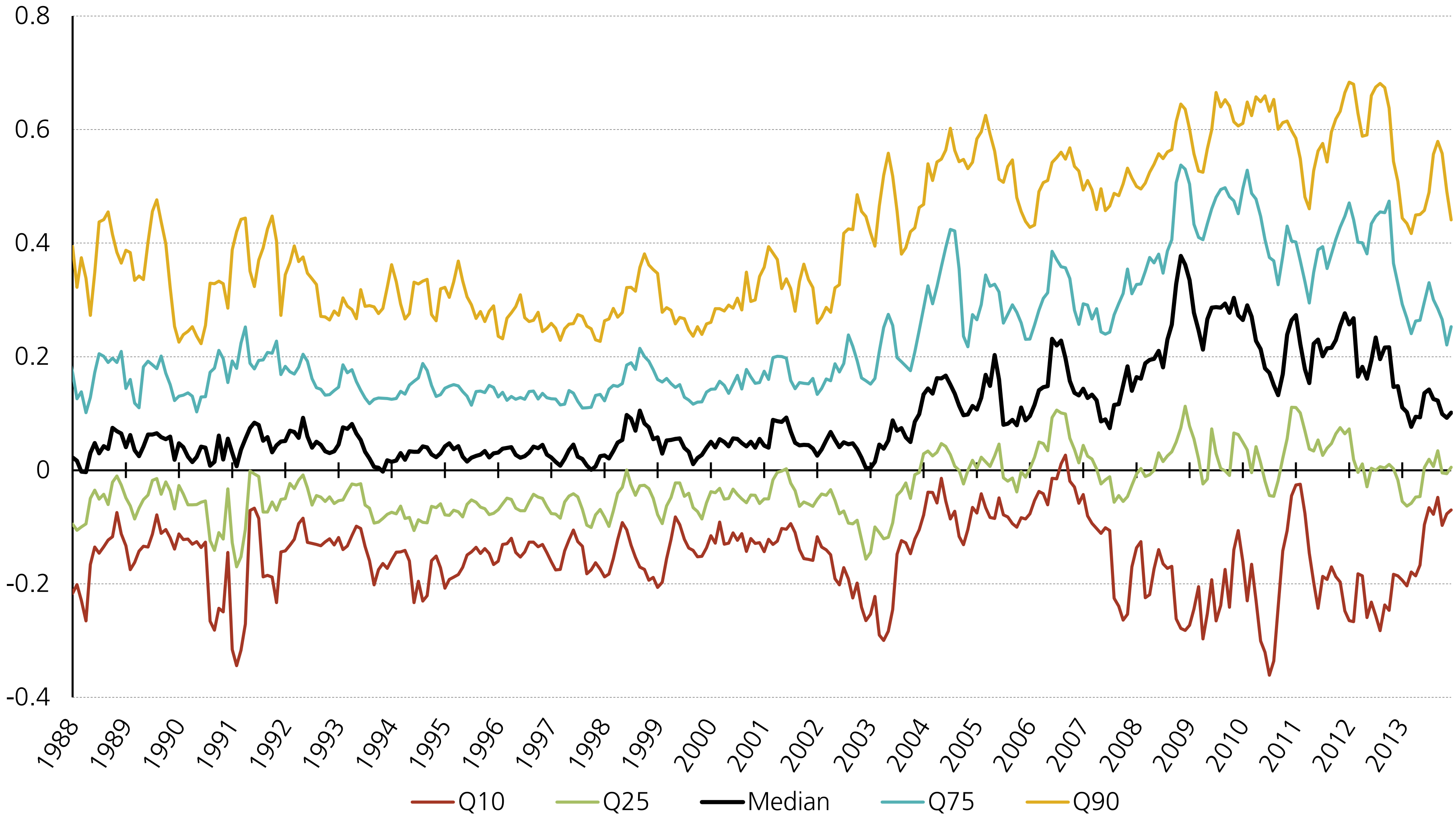
# Appendix D: Distribution of Pairwise Correlations

- We plot below the certain percentiles of the cross-sectional distribution of 90-day pairwise correlations between all the assets of our universe.




Source: UBS Quantitative Research

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