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Global Quantitative & Derivatives Strategy
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Cross Asset Portfolios of Tradable Risk Premia Indices

Hierarchical Risk Parity: Enhancing Returns at Target Volatility

Introducing the Hierarchical Risk Parity (HRP) allocation

We look at a new and interesting portfolio construction technique called the Hierarchical Risk Parity (HRP) introduced by Lopez de Prado (2016). The rationale behind HRP is to avoid the instability and concentration in Minimum Variance portfolios, which tend to have much higher out-of-sample realized volatilities.

Allocation across JPM tradable risk premia indices

We apply HRP to different cross asset universes consisting of J.P. Morgan's tradable risk premia indices. Our results confirm that HRP delivers superior risk-adjusted returns. Whilst both the HRP and the MV portfolios deliver the highest returns, ***the HRP portfolios match with volatility targets much better than MV portfolios***. We also run simulation studies to confirm the robustness of our findings, in which HRP consistently deliver a superior performance over MV and other risk-based strategies.

More uncorrelated exposure in the HRP risk premia portfolio

Whilst risk premia indices are lowly correlated, MV portfolios can still be highly concentrated with smaller number of uncorrelated exposures. On the other hand, HRP portfolios are truly diversified with a higher number of uncorrelated exposures, and less extreme weights and risk allocations.

Global Quantitative and Derivatives Strategy

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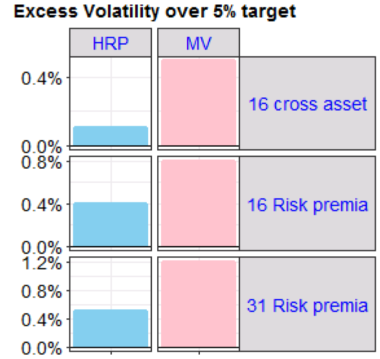
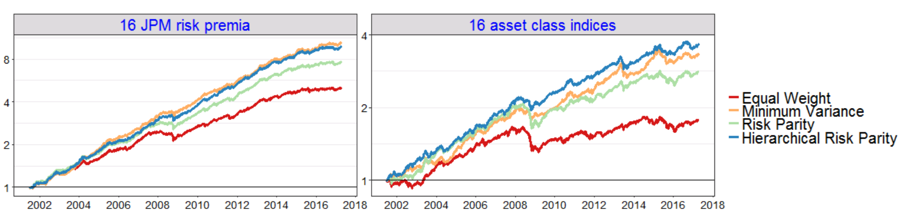
Excess Volatility over 5% target



Backtest performance and diversification properties



		Hierarchical Risk Parity	Minimum Variance	Maximum Diversification	Risk Parity	Equal Risk Contribution	Equal Weight
Backtest Performance	Information ratio	Higher	Higher				Lower
	Returns	Higher	Higher			Lower	Lower
	Volatility target	Good	Poor	Poor	Good		Good
	Max Drawdown	Lower	Lower				Higher
Diversification properties	Diversification ratio			Higher			Lower
	Concentration ratio		Higher	Higher	Lower	Lower	
	No. of uncorrelated exposures	Higher		Higher			Lower
	Extreme weight		Yes		No	No	No
	Extrene risk budget		Yes		No	No	

Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

See page 47 for analyst certification and important disclosures, including non-US analyst disclosures.

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Systematic Cross-Asset Strategies primers

- Systematic Strategies Across Asset Classes: Risk Factor Approach to Investing and Portfolio Management
- Equity Risk Premia Strategies: Risk Factor Approach to Portfolio Management
- Momentum Strategies Across Asset Classes: Risk Factor Approach to Trend Following

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Introduction

Due to the popularity of passive investing, we have published a comprehensive primer on systematic cross asset risk premia strategies in 2013.

Passive investing has become increasingly popular among asset managers in recent years. One of the major reasons is that many investors have been disappointed by the poor performance of active managers. At the same time, simply using market cap-weighted benchmarks (a.k.a. traditional beta) also turns out to be highly inefficient. As such, investors have turned their attention to factors such as value, quality and momentum, which have long been backed by academics to provide a systematic way to harvest risk premia. Systematic strategies that are constructed to have pure exposures to these factors are coined "smart beta" strategies, or in a more modest manner, risk premia investing. For a detailed overview of systematic risk premia strategies across different asset classes, please refer to the cross asset primer published in 2013[1]. In that 205-page comprehensive report, we analyze individual cross asset risk premia, examine their correlations, and discuss various portfolio construction techniques.

A portfolio for cross asset allocation

With over 2000 risk premia indices on the street, investors have to decide how to allocate across different risk premia in an optimal way.

This report aims to answer the above question from a risk-based perspective, using actual tradable JPM indices.

Furthermore, we introduce an interesting idea called Hierarchical Risk Parity, recently proposed by Lopez de Prado (2016).

J.P. Morgan has developed a large suite of risk premia indices across asset classes over the years. For a detailed list of indices, please refer to P.133-158 in the primer on cross asset systematic strategies. These indices are constructed to help investors to gain systematic exposure to various risk premia in a cost-effective way. Some indices may appear in a few different versions due to various overlays or portfolio construction methodologies, which are applied to tailor the need of different investors with varying risk tolerances. Including those provided by other vendors on the street, Hamdan et al (2016) has compiled a comprehensive database of about 2000 indices and ETFs that are deemed to be alternative risk premia products[2].

With so many risk premia products out there, one can imagine that allocating across these risk premia becomes a non-trivial investment decision for asset managers. Many products will be similar and highly correlated, and choosing a universe is not straight forward at all.

To help investors make better decisions, we look at possible ways to allocate across risk premia in order to harvest the returns most efficiently. We introduce a new idea called "Hierarchical Risk Parity" that is first proposed by Lopez de Prado (2016)[3], and compare its performance with other portfolio construction approaches. In contrast to the primer on cross asset risk premia strategies, in this report, we look at actual tradable JPM indices that are currently available for investing. With such indices, we have already taken into account constraints such as capacity issues, liquidity impact, transaction costs, rolling costs as well as feasibility of short selling.

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[1] **Kolanovic, M. and Wei, Zhen (December 2013), Systematic Strategies Across Asset Classes: Risk Factor Approach to Investing and Portfolio Management, J.P. Morgan Quantitative and Derivative Strategy**

[2] **Hamdan, Rayann and Pavlowsky, Fabien and Roncalli, Thierry and Zheng, Ban (2016) A Primer on Alternative Risk Premia. Available at SSRN: https://ssrn.com/abstract=2766850**

[3] **Lopez de Prado, Marcos (2016), Building Diversified Portfolios that Outperform Out-of-Sample. Journal of Portfolio Management, 2016, Forthcoming. Available at SSRN: https://ssrn.com/abstract=2708678**

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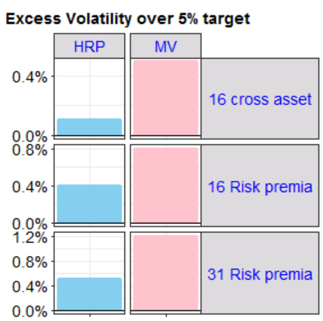
Major findings

While this report spends a considerable length to introduce the new allocation technique of Hierarchical Risk Parity (HRP), it is not just about a description of interesting idea: We do find evidences that HRP is a very good allocation methodology for cross asset indices, no matter the universe is composed of pure, alternative risk premia or traditional market indices across asset classes.

Hierarchical Risk Parity delivers the highest information ratio across various universes, and show robustness in our simulation study. It is also more diversified than the Minimum Variance portfolio.

Whilst Minimum Variance (MV) also scores quite well in terms of returns, its main weakness is that it has significantly higher out-of-sample realized volatility, which coincides with the conclusion in Lopez de Prado (2016). On top of that, we also show that Minimum Variance portfolios are more concentrated than HRP, as measured by various diversification metrics from concentration ratio to the number of uncorrelated exposures made in the portfolio.

Figure 1 summarizes our findings: we observe that amongst various risk-based strategies, Hierarchical Risk Parity gives the best allocation for a cross asset universe in terms of returns, volatilities and diversification measures:



- **Best match with target volatility:** The HRP portfolios are able to match well with the target volatility out-of-sample, but the Minimum Variance portfolios significantly underestimate risk and give significantly higher realized volatilities.
- **Risk-adjusted performances:** HRP delivers one of the highest information ratios across various universes including both alternative and traditional risk premia
- **Robustness:** Apart from using three different universes, we also confirm the out-of-sample superior performance of HRP by using simulation studies. HRP portfolios have the highest returns and lowest out-of-sample volatilities and drawdowns, whilst Minimum Variance (MV) portfolios have the highest realized volatility
- **Diversified portfolio:** Compared with the Minimum Variance (MV) strategy, HRP provides a more diversified portfolio: It has a larger number of uncorrelated exposures and a lower concentration ratio. Also, HRP is less prone to having extreme weights and risk allocations, which is common in MV portfolios.

Together with the sound rationale behind Hierarchical Risk Parity and its relatively simple implementation, we feel that it is a prominent strategy that should be included in the portfolio construction toolbox of asset managers.

Figure 1: Comparisons of the portfolio construction techniques

		Hierarchical Risk Parity	Minimum Variance	Maximum Diversification	Risk Parity	Equal Risk Contribution	Equal Weight
Backtest Performance	Information ratio	Higher	Higher				Lower
	Returns	Higher	Higher			Lower	Lower
	Volatility target	Good	Poor	Poor	Good		Good
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	Extrene risk budget		Yes		No	No	

Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg.

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Risk-based allocations and Hierarchical Risk Parity

Let us start with a few traditional risk-based strategies that only utilize the volatility or covariance structure of the underlying risk premia. This is in contrast to Markowitz's Mean-Variance Optimization (MVO), where expected returns are also required. The five strategies that we consider are:

- Equal Weight (EW)
- Minimum Variance (MV)
- Risk Parity (RP)
- Equal Risk Contribution (ERC)
- Maximum Diversification (MD)

We consider five risk-based strategies, which aim to minimize or diversify various measures of "risk".

The goal of risk-based allocations lies in the concept of diversification: Since we do not have an idea of expected returns, we would rather focus our attention to either minimize and/or diversify risk. As highlighted in Jean-Charles et al (2015), one can define different measures of diversification, and each measure could lead to a particular risk-based portfolios. For instance, an equal-weighted portfolio diversifies in terms of asset weights; a portfolio built to have equal risk contributions diversifies in terms of risk budgets, etc.

Overview of portfolio construction methodologies

In the following, we briefly revisit some of the most popular portfolio construction methodologies. More details can be found in the primer on Systematic Strategies (Kolanovic and Wei, 2013).

Minimum Variance

Minimum Variance portfolios have a very simple objective, which is to minimize the expected portfolio variance:

$$w_{MV} = \arg\min_{w} \quad w'\Sigma w$$

Such portfolios have been documented to have high out-of-sample returns, especially in equities (Clarke et al 2011). Together with the low volatility (provided that one does not leverage), Minimum Variance portfolios tend to have high information ratios. However, if we look at a very large universe (e.g. hundreds of stocks), the performance of Minimum Variance usually deteriorates. This is largely due to two issues in Minimum Variance portfolios:

- **Sensitivity to inputs:** To obtain the optimal weights in an MV portfolio, one has to invert the covariance matrix. Such inversion makes it very sensitive to the noises in the covariance estimates, especially when there are highly correlated assets that render the covariance matrix close to singular.
- **Concentrated positions:** MV tends to assign concentrated weights to only a few assets, and as such, even within a large universe, the actual uncorrelated number of exposures is low. Concentrated portfolios tend to be more prone to sudden drawdowns and have higher realized volatilities.

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Risk Parity

Here we use the term Risk Parity to mean a strategy that allocates weights inversely proportional to asset volatility:

$$w_i \propto 1/\sigma_i$$

i.e. it is a "naïve" form of risk parity which does not take into account correlations. This is to align with the notations being used when we introduce the Hierarchical Risk Parity in the next section (Lopez de Prado (2016)).

Equal Risk Contribution

This strategy assigns weights so that all assets have the same contribution to total portfolio risk (Maillard et al 2010). This is another popular risk-based strategy which is first introduced by Bridgewater Associates as the "All-Weather Story"[4]. One may recall that Total Risk Contribution (TRC) is the proportion of risk of an asset contributed to the final portfolio volatility:

$$\text{Marginal risk contribution } MRC_j = \frac{\partial \sigma_p}{\partial w_j} = (\Sigma w)_j$$

$$\text{Total risk contribution} = TRC_j = w_j MRC_j$$

$$\text{Portfolio risk} = \sigma_p = \sum_j TRC_j$$

A strategy with Equal Risk Contribution means that risk budgets (i.e. TRC) are equal for any assets *i, j*:

$$w_i(\Sigma w)_i = w_j(\Sigma w)_j$$

Maximum Diversification

Maximum Diversification (MD): Maximize the diversification ratio (Choueifaty and Coignard 2008), defined as the ratio of weighted volatility to portfolio volatility:

$$DR = \frac{\sum_j w_j \sigma_j}{\sqrt{w' \Sigma w}}$$

An interesting property of the Maximum Diversification portfolio is that all assets have the same positive correlation with the portfolio[5]. Choueifaty et al (2011) provides more insightful analysis on the properties of this Most Diversified portfolio.

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[4] **The All Weather Story, Bridgewater Associates (https://www.bridgewater.com/resources/all-weather-story.pdf)**

[5] **This is intuitive, because if one asset has a higher correlation with the portfolio, that asset is deemed to be "over-represented". We will then increase the diversification ratio by decreasing the weight of that asset, hence its correlation with the portfolio will decrease.**

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Hierarchical Risk Parity (HRP)

Lopez de Prado (2016) introduced a new and interesting idea of allocation called Hierarchical Risk Parity. It is termed "Hierarchical" because it makes use of the hierarchical clustering algorithm to assign assets into similar groups, and then apply the (naïve) Risk Parity allocations recursively across asset groups. As such, HRP also considers correlations among assets instead of simply looking at asset volatilities.

The rationale behind HRP is to avoid the instability and concentration in Minimum Variance (MV) portfolios that rely on the inversion of covariance matrix, which is problematic when there are highly correlated assets that render the covariance matrix close to singular.

Actually, rather than trying to improve upon the naïve Risk Parity approach, Lopez de Prado (2016) comes up with the idea of HRP so as to improve upon the Minimum Variance strategy. The rationale behind HRP is to avoid the instability and concentration in Minimum Variance (MV) portfolios that rely on the inversion of covariance matrix, which is problematic when the matrix is close to singular – this happens when there are highly correlated assets. Furthermore, estimations of full covariance matrices could be noisy or spurious, especially when the number of assets is large and the number of observations is relatively small[6]. HRP comes as a solution to get around the above issues by allocating to clusters of similar assets.

In the following, we describe the algorithm in more details for the inquisitive readers. Those who are interested in the performance of the strategies can go directly to the next section.

Algorithm

The Hierarchical Risk Parity algorithm consists of 3 major steps:

1. Define the distances:
   Compute a distance matrix among the assets based on correlations:

$$d_{i,j} = \sqrt{(1 - \rho_{i,j})/2}$$

2. Quasi-Diagonal Covariance:
   Based on the distance matrix, re-order the assets into clusters so that assets closer to each other are more similar. This will lead to a Quasi-Diagonalize correlation matrix with large values 'closer' to the diagonal.

3. Recursive Bisection:
   Allocate weights inversely proportional to the volatility of the clusters in an iterative manner, starting from the largest cluster. In each iteration, we bisect the larger clusters into two smaller ones and re-distribute the weights across the clusters based on their volatilities.

For readers who want to try this recipe themselves, Lopez de Prado (2016) provides Python codes for an implementation of Hierarchical Risk Parity[7].

Toy example with four stocks

The clustering methodology in HRP can also be viewed as a "top-down" allocation approach. This may be better explained in terms of stocks, as it makes intuitive sense that stocks in the same sectors tend to cluster together. As a toy example, let us consider four stocks: Apple, Google, J.P. Morgan and Bank of America.

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[6] There are various techniques to de-noise covariance estimations, e.g. Bayesian shrinkage approaches (Ledoit and Wolf (2004)).

[7] The Python codes and descriptions can be found under the Software page on http://quantresearch.info/ (or http://quantresearch.info/HRP.py.txt)

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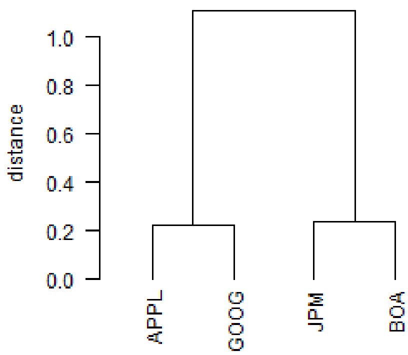
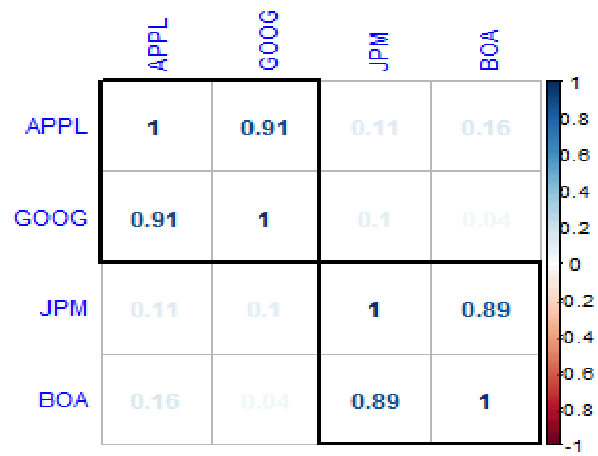
First, using the distances calculated from the correlation matrix[8], we perform hierarchical clustering in order to put assets into clusters. In the hierarchical clustering algorithm, we iteratively merge two smaller clusters to form a larger one, until we merge all clusters into one. The ordering obtained is as shown in the dendogram in Figure 2. We can then re-order the correlation matrix so that it becomes Quasi-Diagonal, where we highlight the clusters in squares.

Figure 2: Hypothetical dendogram and correlation clusters of a toy example with four stocks





Source: J.P. Morgan Quantitative and Derivatives Strategy.

In this toy example of four stocks, the HRP algorithm firstly re-orders the correlation matrix based on the clusters, and then assign weights inversely proportional to the volatility of the clusters.

The algorithm starts with the same weight of one for all stocks, and iterate as follows:

- From the largest cluster (four stocks), split into two smaller clusters: (APPL, GOOG) and (JPM, BoA).
- Calculate the volatility of each of the clusters, and obtain a scaling parameter α, which is used to distribute the weights inversely proportional to the cluster volatility:

$$\sigma_{clus1} = \sqrt{w_1' \Sigma w_1}$$

$$\sigma_{clus2} = \sqrt{w_2' \Sigma w_2}$$

$$\alpha = 1 - \frac{\sigma_{clus1}}{\sigma_{clus1} + \sigma_{clus2}}$$

- Re-weight the assets in each cluster, i.e. if cluster 1 has a higher volatility than cluster 2, we will scale down the weights of assets in cluster 1:

$$w_1 \rightarrow \alpha w_1$$

$$w_2 \rightarrow (1 - \alpha) w_2$$

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[8] **Here we use a hypothetical correlation matrix for illustration purpose**

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The dark blue vertical bar highlights a cluster of volatility risk premia.

The Quasi-diagonal correlation matrix will be re-ordered based on Hierarchical clustering.

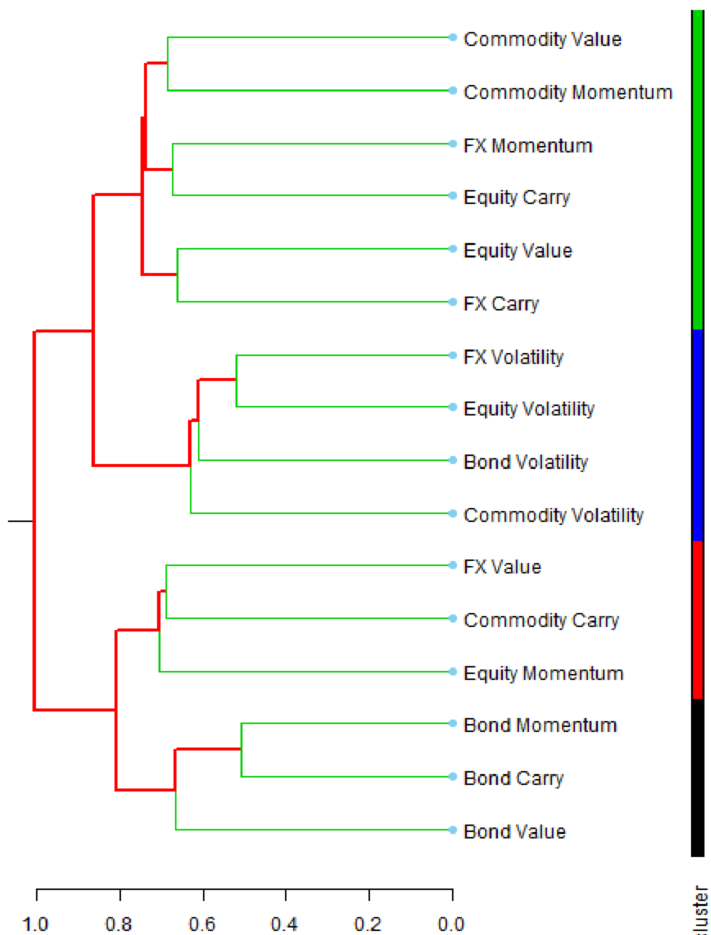
16 JPM cross asset indices: A more realistic picture

Let us also demonstrate the hierarchical clustering approach in HRP using a larger universe of 16 JPM cross asset indices, where we will provide more details in the next section. With a larger universe, one will see that the asset order determined by Hierarchical clustering plays an important role in HRP.

Using the hierarchical clustering algorithm, we can group the indices into nearby clusters for better visualization. Here we choose to highlight four clusters, but note that the number of clusters does not matter in the algorithm of HRP. In fact, only the ordering matters, since the number of clusters depends on where we cut the tree.

Looking at the dark blue vertical bar which highlights a cluster, we see that all volatility risk premia are highly correlated, and hence they will be situated next to each other in the re-ordered correlation matrix in Figure 4.

Figure 3: Dendogram of 16 JPM cross asset indices based on Hierarchical clustering. This ordering will be used to re-order the correlation matrix in a Quasi-diagonal format



Source: J.P. Morgan Quantitative and Derivatives Strategy

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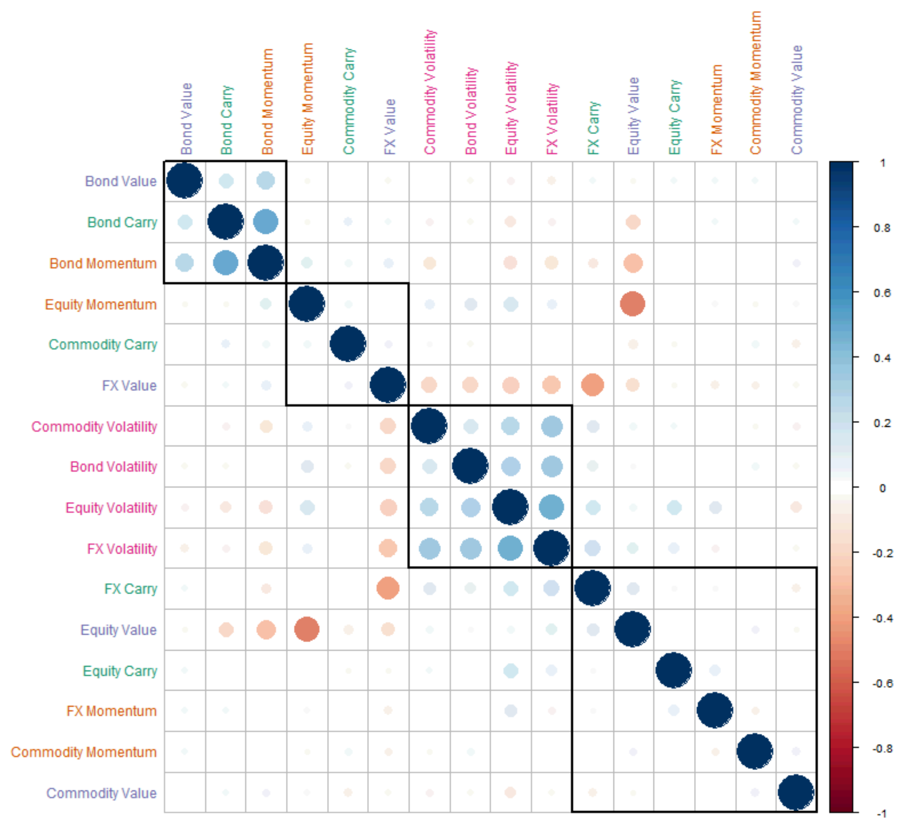
From the ordering determined by the hierarchical clustering algorithm, we can arrange the correlation matrix into a Quasi-diagonal format. This helps us to define which indices are highly correlated with each other, and hence we can determine which cluster of indices to look at when we assign the weights inversely proportional to the clusters.

This order plays an important role in HRP because of the bisection procedure.

This order plays an important role in HRP because of the bisection procedure: We start from the largest cluster with 16 indices, and in the first iteration we perform bisection and consider two smaller clusters each with eight indices. One may argue that such a simplistic bisection approach may not be ideal, because we restrict ourselves to clusters of the same sizes. We feel that this could be an area of further research, although bisection is the simplest algorithm to start with. We repeat the process of bisection until each cluster has only one asset remained. Lopez de Prado (2016) coined the process as "recursive bisection".

Figure 4: Quasi-diagonal correlation, re-ordered based on the Hierarchical clustering algorithm



Source: J.P. Morgan Quantitative and Derivatives Strategy

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Performance comparisons of cross asset portfolios

To put theories into action, we backtest the above risk-based strategies in several cross asset universes. All backtests start from July 2001 to April 2017. We estimate the covariance matrices every month end, using the past one year of daily returns with an exponential weighting, where we choose a half-life of about six months[9]. We then estimate the weights for each allocation strategy based on the covariance matrices. An asset will only enter the universe when we have enough observations of daily returns to estimate the covariance.

Long-only constraints

We also impose a constraint on the strategies so that we only have long-only positions. This is due to our focus on risk premia indices: To be qualified as a true risk premia, over the long run it should deliver positive returns. In the wordings of Ang (2013), risk premia are the expected returns demanded by investors for bearing the risk during “bad times”.

Volatility targeting at 5%

Since many risk premia indices tend to have relatively low volatilities, we use volatility targeting to leverage the returns of the strategies. This can also allow a fairer comparison of performances across difference universes and allocations.

We choose 5% annual volatility as our target, and we leverage the weights using a scale factor k, which is the ratio of the target volatility to our predicted portfolio volatility σ_p:

$$w \to kw$$

$$k = \frac{\sigma_{target}}{\sigma_p}$$

Using forecasted portfolio volatility in general leads to much higher realized volatility than the target.

The best volatility targeting approach is based on historical portfolio volatility estimated from daily returns.

Clearly, a good forecast of the portfolio volatility is crucial for hitting the target. It turns out that we are vastly underestimating volatility if we calculate portfolio volatility based on the estimated covariance matrix:

$$\sigma_p = \sqrt{w'\Sigma w}$$

To better target on volatility, we look at historical volatility of the portfolios instead, using the past 12 months of realized portfolio returns based on the particular allocation. Still, we are underestimating volatility, but to a lesser extent.

Using daily returns will lead to a more accurate estimate of the portfolio volatility. As such, we decide to look at the past 252 days of portfolio volatility as an estimator of σ_p.

[9] **We have tried to use a longer lookback window up to 5 years, and a longer half-life. The rankings of the strategies remain similar**

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Cross asset risk premia indices from representative styles

In this first allocation exercise, we use a suite of 16 JPM tradable cross asset risk premia that best represents the standard grouping of risk premia across four asset classes (Bond, Commodity, Equity, FX) and four styles (Carry, Momentum, Value, Volatility). These 16 JPM indices are summarized in the table below

Table 1: 16 JPM tradable cross asset indices

Risk premia	Ticker	Index name	Strategy summary
Bond Carry	JCMXF6US	CarryMax Future	Long-short strategy aiming to capture yield differential & rates slide in govt. bond futures
Bond Momentum	JMOZFI2U	Mozaic Fixed Income	Long and/or short exposure to a basket of money market and government bond futures selected on the basis of recent relative returns
Bond Value	JPCVTUS	CurveTrader M+	The index seeks to take advantage of 2s-10s yield curves moves using central bank rate announcements as signals
Bond Volatility	JPVLUTYO	J.P. Morgan Volecule UST	Pure short gamma exposure on UST 10Y
Commodity Carry	JMABDJSE	Curve Select	22 commodities with different rolls optimized to extract the carry in the futures curves
Commodity Momentum	JMABSSPE	Seasonal Spreads	Applying seasonal momentum within commodity pairs
Commodity Value	JCOPC	Compendium	Momentum strategy based on fundamental, sectorial and macro indicators
Commodity Volatility	JMAB184E	Commodity volatility	Short volatility on 12 commodity underlyings to target 50bps of vega on the strategy notional
Equity Carry	JPEDIUFX	Divimont Short dated Index	The strategy is long the 1st and 2nd year dividend futures and short the Stoxx 50
Equity Momentum	ERJPMOGU	ERP Global Momentum	Long Short on Single stocks from MSCI world universe based on momentum signal
Equity Value	ERJPVLGU	ERP Global Value	Stock selection based on value factor approach on global universe
Equity Volatility	JPOSGLMR	Equity Volatility Basket with Mean Reversion	Systematic short gamma combined with mean reversion
FX Carry	JPFCCP02	FX Currency Carry Pairs	Currency pairs with the highest carry to risk are selected. A correlation filter is used to filter out pairs which are less correlated
FX Momentum	JTRDX2BU	FX Trends	A basket of momentum and mean reversion strategies on FX pairs using various moving averages
FX Value	JPFCVA01	FX PPP DM	Strategy aims to capture value in FX pairs using PPP (DM currencies)
FX Volatility	JPVOFXB2	FX Volecule Basket	Short volatility strategy on FX pairs through delta hedged short straddles

Source: J.P. Morgan Quantitative and Derivatives Strategy

For more details on the long term correlations and returns statistics of the indices, please refer to page 40 in the Appendix.

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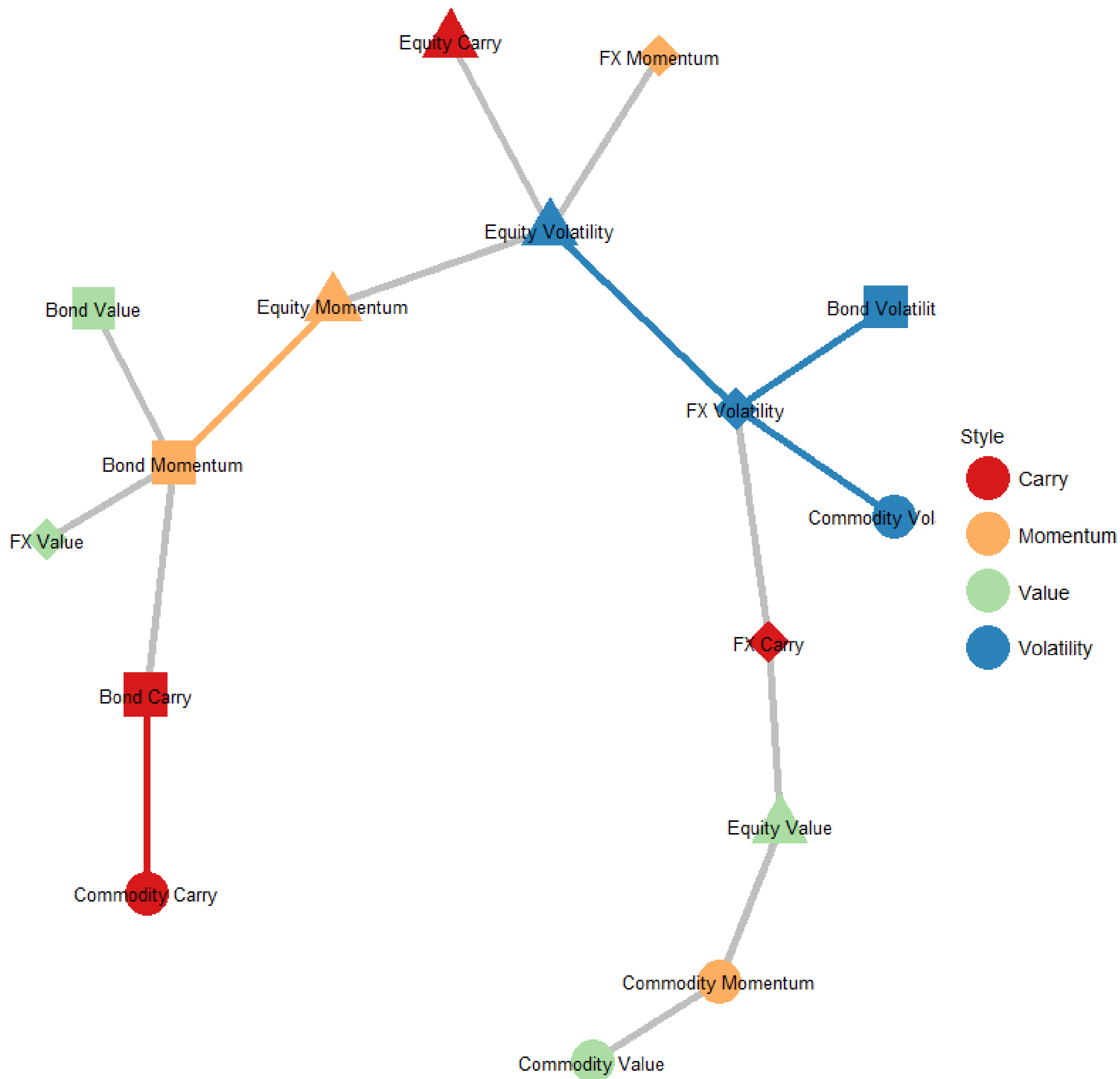
Figure 5 is a Minimum Spanning Tree[10] constructed from the correlation matrix of the 16 risk premia indices, which provides a useful visualization of the clusters of indices.

- Volatility indices are highly correlated with each other

Figure 5: Minimum Spanning Tree of the 16 JPM tradable cross asset indices, based on correlations of daily returns



Source: J.P. Morgan Quantitative and Derivatives Strategy

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10 A spanning tree is a connected undirected graph with no cycles. A minimum spanning tree is a spanning tree with the shortest weighted edges, where an edge represents the distance between two nodes. Here we use the correlation as a measure of distance.

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Below shows the performance of each cross asset indices since 2001:

- FX Momentum has the highest information ratio (1.8)
- Commodity related risk premia, especially Momentum, Carry and Volatility, have performed well compared with Equity and Bond
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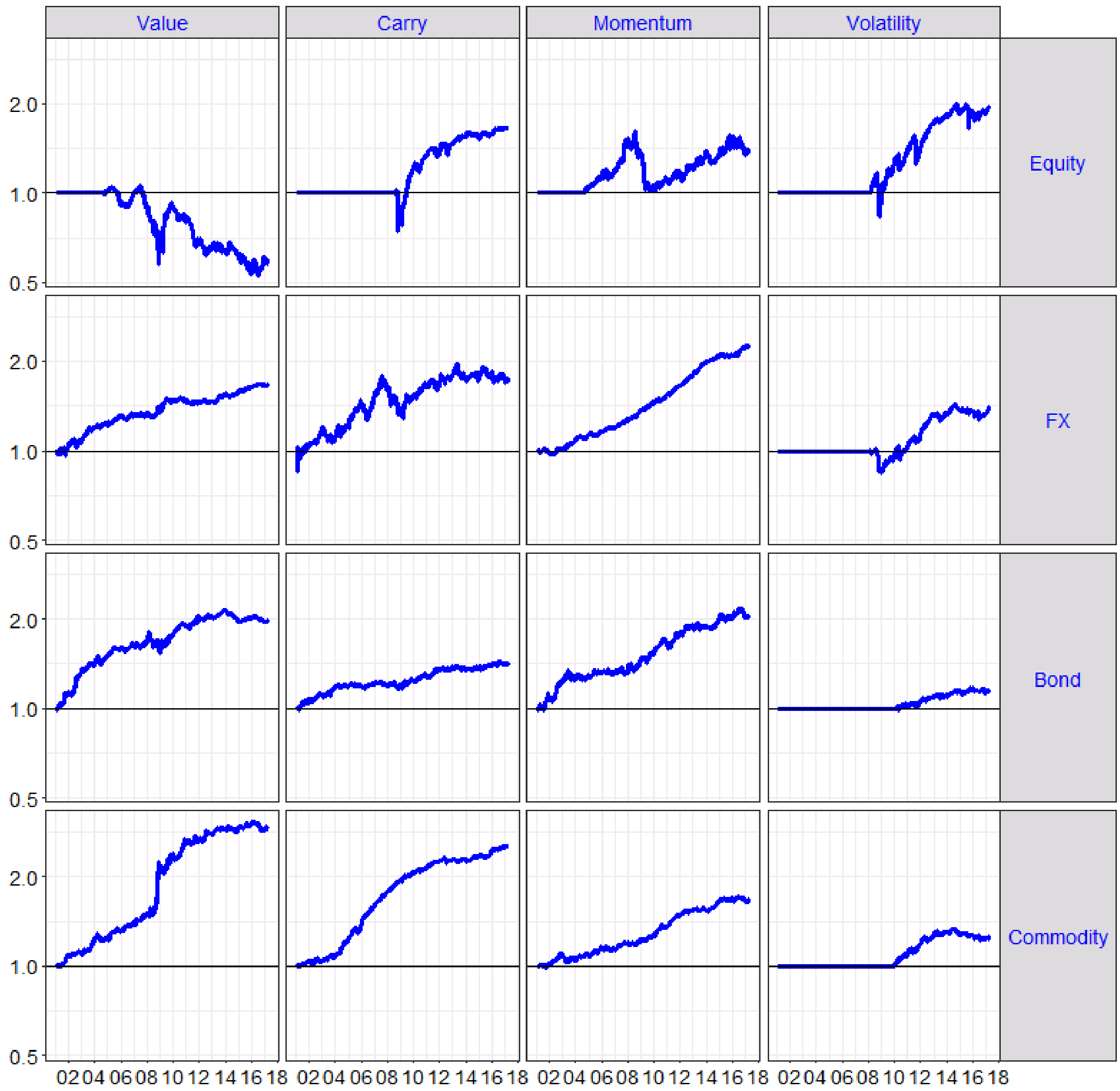
Figure 6: Wealth curves of 16 JPM tradable cross asset indices since 2001



Source: J.P. Morgan Quantitative and Derivatives Strategy

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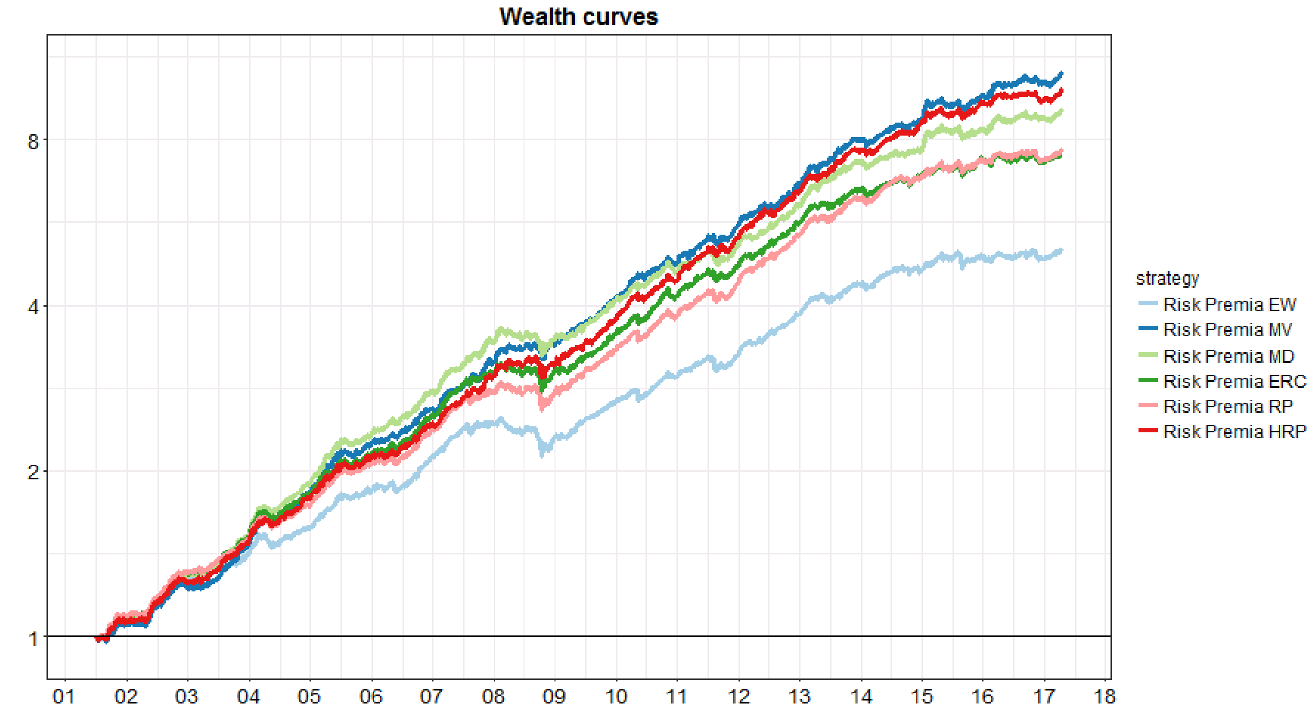
With the 16 risk premia indices, let us look at the various risk-based strategies that allocate across them.

- HRP delivers the highest information ratio, followed by MV
- EW is the least efficient allocation strategy and suffers from the largest drawdown

Figure 7: Wealth curves of the long-only allocation strategies using 16 JPM cross asset risk premia indices. Backtest period: 2001-07-02 to 2017-04-18



Source: J.P. Morgan Quantitative and Derivatives Strategy

Table 2: Daily returns statistics sorted by IR (2001-07-02 to 2017-04-18)

Strategy	CAGR (%)	Annualized Vol (%)	IR	Max DD (%)	Hit ratio (%)	CAGR (%, Past 3Yr)	Vol (%, Past 3Yr)	IR (%, Past 3Yr)
HRP	15	5.4	2.76	9.1	58.2	8	5.3	1.52
MV	15.5	5.8	2.7	7.3	57.6	9	5.9	1.53
MD	14.4	5.7	2.51	11.4	57.4	6.8	6	1.12
RP	13.3	5.3	2.49	11	59.4	6	5.5	1.09
ERC	13.2	5.4	2.43	11.1	58.7	4.8	5.6	0.85
EW	10.4	5.2	2	14.5	59	3.8	5.5	0.7

Source: J.P. Morgan Quantitative and Derivatives Strategy

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A larger suite of cross asset risk premia indices

There are many similar smart beta indices that attempt to capture a particular risk premia.

Instead of pre-selecting a few indices from each category, we consider a broad universe of 31 JPM indices, and let the algorithm decide an optimal weight to allocate across the indices.

The 16 cross asset risk premia used in the last section is a good starting point as an example to illustrate the strategies. Nevertheless, in reality, there can be many similar smart beta indices that attempt to capture a particular risk premia. For instance, when people talk about "FX Value", are they looking at a universe of DM currencies, EM currencies, or both? When an asset manager wants to harvest volatility premia, does he or she want to look at rates volatility using treasury futures, or US equity volatility based on VIX futures? These are practical questions in the implementation of smart beta portfolios. One of the solutions is to consider a broad universe and let the algorithm decide an optimal weight to allocate across the indices.

To analyze such a realistic scenario in the world of smart beta, we consider allocating across a larger universe of 31 JPM tradable cross asset risk premia indices, covering various systematic risk premia strategies which are liquid, live and tradable as of 18 April 2017. The 31 indices in Table 3 serve as a representative set from different asset classes and are targeted to capture a wide range of cross asset premia. In some cases, practical enhancements and overlays are also included.

Table 3: A larger suite of 31 JPM tradable cross asset risk premia indices, which serves as a representative set from different asset classes

Ticker	Name	Class	Details
ERJPMFGU	ERP Global Multi-Factor	Equity	Stock selection based on core five factor approach on global DM universe
CIJPJMLS	Japan Mean Reversion	Equity	Stock selection based recent performance, short benchmark
JPUSQEM2	QES	Equity	Technical strategy which aims to capture intraday momentum on SPX futures
JPMZKRN2	Kronos US	Equity	Technical strategy on S&P500 futures
JCOPCF	Compendium Fundamental	Commodities	Using momentum on fundamental signals to go long-short commodities
JMABSSPE	Seasonal Spreads	Commodities	Applying seasonal momentum within commodity pairs
JMABCCLE	WTI Crude Continuum	Commodities	Strategy aims to capture trends and mean reversion within WTI
JMC13CLA	Curve WTI	Commodities	Capture commodity curve carry within WTI
JMABDJSE	Curve Select	Commodities	Capture commodity curve carry within single sector commodities across BCOM benchmark
JMABRALO	Ranked Alpha	Commodities	Strategy uses momentum to go long curve alpha pairs
JMABCCVP	Commodity Curve Value	Commodities	Capture value within commodity curve
JGCTRCCU	Govt. Bond Carry	Rates	Directional strategy aiming to capture yield differential & rates slide in govt. bond futures
JCMXF6US	CarryMax Future	Rates	Long-short strategy aiming to capture yield differential & rates slide in govt. bond futures
JPCVTUS	Curve Trader M+	Rates	Strategy based on momentum and carry in govt. bond futures in EUR and USD
JMOZF2CE	Mozaic Fixed Income Series 2	Rates	Long Short strategy aiming to capture momentum in interest rate futures
JTRDFXB2	FX Trends	Currency	Sophisticated technical strategy on 7 USD currency pairs
JPFCDYB1	FX Markowitz	Currency	Strategy aims to capture trends in FX pairs using MPT allocation
JPFCARRU	FX Carry	Currency	Classic FX carry strategy applied to 8 USD currency pairs
JPFCCP01	FX CCP	Currency	Enhanced carry strategy with less concentration to USD
JPFCVA01	FX PPP DM	Currency	Strategy aims to capture value in FX pairs using PPP (DM currencies)
JPFCVA05	FX PPP EM	Currency	Strategy aims to capture value in FX pairs using PPP (EM currencies)
JPMZVEL1	FX Equity Momentum	Currency	Strategy relies on equity market performance as a leading indicator of FX returns
JPOSGLSO	Equity Volatility Basket	Short Volatility	Pure short gamma exposure across a wide range of global indices
JPVOBA1E	Volemont Commodity Basket	Short Volatility	Pure short gamma exposure across a wide range of commodities
JPVLUTYO	J.P. Morgan Volecule UST	Short Volatility	Pure short gamma exposure on UST 10Y
JPVOFXB1	FX Volatility Basket	Short Volatility	Pure short gamma exposure across 5 USD currency pairs
JPOSGLMR	Equity Volatility Basket with MR	Short Volatility enhanced	Systematic short gamma combined with mean reversion
JMAB184E	Commodity Volatility Basket with BE	Short Volatility enhanced	Short / neutral exposure to short gamma based on break-even volatility signal
JPMZVUS2	Macro Hedge US Short Only VT 2%	VIX Futures Based	Short only strategy on 1-2 month VIX futures with a vega target of 2%
JPMZVMS2	Macro Hedge Enhanced VT 2% Short-Only	VIX Futures Based	Short only strategy on 4-7 month VIX futures with a vega target of 2%
JPMZVP4G	US Volatility Term Premia	VIX Futures Based	Systematic long puts on VIX Futures

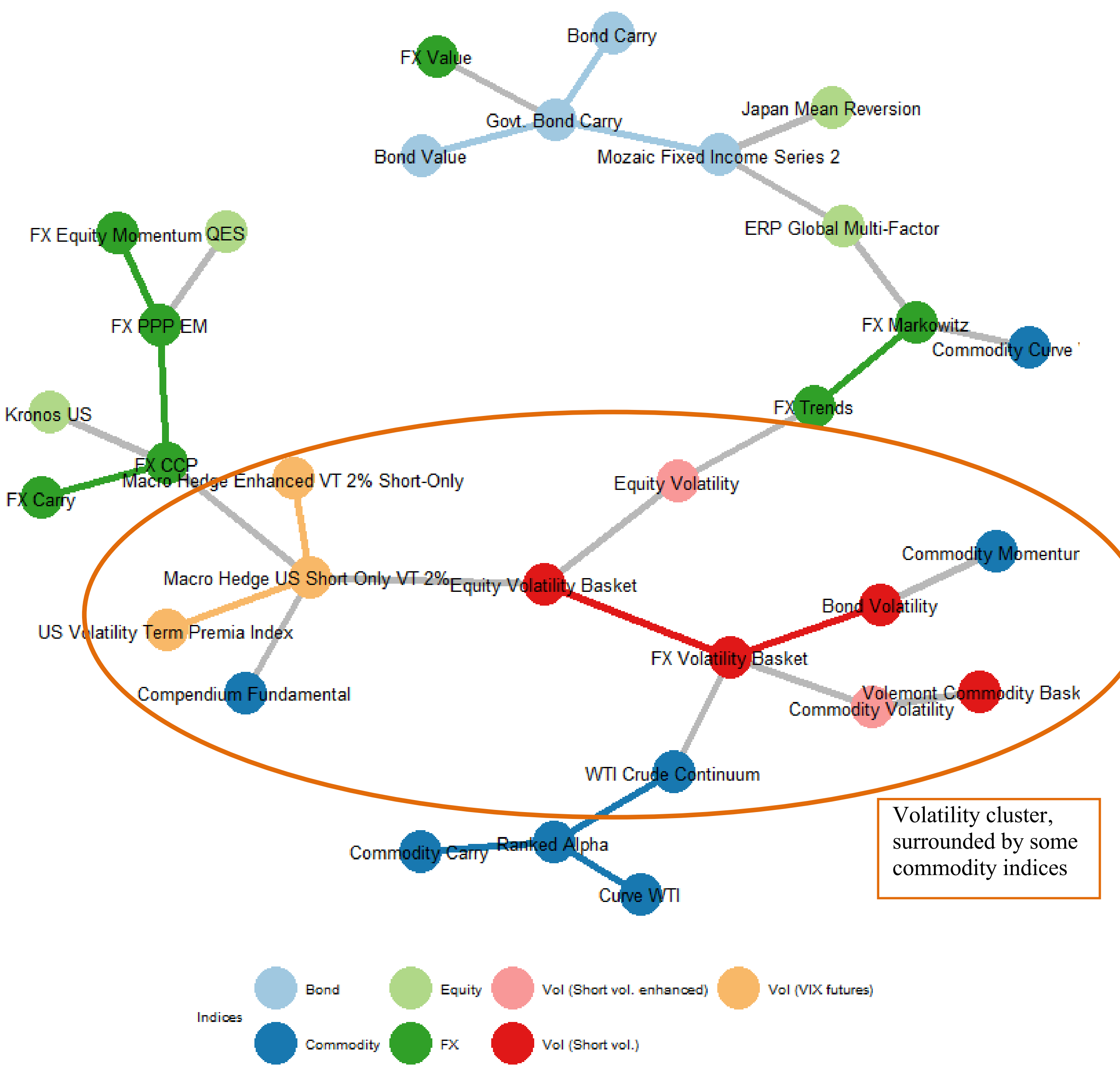
Source: J.P. Morgan Quantitative and Derivatives Strategy

For more details on the long term correlations and returns statistics of the indices, please refer to page 41 in the Appendix.

Figure 8 displays a Minimum Spanning Tree that is built from the correlation of these 31 indices. This gives an illustrative picture of groups of similar risk premia strategies:

- Volatility strategies are closely related and form a cluster
- Commodity indices have relatively high correlations to volatility indices
- FX and Equity indices tend to be neighbors in the tree

Figure 8: Minimum Spanning Tree of 31 JPM cross asset indices



Source: J.P. Morgan Quantitative and Derivatives Strategy

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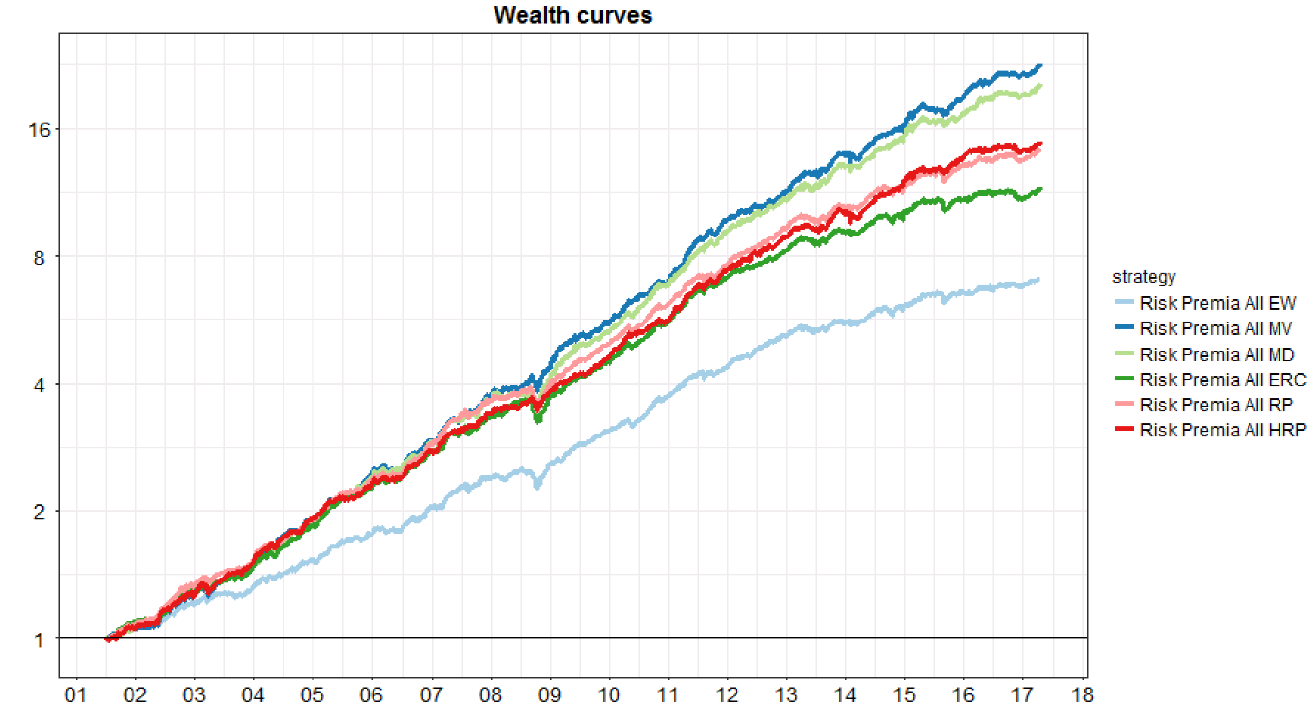
When we run the allocation strategies in this larger universe of 31 JPM indices, we find that Minimum Variance gives the highest information ratio (IR) and returns, but at a relatively high volatility of 6.1%.

On the other hand, HRP delivers a similar IR but at a volatility of 5.4%, matching much better with our target of 5% per annum.

HRP also gives the lowest drawdown (7.8%) among all strategies.

Figure 9: Wealth curves of the long-only allocation strategies using a larger suite of 31 JPM cross asset risk premia indices. Backtest period: 2001-07-02 to 2017-04-18



Source: J.P. Morgan Quantitative and Derivatives Strategy

Table 4: Daily returns statistics sorted by IR (2001-07-02 to 2017-04-18).

Strategy	CAGR (%)	Annualized Vol (%)	IR	Max DD (%)	Hit ratio (%)	CAGR (%, Past 3Yr)	Vol (%, Past 3Yr)	IR (%, Past 3Yr)
MV	21	6.1	3.43	8.1	59.4	16.6	6.1	2.71
HRP	17.9	5.4	3.3	7.8	59.9	12.9	5.2	2.47
MD	20.2	6.1	3.3	11.8	60.1	14.4	6.5	2.21
RP	17.7	5.4	3.27	12.6	61.5	10	5.7	1.77
ERC	16.2	5.3	3.05	11.7	60.7	7.6	5.5	1.38
EW	12.7	5.1	2.5	10.8	59.5	7.6	5.3	1.44

Source: J.P. Morgan Quantitative and Derivatives Strategy

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Traditional asset class risk premia

Are the previous backtest results sensitive to our choice of risk premia universes?

To see if our strategies also work well in other cross asset universes, we look at 16 long-only traditional asset class indices as a comparison.

From the above analysis, we see that risk-based strategies, especially Hierarchical Risk Parity and Minimum Variance, have played well in allocating across risk premia indices. Readers may be curious to know if those results are largely confined to our choice of risk premia universe. After all, risk premia indices have been purposely constructed to capture positive returns by exposing to undiversifiable sources of risk, and hence they may perform particularly well in backtests.

As such, let us dig deeper and turn our attention momentarily to traditional risk premia, which are also known as traditional beta, market beta, or simply asset classes. These are long-only indices that track the equity, bond, currency and commodity markets.

To select a representative set of market indices, we consult the literature: One recent paper by Hamdan et al (2016)[11] catches our attention, since it is one of the most comprehensive studies, which looks at a large database of about 2000 commercial indices and investment products that replicate risk premia. Apart from alternative risk premia, the authors also compare some of the results with traditional risk premia from asset classes. We decide to use the same set as a comparison, and the 16 asset class indices are shown in Table 5.

Table 5: 16 traditional asset class indices that are studied in Hamdan et al (2016)

Ticker	Name	Asset Class
M2WD Index	MSCI ACWI Gross Total Return USD Index	Equity
M2WO Index	MSCI World Gross Total Return USD Index	Equity
M2EF Index	MSCI Emerging Markets Gross Total Return USD Index	Equity
M2US Index	MSCI USA Gross Total Return USD Index	Equity
M8EU Index	MSCI Europe Gross Return EUR Index	Equity
M8JP Index	MSCI Japan Gross Return JPY Index	Equity
M1AP Index	MSCI AC Asia Pacific Net Total Return USD Index	Equity
LGAGTRUH Index	Bloomberg Barclays Global Aggregate Government Total Return Index Hedged USD	Rates
LUAGTRUU Index	Bloomberg Barclays US Govt Total Return Value Unhedged USD	Rates
LEATTREU Index	Bloomberg Barclays EuroAgg Treasury Total Return Index Value Unhedged EUR	Rates
LGCPTRUH Index	Bloomberg Barclays Global Aggregate Corporate Total Return Index Hedged USD	Credit
LUACTRUU Index	Bloomberg Barclays US Corporate Total Return Value Unhedged USD	Credit
LP05TREH Index	Bloomberg Barclays Pan European Aggregate Corporate TR Index Hedged EUR	Credit
ADXY Index	Bloomberg JPMorgan Asia Dollar Index	Asian currency
DXY Index	Dollar Index	USD
BCOMTR Index	Bloomberg Commodity Index Total Return	Commodity

Source: J.P. Morgan Quantitative and Derivatives Strategy, Hamdan et al (2016)

For more details on the long term correlations and returns statistics of the indices, please refer to page 43 in the Appendix.

[11] **Hamdan, Rayann and Pavlowsky, Fabien and Roncalli, Thierry and Zheng, Ban (2016) A Primer on Alternative Risk Premia. Available at SSRN: https://ssrn.com/abstract=2766850**

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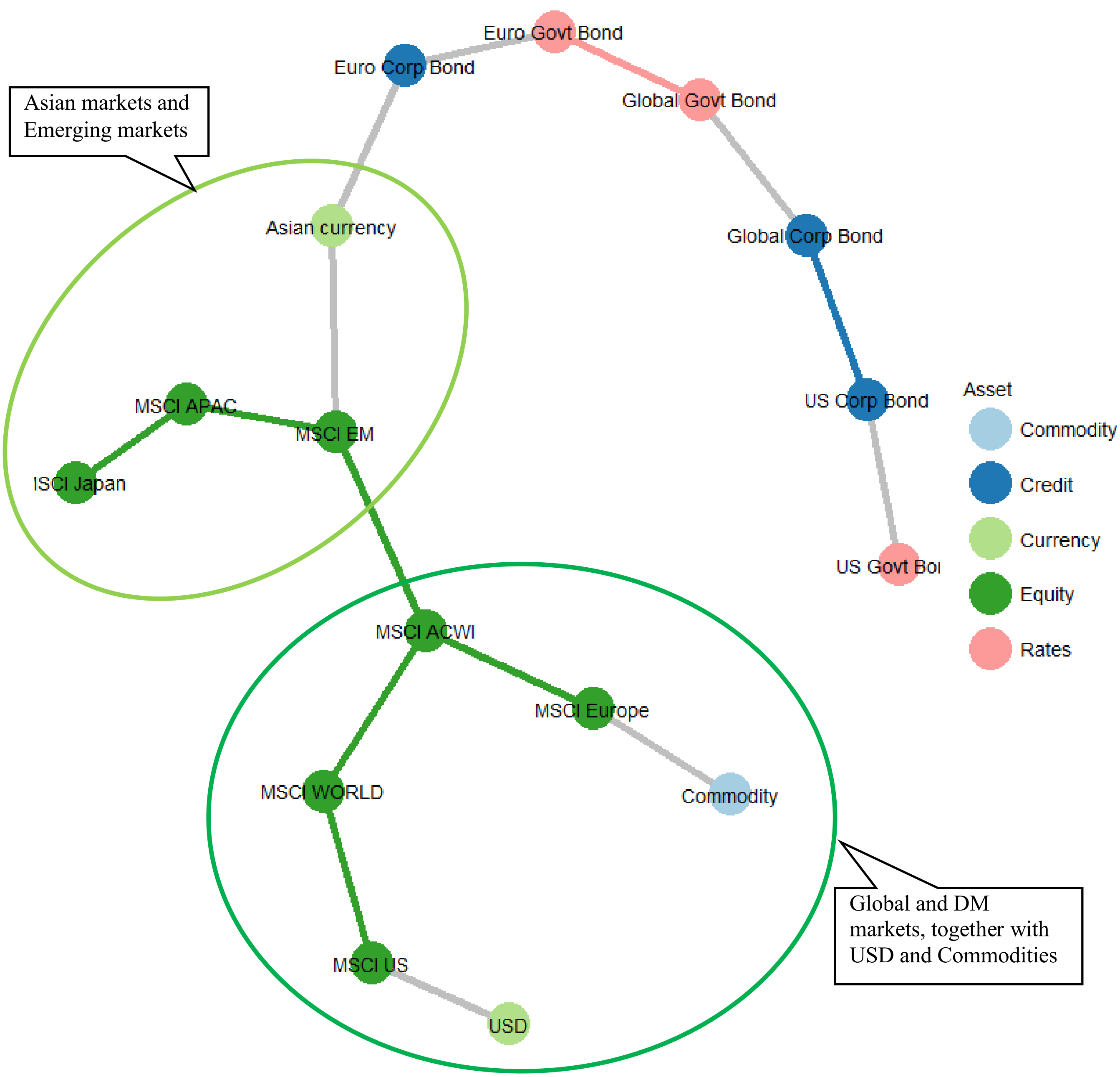
The Minimum Spanning Tree in Figure 10 illustrates the traditional asset classes that we consider, and highlights the group of assets that tend to move in tandem:

- Rates (government bond) and credit (corporate bond) indices are correlated
- Equity indices belong to another cluster

Figure 10: Minimum Spanning Tree for 16 traditional asset class indices that are studied in Hamdan et al (2016)



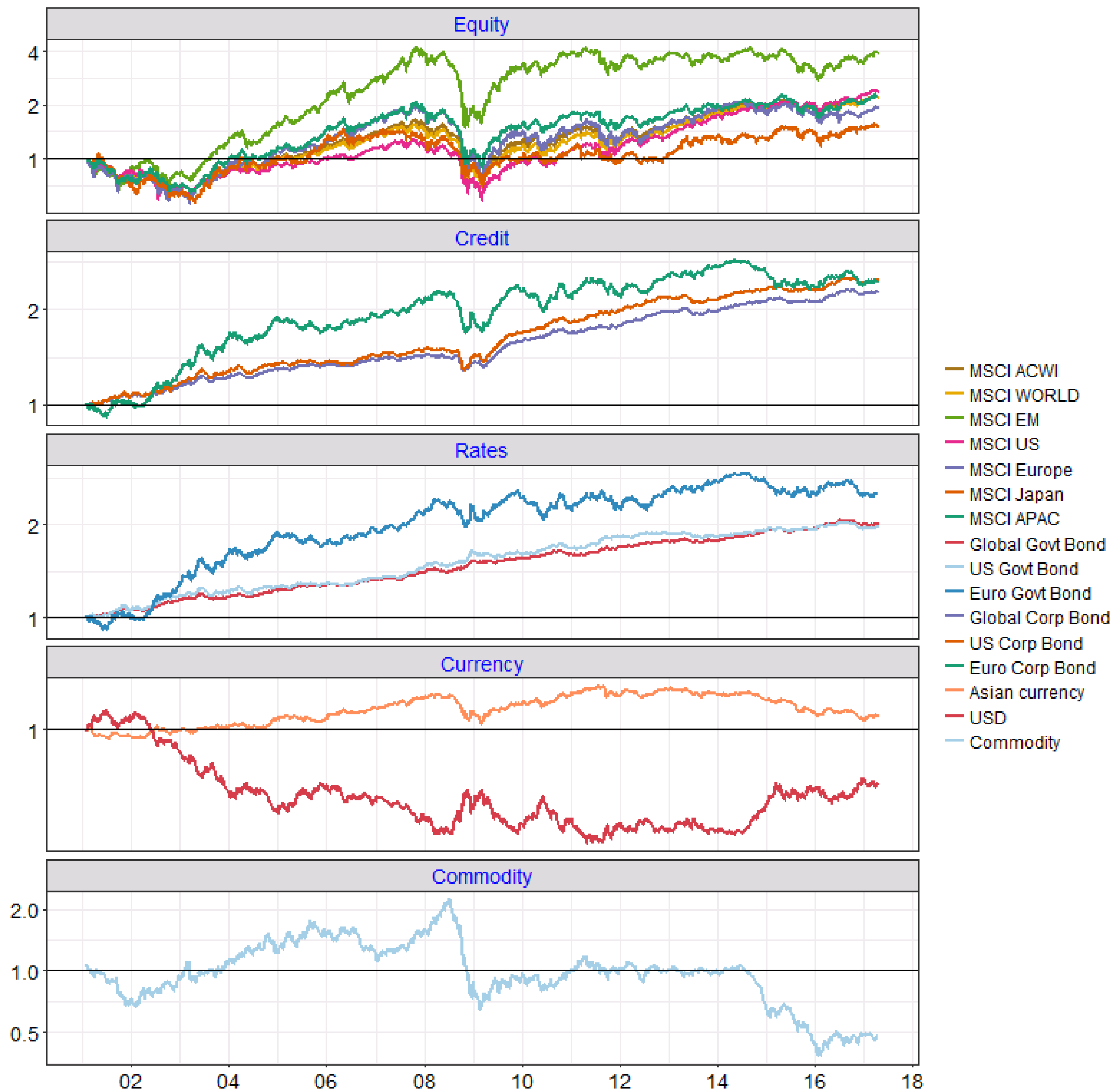
Source: J.P. Morgan Quantitative and Derivatives Strategy

Among the traditional asset class indices, sovereign and corporate bonds have the highest information ratio, mainly driven by the low interest rates in developed markets during this period.

On the other hand, long-only equities indices suffer from large drawdowns. This is in contrast to many long-short equity risk factor strategies, which in general have better risk-adjusted performances.

Commodities have relatively large drawdowns.

Figure 11: Wealth curves of the 16 traditional asset class risk premia indices as in Hamdan et al (2016)



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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HRP continues to perform well in this asset class universe, delivering a significantly higher information ratio than other strategies.

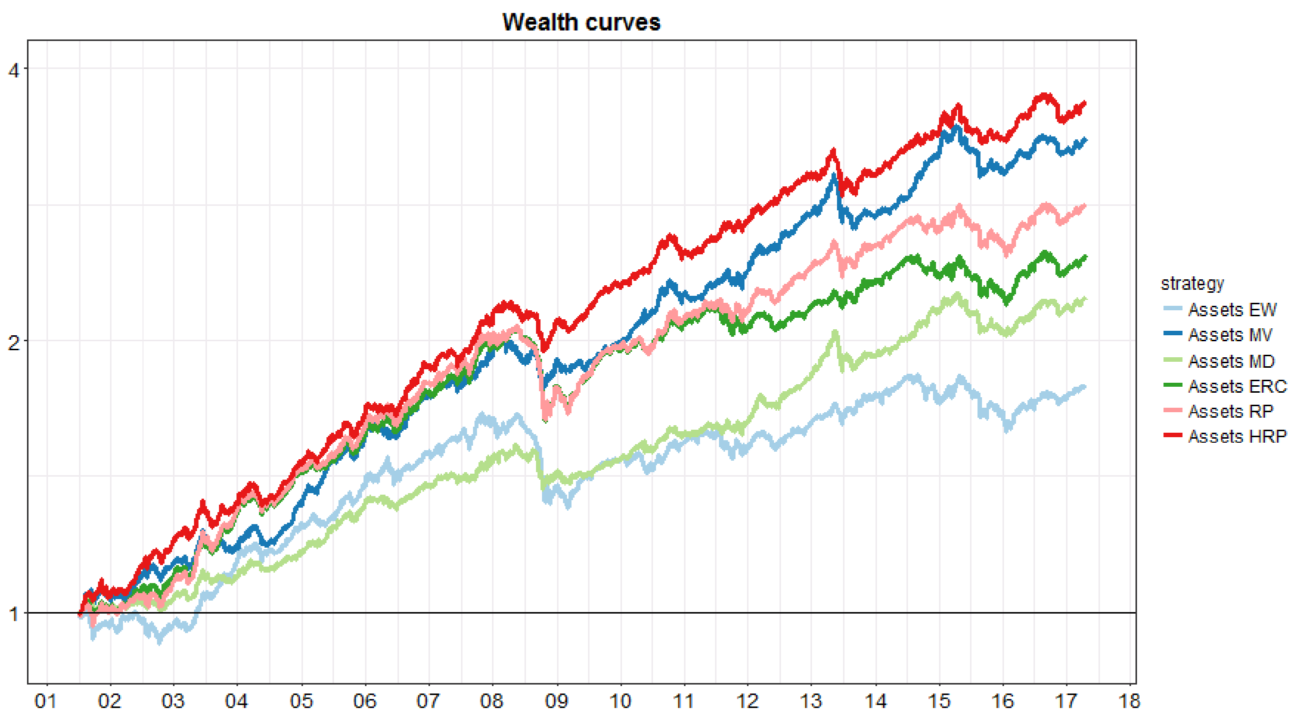
Interestingly, the performance of the Maximum Diversification strategy seems to deteriorate in this universe of more correlated assets.

Now, let us backtest the risk-based strategies within this traditional asset class universe. It turns out that Hierarchical Risk Parity (HRP) continues to perform well in this more volatile universe, and deliver a significantly higher information ratio than other strategies. HRP strategy also gives a realized volatility of 5.1%, matching very close to our target of 5% per annum.

Another interesting observation is that the Maximum Diversification strategy has dropped in performance when it comes to traditional asset classes. The major reason is likely due to the significantly higher correlations among the long-only indices, which hinders the ability of the Maximum Diversification strategy to diversify. In our experience, Maximum Diversification tends to perform much better in universe of lowly correlated assets.

The Equal-Weighted portfolio is again the least efficient way of portfolio allocation, no matter for an alternative risk premia universe or a traditional asset class universe.

Figure 12: Wealth curves of the long-only allocation strategies using 16 traditional asset class risk premia indices. Backtest period: 2001-07-02 to 2017-04-18



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

Table 6: Daily returns statistics sorted by IR (2001-07-02 to 2017-04-18)

Strategy	CAGR (%)	Annualized Vol (%)	IR	Max DD (%)	Hit ratio (%)	CAGR (%, Past 3Yr)	Vol (%, Past 3Yr)	IR (%, Past 3Yr)
HRP	8.3	5.1	1.62	11.8	56.5	4.8	5.3	0.91
MV	7.6	5.5	1.39	13	55.5	5.5	5.5	1
RP	6.6	5.3	1.25	21.4	56	2.4	5.4	0.44
ERC	5.7	5.2	1.09	21.4	55.4	1	5.5	0.19
MD	5	5.3	0.94	10.7	53.7	3.9	5.3	0.74
EW	3.6	5.3	0.68	21.5	55	0.1	5.3	0.02

Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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Comparing all strategies

Having looked into the strategy backtests in three different cross asset universes, let us put things together and make a comparison of the strategies.

Hierarchical Risk Parity delivers the highest information ratio across the universes, followed by Minimum Variance.

Information ratios

In terms of risk-return profiles, it turns out that Hierarchical Risk Parity (HRP) is the best candidate for cross asset risk premia allocation. It has delivered the highest information ratio in our backtest since 2001, and has also performed consistently in the past 3 years.

Figure 13: Comparison of information ratios (IR) for all backtests across three universes (16 asset class indices, 16 JPM risk premia indices and 31 JPM risk premia indices) and six risk-based allocation strategies

Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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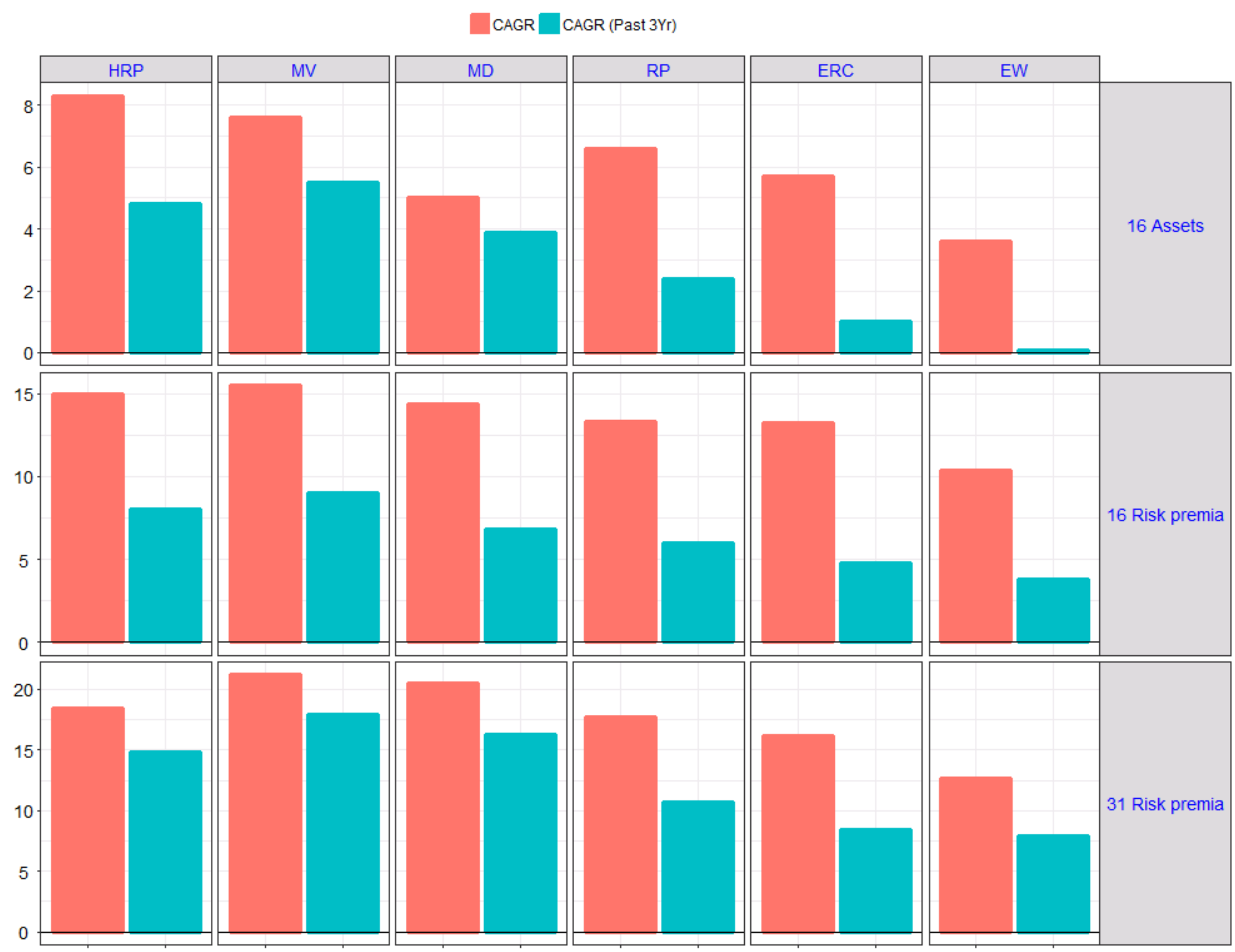
HRP delivers decent returns in most cases, but MV in general gives higher returns. A reason is that MV strategies tend to have higher realized volatilities.

Annualized returns (CAGR)

HRP portfolios deliver decent returns in most cases, although in general Minimum Variance strategies give the best annualized returns. Returns from equal-weighted portfolios are significantly worse than the other strategies.

Nevertheless, we should bear in mind that the levels of returns depend on leverage. In Figure 15 on the next page, we will see that Minimum Variance strategies have higher volatilities and drawdowns compared to HRP. As a result, risk-adjusted returns and information ratios tend to be lower for Minimum Variance portfolios.

Figure 14: Comparison of annualized returns in % (CAGR) for all backtests across three universes (16 asset class indices, 16 JPM risk premia indices and 31 JPM risk premia indices) and six risk-based allocation strategies



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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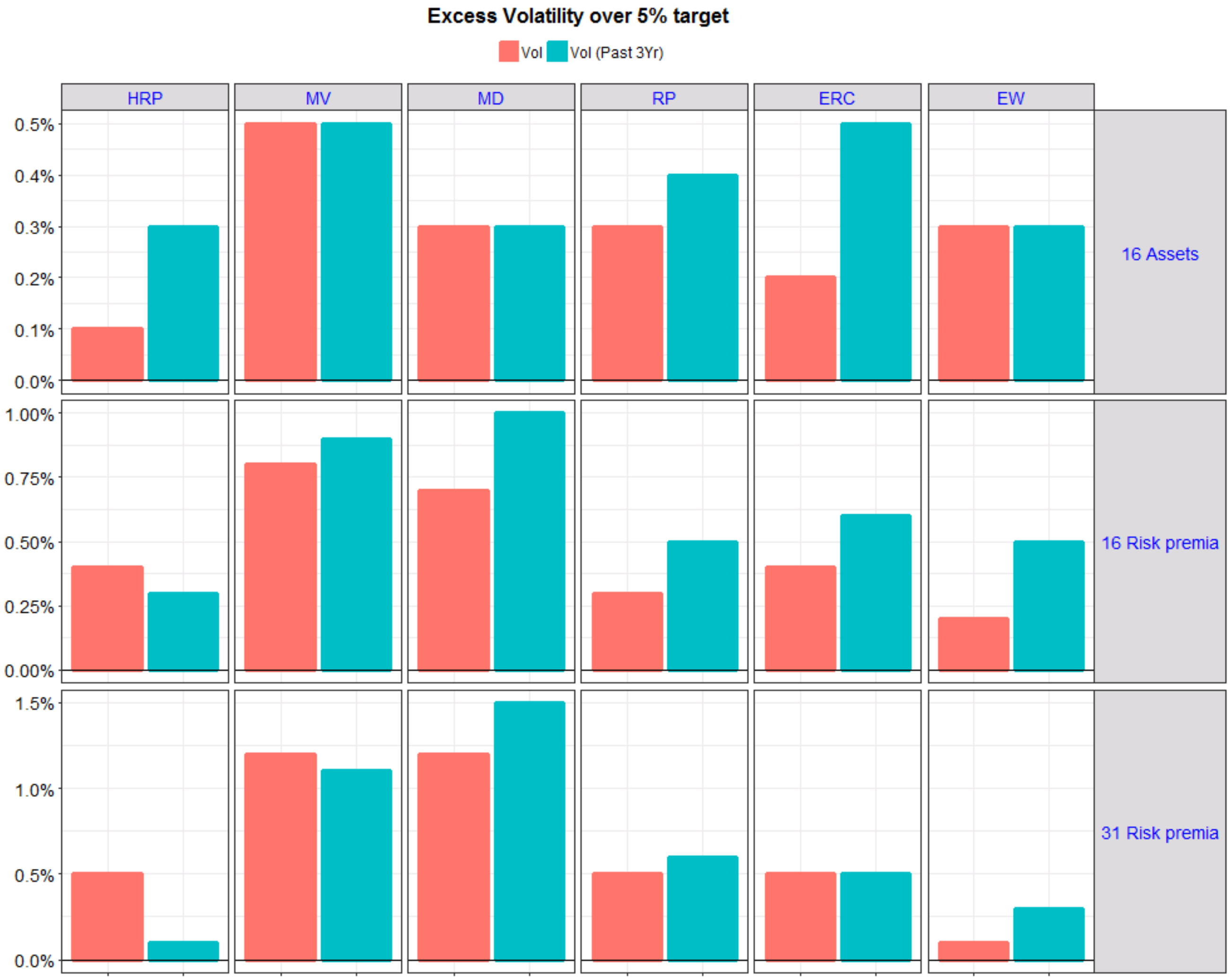
HRP strategies hit the target volatilities very well, whilst Minimum Variance and Maximum Diversification tend to vastly underestimate risk, leading to higher realized volatilities.

Annualized Volatility

Since we target at 5% volatility per annum, we do observe relatively comparable levels of volatilities across the strategies. To better understand how well the strategies hit the volatility targets, we look at the difference between their annualized volatilities and the 5% target level.

It is obvious that the Minimum Variance and Maximum Diversification strategies tend to underestimate risk, leading to much higher than expected out-of-sample volatilities up to 6%. On the other hand, HRP strategies in general match with the target volatilities very well, only overshooting 0.5% at most.

Figure 15: Comparison of annualized volatilities in % over our 5% target, for all backtests across three universes (16 asset class indices, 16 JPM risk premia indices and 31 JPM risk premia indices) and six risk-based allocation strategies



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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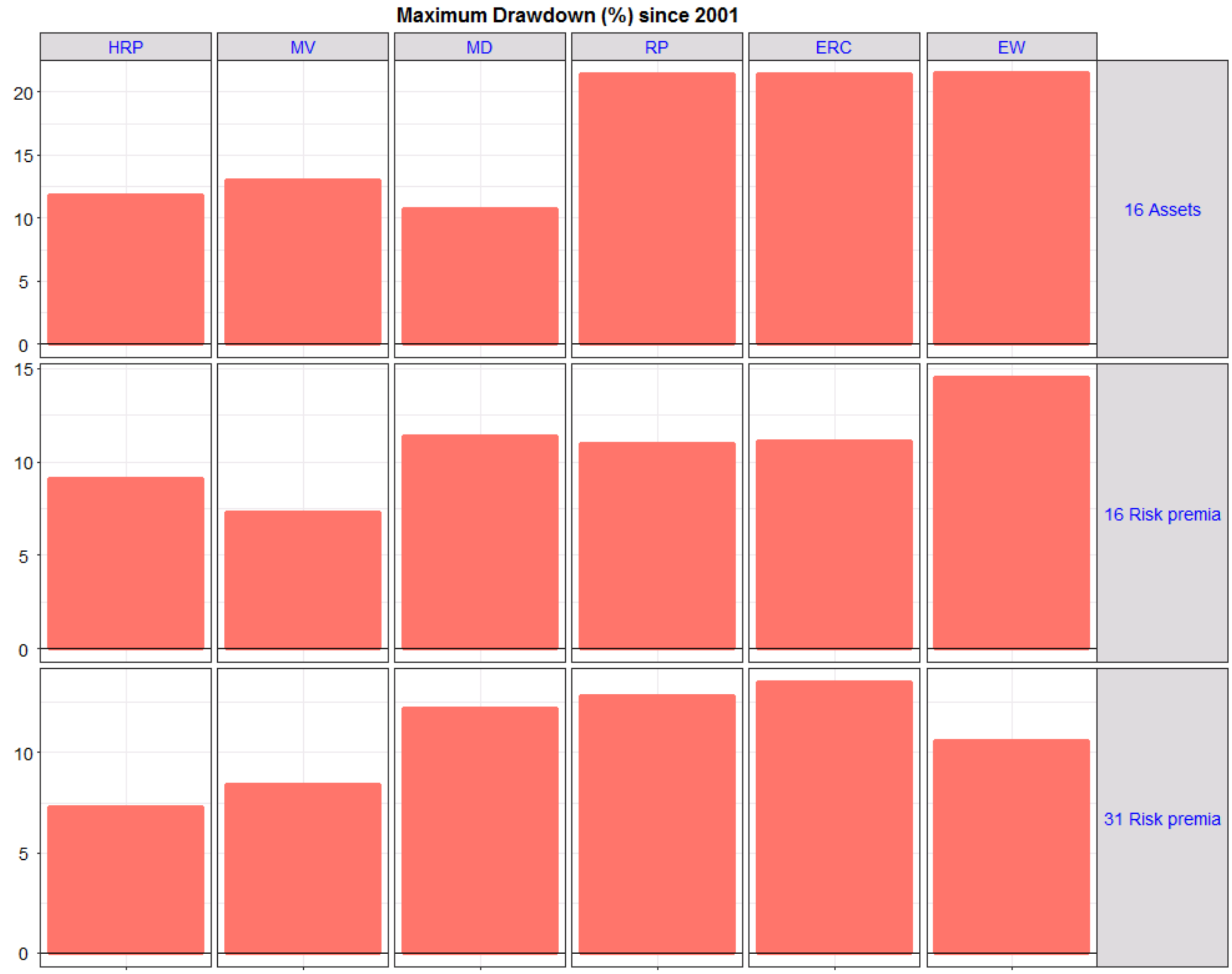
Maximum Drawdown

HRP and Minimum Variance strategies have significantly lower drawdowns than other allocations, especially within the traditional asset class universe.

Figure 16: Comparison of maximum drawdowns in %, for all backtests across three universes (16 asset class indices, 16 JPM risk premia indices and 31 JPM risk premia indices) and six risk-based allocation strategies



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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Simulation studies

Rationale and setup

A common issue regarding backtests is that we do not know how much of the performance is due to the merits of a particular portfolio construction methodology, and how much is merely due to randomness such as the choice of our chosen historical sample and universe. To better gauge the significance of the backtests, let us run a simulation study to repeat the strategies many times, using randomly generated returns that are drawn from the historical distributions of the 16 JPM cross asset risk premia indices as shown in Table 1.

To ensure our backtest results are not merely due to the choice of our historical sample, we run the backtests 100 times using randomly sampled returns from the 16 JPM cross asset risk premia indices.

First, we generate 100 samples of daily returns for the set of 16 risk premia indices, with the same number of observations that we have used in the backtests in previous sections. Each random sample of the risk premia is drawn from its distribution of historical returns, in the sense that we draw the samples (with replacement) from the historical returns. We do not consider the correlations between the risk premia in the random samples, although one could have taken this into account. For each sample, we repeat the same procedure of backtests as below:

1. Estimate the covariance matrices across the risk premia indices based on the past year of daily returns, using the same exponentially-weighted approach
2. Calculate the weights of the risk premia indices for each strategy based on the covariance matrices
3. Leverage the weights to target at 5% annualized volatility
4. Calculate the returns of the strategies, as well as the returns statistics (e.g. information ratio, drawdowns etc)

Here we only focus on four of the strategies for clearer comparisons:

- Minimum Variance (MV)
- Maximum Diversification (MD)
- Risk Parity (RP)
- Hierarchical Risk Parity (HRP)

Robustness of our results

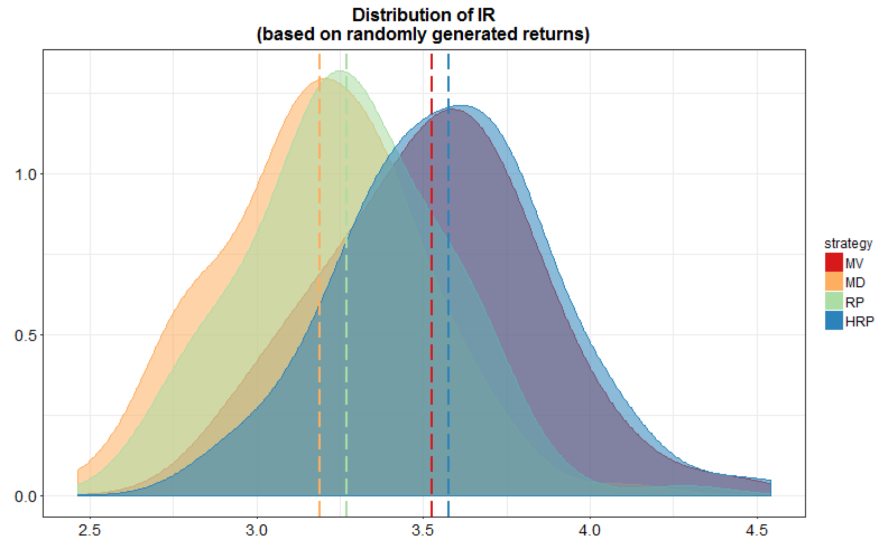
In the following plots, we show the distributions of various returns statistics from the 100 backtests that we simulate.

Information ratio

As shown in Figure 17, Hierarchical Risk Parity gives higher information ratios consistently over both Risk Parity and Maximum Diversification portfolios. HRP only marginally beats the MV strategy in terms of risk-adjusted returns.

Figure 17: Distribution of Information Ratio (IR). The dashed lines are mean values

	MV	MD	RP	HRP
Min.	2.85	2.46	2.63	2.89
1st Qu.	3.3	3.03	3.11	3.38
Median	3.54	3.18	3.26	3.58
Mean	3.52	3.19	3.27	3.58
3rd Qu.	3.72	3.37	3.47	3.76
Max.	4.41	4.12	4.28	4.54



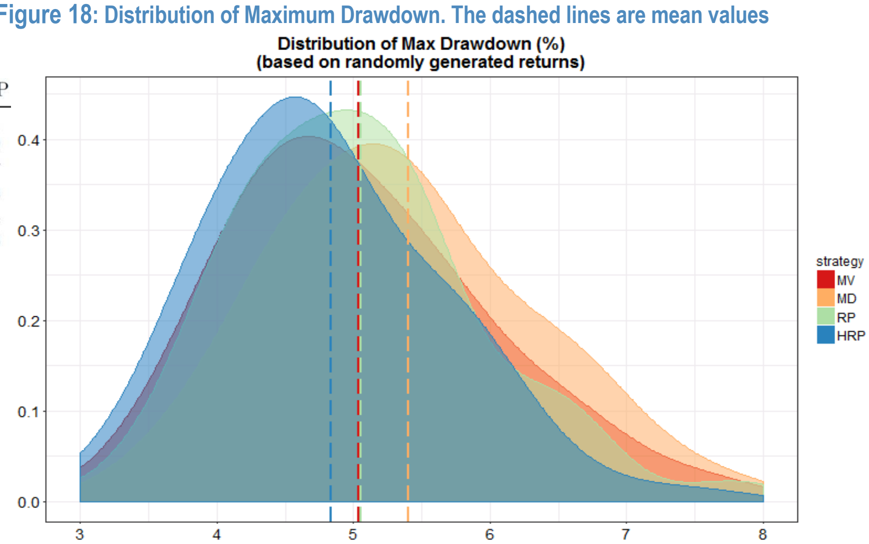
Source: J.P. Morgan Quantitative and Derivatives Strategy

Maximum Drawdowns

HRP has the lowest drawdowns whilst Maximum Diversification portfolios suffer from larger drawdowns on average.

Figure 18: Distribution of Maximum Drawdown. The dashed lines are mean values

	MV	MD	RP	HRP
Min.	3.2	3.5	3.1	3.1
1st Qu.	4.3	4.7	4.4	4.2
Median	4.8	5.3	5	4.7
Mean	5	5.4	5.1	4.8
3rd Qu.	5.6	6	5.5	5.4
Max.	7.8	8.3	8.3	8.3



Source: J.P. Morgan Quantitative and Derivatives Strategy

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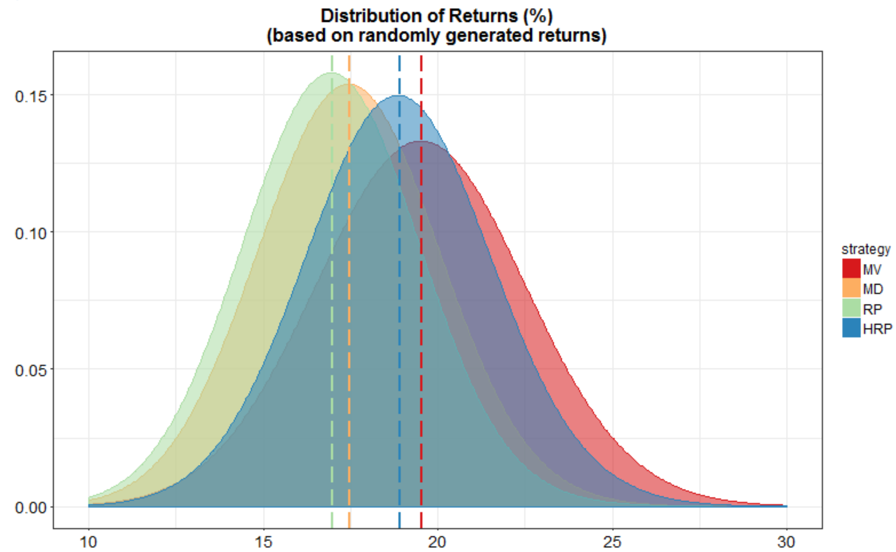
Annualized returns

In terms of returns, Minimum Variance portfolios in general give the highest returns, as we have seen before. This is closely followed by HRP.

	MV	MD	RP	HRP
Min.	15.8	13.5	13.6	15.2
1st Qu.	18.3	16.6	16.1	17.9
Median	19.6	17.4	16.9	18.9
Mean	19.5	17.5	17	18.9
3rd Qu.	20.6	18.5	18	19.9
Max.	24.6	22.5	22.3	24

Figure 19: Distribution of Annualized Returns. The dashed lines are mean values



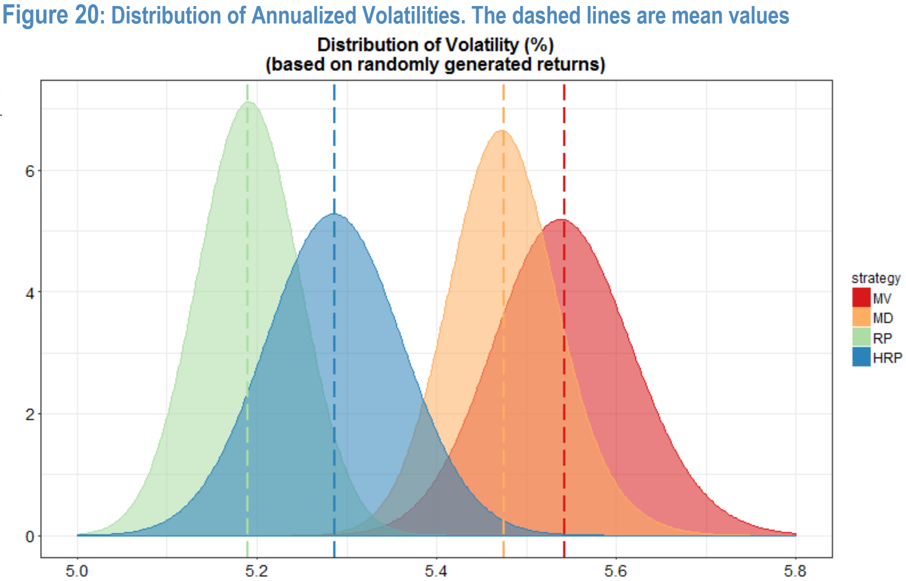
Source: J.P. Morgan Quantitative and Derivatives Strategy

Annualized volatilities

It is of no surprise that the realized volatilities are all close to our target of 5%. It is interesting to see that we almost always underestimate risk, i.e. realized volatilities are rarely below 5%. This simulation study also confirms that out-of-sample realized volatilities of the Minimum Variance portfolios tend to be highest, as we have already seen in previous sections.

	MV	MD	RP	HRP
Min.	5.4	5.4	5.1	5.2
1st Qu.	5.5	5.5	5.2	5.3
Median	5.5	5.5	5.2	5.3
Mean	5.5	5.5	5.2	5.3
3rd Qu.	5.6	5.5	5.2	5.3
Max.	5.7	5.6	5.3	5.4

Figure 20: Distribution of Annualized Volatilities. The dashed lines are mean values



Source: J.P. Morgan Quantitative and Derivatives Strategy

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Are the portfolios truly diversified?

Having compared the risk and returns profiles of the strategies, let us turn our attention and run some analysis on their diversification properties. This is important since an inherently concentrated portfolio may lead to unexpectedly large drawdowns. After all, risk-based allocations are designed to diversify risk.

Of course, there could be many definitions of diversifications, ranging from simple intuition (e.g. maximum weights) to metrics used in information theory (e.g. entropy-related measures). In the following, we look at various metrics that are commonly used to measure portfolio diversification[12]:

- Diversification ratio (DR) and Concentration ratio (CR)
- Uncorrelated number of exposures
- Maximum weight and Maximum risk budget

Diversification ratio is a metric introduced by Choueifaty and Coignard (2008). It is designed to measure the extent of volatility reduction in the portfolio level by combining assets that are not perfectly correlated. It is defined as the weighted average of asset volatility over the portfolio volatility:

$$DR = \frac{\sum_j w_j \sigma_j}{\sqrt{w' \Sigma w}}$$

Choueifaty et al (2011) shows that the diversification ratio can be decomposed into a volatility-weighted average correlation ρ, and a volatility-weighted concentration ratio CR[13]:

$$DR = (\rho(1 - CR) + CR)^{-1/2}$$

$$CR = \frac{\sum_j (w_j \sigma_j)^2}{(\sum_j w_j \sigma_j^2)^2}$$

where ω_j and σ_j are the weight and the volatility of asset j respectively.

This gives an intuitive sense of how to increase the diversification ratio: one can either include less correlated assets (i.e. decrease ρ), or decrease the concentration ratio CR. A concentrated portfolio of one single asset has $CR = 1$, while an equal volatility-weighted portfolio has the lowest CR of $1/\sqrt{N}$.

---

[12] By construction, certain risk-based strategies are "optimal" in terms of a particular diversification measure. For instance, MD portfolios have the highest diversification ratios; RP portfolios have the lowest concentration ratios; EW portfolios have the lowest maximum weights; ERC portfolios have the lowest maximum risk budgets

[13] As pointed out by Choueifaty et al (2011), this concentration ratio is a generalization of the Herfindahl Index: Here we measure the concentration of risk, and in other cases one may measure the concentration of weights (e.g. to determine the market shares of companies within an industry).

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Diversification ratio

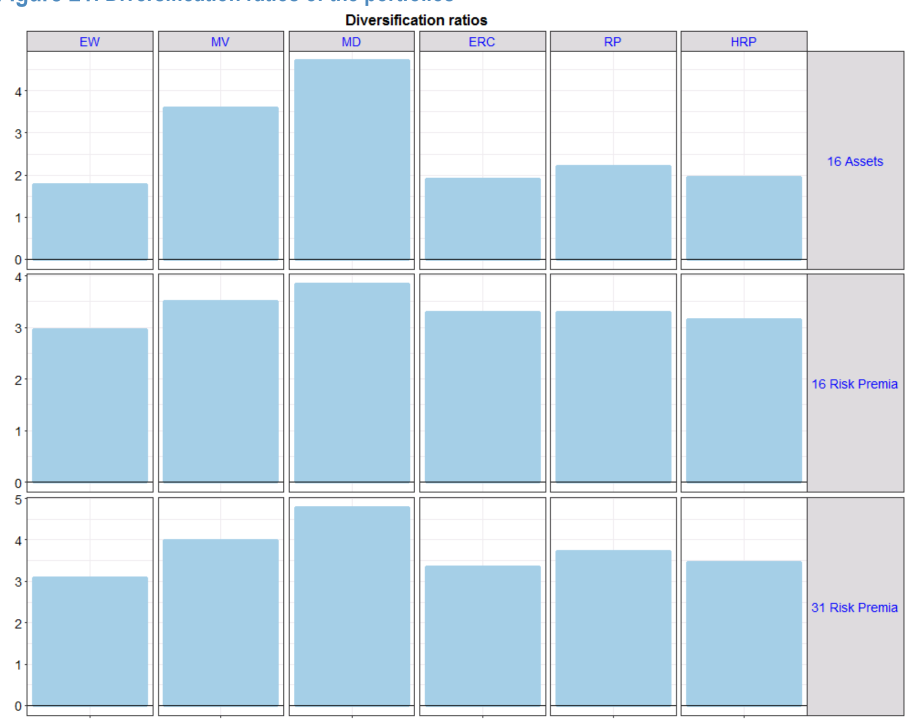
As expected, the Maximum Diversification strategy has the highest diversification ratios on average, since its objective is to maximize such a ratio.

In a first glance, it looks a bit surprising to see that Minimum Variance strategies, which tend to have more concentrated allocations, actually have relatively high diversification ratios. However, this could actually happen as Minimum Variance portfolios are designed to minimize portfolio volatility, which is the denominator in the diversification ratio:

$$DR = \frac{\sum_j w_j \sigma_j}{\sqrt{w' \Sigma w}}$$

It turns out that diversification ratios of the strategies other than MV and MD are quite similar.

Figure 21: Diversification ratios of the portfolios

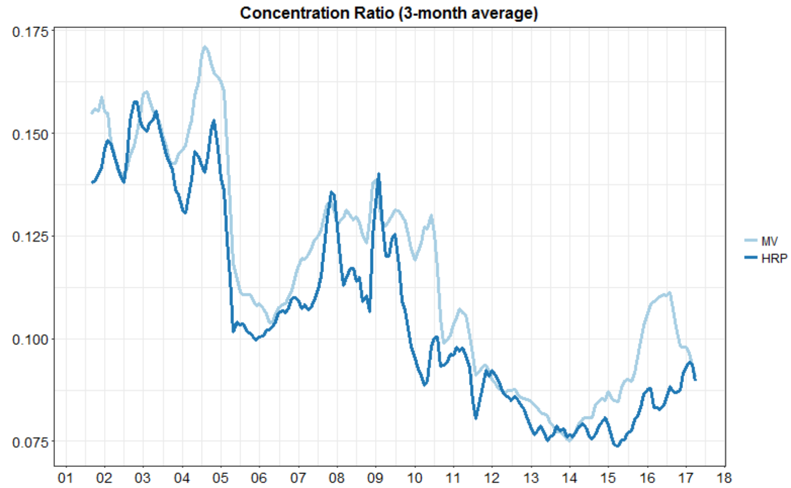


Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

Concentration ratio

Minimum Variance strategy has a higher concentration ratio compared with the HRP strategy.

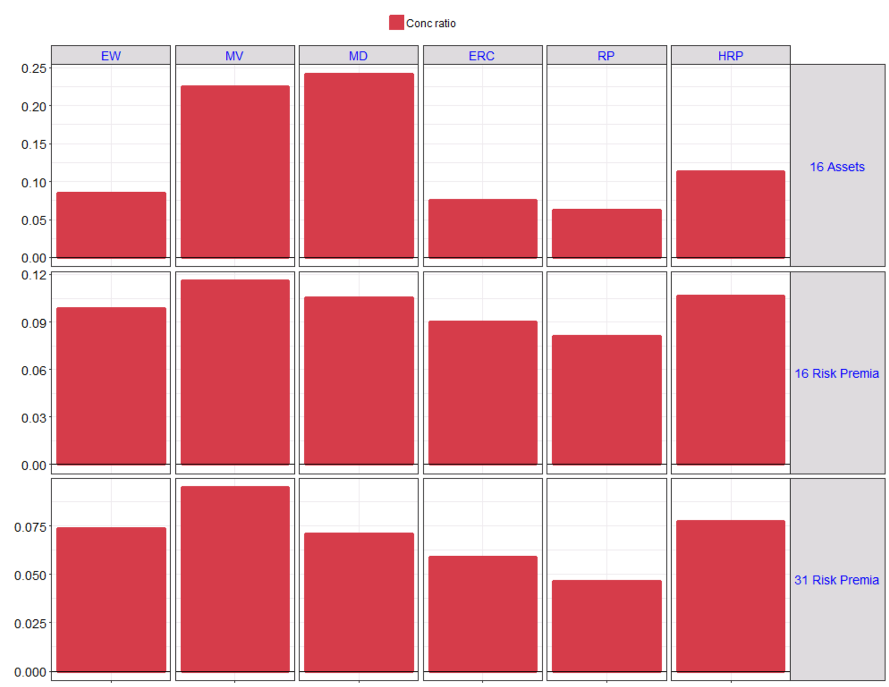
Figure 22: Concentration ratio of MV and HRP portfolios



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

As described above, an equal volatility-weighted portfolio has the lowest concentration ratio: In our notation, it corresponds to the Risk Parity (RP) portfolio.

Figure 23: Concentration ratios of the portfolios



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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How many uncorrelated exposures are we making?

Meucci (2009) introduced the concept of the number of uncorrelated exposures in a portfolio, which is linked to principal component analysis. Instead of looking at the correlated assets, we decompose them into uncorrelated portfolios. The uncorrelated portfolios (also called principal portfolios) are just linear combinations of the original assets. Each of the principal portfolios explains a proportion of variance of the risk-based portfolios. If all proportions are equal, we have a uniform distribution; and if only one single principal portfolio explains all the variances, we have an extremely concentrated distribution.

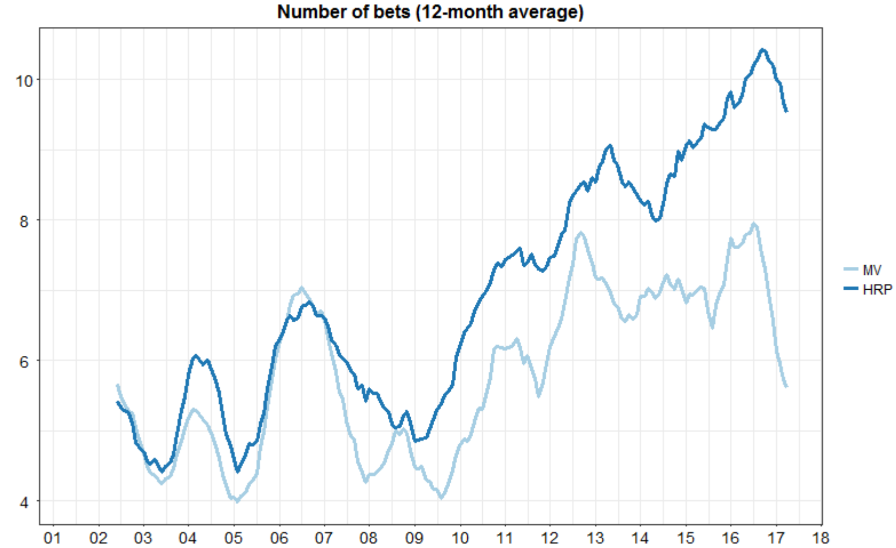
Denoting the proportion of variance explained by each principal portfolio by p_i, the number of uncorrelated exposures is defined from an information theoretic perspective. It is defined as the exponential of the negative of Shannon's entropy:

$$N_{bet} = \exp\left(-\sum_{i=1}^{N} p_i \log p_i\right)$$

For more details, please refer to Page 44 in the Appendix. Note that this measure has been applied in Lohre et al (2012) to construct a diversified risk parity portfolio, which aims to maximize the number of uncorrelated exposures.

In the 16 JPM cross asset risk premia universe, we see that there are about ten uncorrelated exposures recently in the HRP portfolio, but only six in the MV portfolio

Figure 24: Number of uncorrelated exposures of the MV and HRP portfolios using the 16 JPM cross asset risk premia indices



Source: J.P. Morgan Quantitative and Derivatives Strategy

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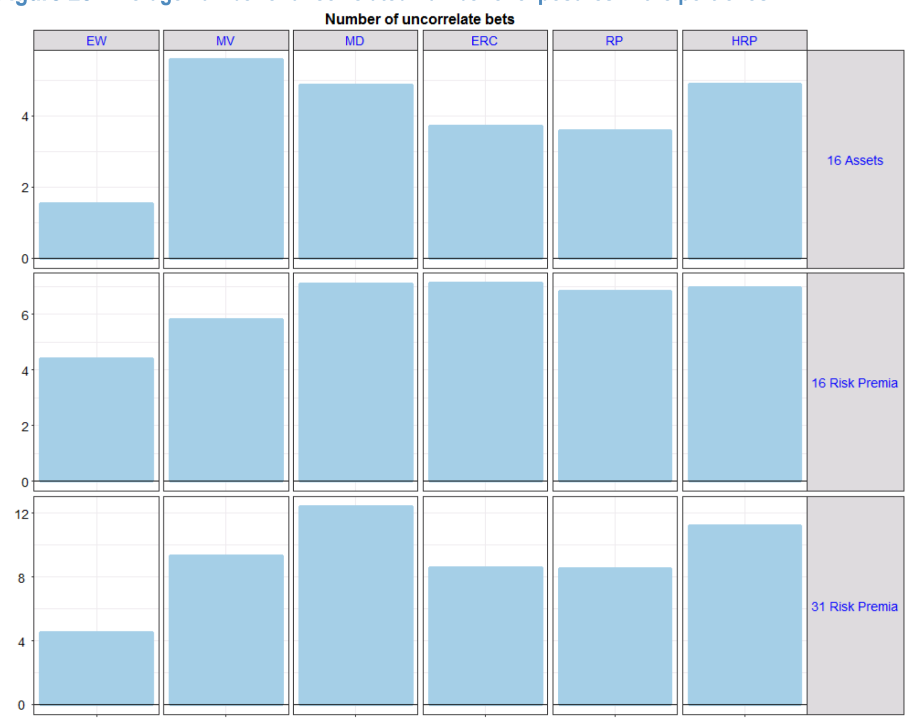
On average, HRP portfolios consist of a larger number of uncorrelated exposures compared to other strategies.

Equal-weighted portfolios have significantly lower numbers of uncorrelated exposures, which could be fewer than two in the traditional asset class universe.

Another interesting point to note is that the numbers of uncorrelated exposures are significantly lower across the 16 traditional asset class universe, compared with the 16 JPM cross asset universe. This is due to the high correlations among the asset class indices.

Figure 25: Average number of uncorrelated number of exposures in the portfolios



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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Are there any extreme allocations?

Finally, we check whether our strategies lead to any extreme allocations on average. We consider two measures:

- Asset weight based on capital allocation
- Risk budget in terms of total risk contribution

Total risk contribution (TRC) is the proportion of risk of an asset contributed to the total portfolio volatility.

$$\text{Marginal risk contribution } MRC_j = \frac{\partial \sigma_p}{\partial w_j} = (\Sigma w)_j$$

$$\text{Total risk contribution} = TRC_j = w_j MRC_j$$

$$\text{Portfolio risk} = \sigma_p = \sum_j TRC_j$$

We see that Minimum Variance portfolios tend to have the most extreme weights and more concentrated risk budgets.

We see that Minimum Variance portfolios tend to have the most extreme weights and more concentrated risk budgets.

By construction, Equal Risk Contribution (ERC) portfolios have the most diversified risk budgets, and hence the smallest maximum risk allocated to an asset. Similarly, it is by construction that Equal-Weighted (EW) portfolios have the most diversified weights.

Figure 26: Maximum risk contributions and maximum weights in the portfolios

Source: J.P. Morgan Quantitative and Derivatives Strategy

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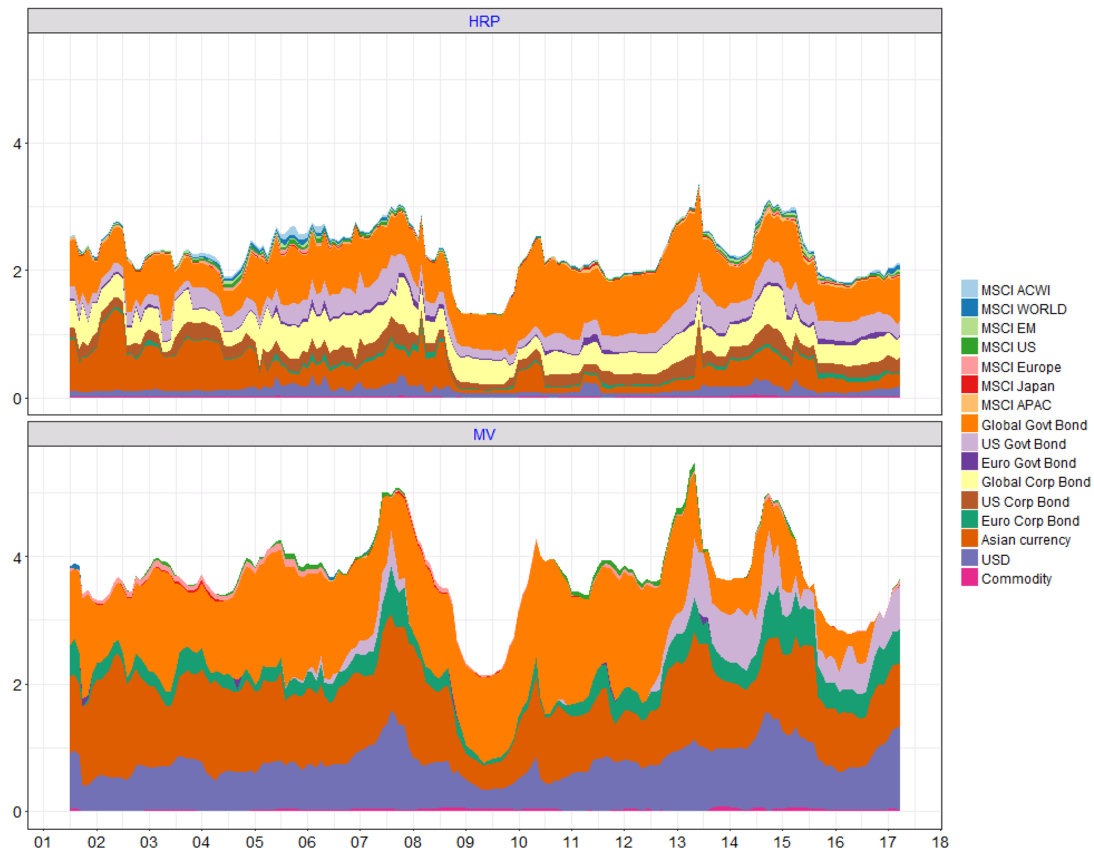
Minimum Variance portfolios can have very concentrated allocations

Finally, we would like to take a closer look at the allocations in the Minimum Variance portfolio, so as to highlight the situations when it may have extreme weights. We use the 16 traditional asset class indices as an example, since they have high correlations as shown in Figure 33 in the Appendix. In this universe, the Minimum Variance portfolio has large allocations on 3 assets:

- **Global Government Bond:** It has the lowest volatility (2.5%) amongst all indices
- **USD:** It is negatively correlated with almost all other indices
- **Asian Currencies:** Volatility is low (3.6%), and at that same time it is uncorrelated with Global Government Bond[14]

On the other hand, the HRP portfolio has less concentrated positions.

Figure 27: Asset weights in the HRP and MV strategies for the 16 traditional asset class indices. Global Government Bond has the lowest volatility, which leads to a large weight in the MV portfolio. Asian currencies and USD are negatively correlated with many other indices, and hence also dominate the weights in the MV portfolio



Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

[14] Volatility of Global Corporate Bond is also low (3.4%), but it is highly correlated with Global Government Bond, which already has a large proportion in the MV portfolio. Hence, the weight of Global Corporate Bond is not too large.

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Recent HRP allocations

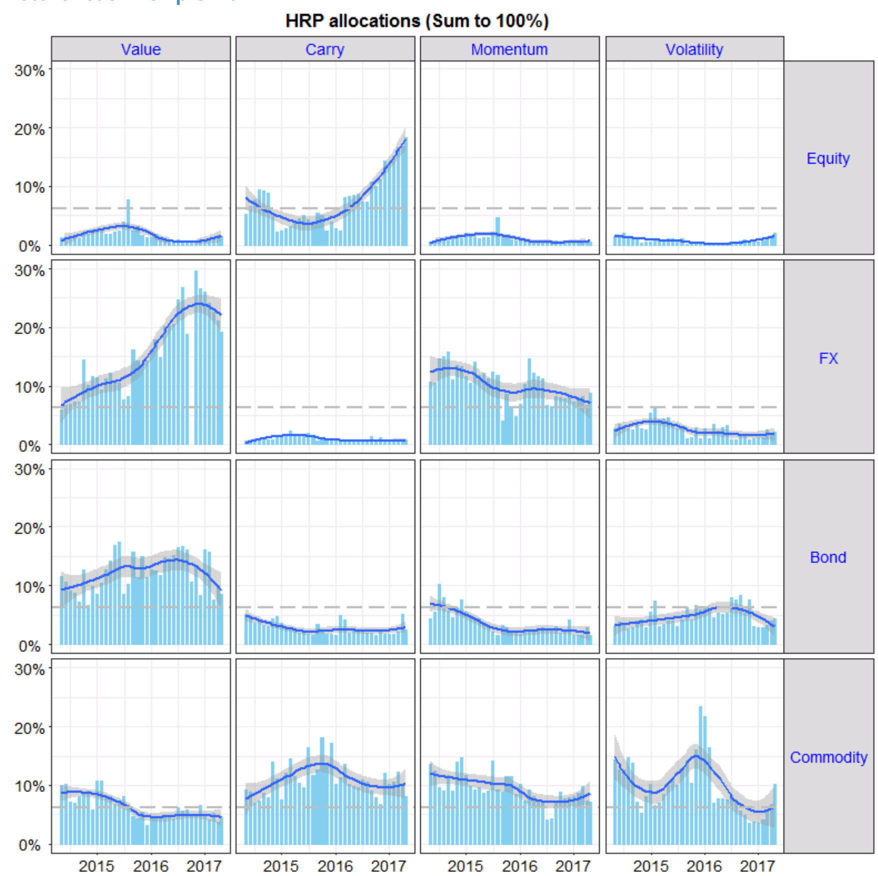
Having seen that the Hierarchical Risk Parity (HRP) portfolios have delivered the best risk-return profile across different cross asset universes, as well as being more diversified than other strategies, let us take a closer look at its allocations across the 16 JPM cross asset risk premia indices (for details please refer to Table 1).

In **Error! Reference source not found.Error! Reference source not found.**, we show the weights in the HRP portfolio, where we scale it to 100% so that we do not consider leverage. The aim is to understand which risk premia is being favored over time.

- FX Value and Equity Carry have the largest weights (close to 20% each)
- In the past year, allocations towards Equity Carry have been increasing steadily. In particular, Carry dominates amongst Equity risk premia, where the HRP portfolio has tiny weights on Equity Value, Equity Momentum and Equity Volatility.

Figure 28: Allocations of the HRP portfolio on the 16 JPM cross asset risk premia indices in the past three years. The grey horizontal dashed line represents an equal-weighted allocation, i.e. 6.25% for each risk premia

Risk Premia	Latest weight
Equity Value	1.5%
Equity Carry	18.4%
Equity Momentum	0.5%
Equity Volatility	2.1%
FX Value	19.2%
FX Carry	0.8%
FX Momentum	8.7%
FX Volatility	2.2%
Bond Value	8.4%
Bond Carry	2.6%
Bond Momentum	1.5%
Bond Volatility	4.3%
Commodity Value	4.5%
Commodity Carry	8.2%
Commodity Momentum	7.1%
Commodity Volatility	10.1%



Source: J.P. Morgan Quantitative and Derivatives Strategy

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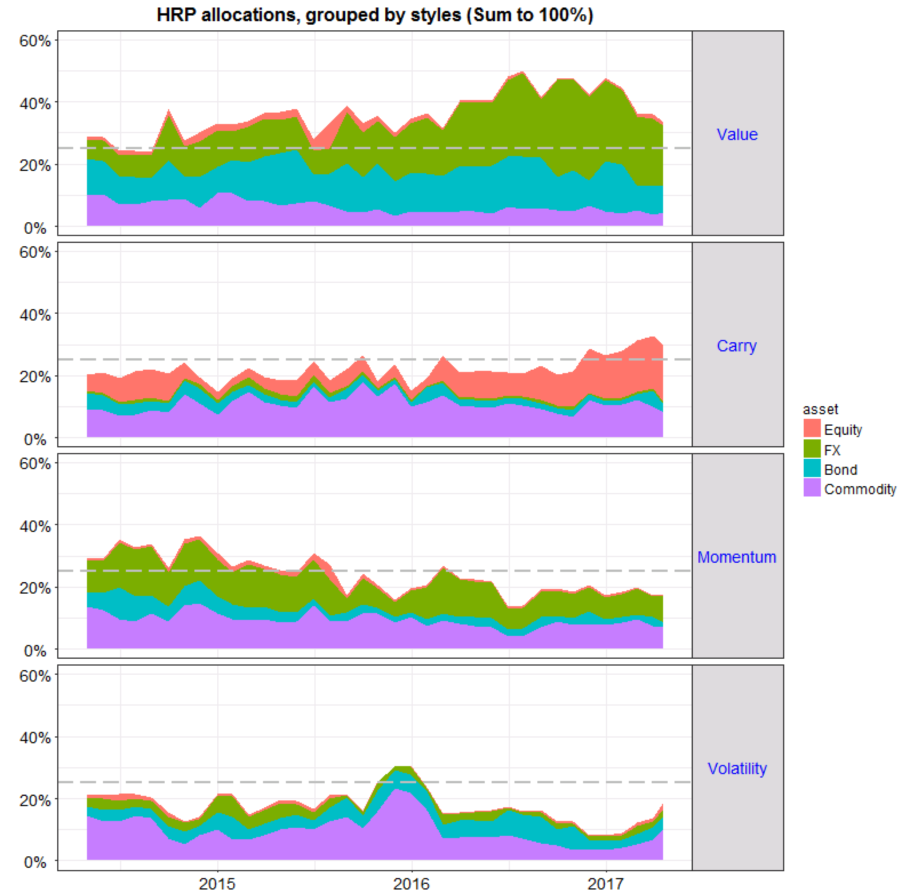
Which styles do we favor?

Now let us group the 16 cross asset risk premia by styles and examine if the HRP portfolio is tilted towards a particular style in terms of Value, Carry, Momentum and Volatility.

- In the past 3 years, the HRP portfolio is increasing its allocation to Carry, mainly due to its increasing weights on Equity Carry
- Value dominates over other styles in the HRP portfolio, with FX Value accounting for a large proportion of weights
- The allocations on Volatility risk premia have continued to-rise since 2017

Style	Latest weight
Value	33.6%
Carry	29.9%
Momentum	17.8%
Volatility	18.7%

Figure 29: HPR portfolio allocations to each of the 16 JPM cross asset risk premia in the past three years, grouped by styles. The grey horizontal dashed line represents an equal-weighted allocation, i.e. 25% for each style



Source: J.P. Morgan Quantitative and Derivatives Strategy

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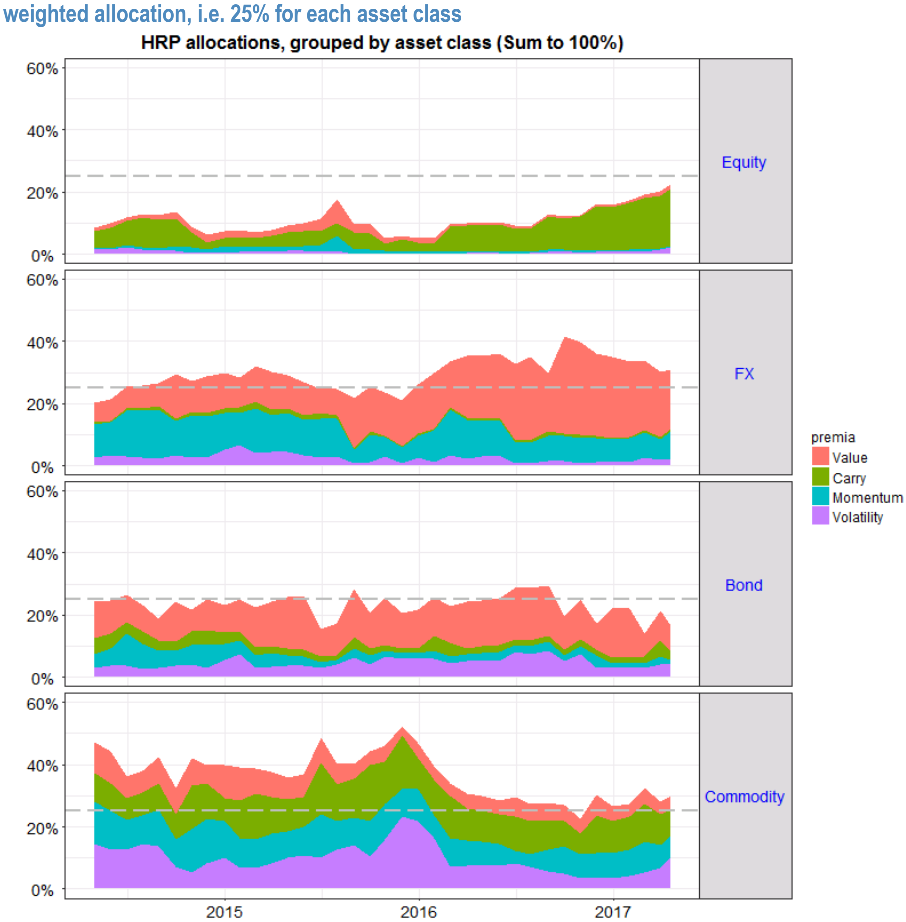
Which asset classes do we favor?

Next, we group the 16 cross asset risk premia in terms of four asset classes: Equity, FX, Bond and Commodity.

- The HRP portfolio has put a significant proportion of weights (as much as 50%) on Commodity risk premia before 2016. Although the weights have slightly decreased since then, Commodity risk premia still correspond to 30% of weights as in April 2017
- Apart from Commodity, FX risk premia also accounts for a large weight (30.9%) in the HRP portfolio, which is largely due to FX Value
- Weight allocated to Equity risk premia has seen a significant increase from 5% in 2016 to over 20% recently, solely driven by an increase in the allocation to Equity Carry risk premia.

Asset class	Latest weight
Equity	22.4%
FX	30.9%
Bond	16.7%
Commodity	30.0%

Figure 30: HPR portfolio allocations to each of the 16 JPM cross asset risk premia in the past three years, grouped by asset classes. The grey horizontal dashed line represents an equal-weighted allocation, i.e. 25% for each asset class



Source: J.P. Morgan Quantitative and Derivatives Strategy

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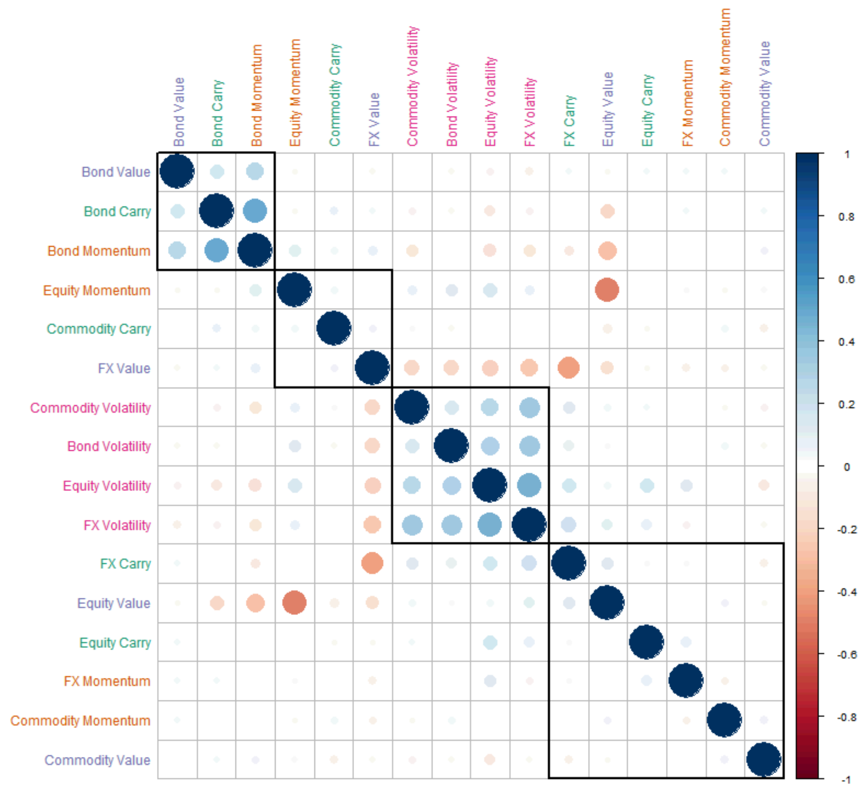
Appendix

16 JPM cross asset risk premia indices

Figure 31: Correlation clusters based on monthly returns



Source: J.P. Morgan Quantitative and Derivatives Strategy

Table 7: Daily returns statistics of the 16 JPM risk premia indices, sorted by Information Ratio

	start date	CAGR (%)	Vol (%)	Information Ratio	max drawdown (%)	hit ratio (%)
FX Momentum	2001-02-01	4.9	2.7	1.85	4.3	52
Commodity Carry	2001-02-01	5.7	3.1	1.82	4.3	54.1
Commodity Momentum	2001-02-01	3.1	3	1.05	6.8	50.8
Commodity Value	2001-02-01	6.5	6.4	1.01	8.7	51.1
Commodity Volatility	2010-01-01	3.1	3.3	0.93	8.6	59.5
Bond Momentum	2001-02-02	4.3	5	0.86	8.3	53.8
Bond Value	2001-02-01	4.1	4.9	0.84	15.1	51.6
Equity Carry	2008-08-04	5.8	7.5	0.77	27.6	51.6
FX Value	2001-02-01	3.1	4.3	0.74	7.3	48
Equity Volatility	2008-02-18	7.3	11.3	0.65	29.1	59.7
FX Volatility	2008-01-03	3.5	5.9	0.6	18	53.8
Bond Volatility	2010-01-05	1.8	3.7	0.48	4.2	59.3
Bond Carry	2001-02-01	2.1	5.5	0.39	6.2	50.5
FX Carry	2001-02-01	3.4	9	0.37	28	49.1
Equity Momentum	2004-08-23	2.4	8.4	0.28	37.8	52.8
Equity Value	2004-08-23	-4.1	8.9	-0.46	50.3	46

Source: J.P. Morgan Quantitative and Derivatives Strategy

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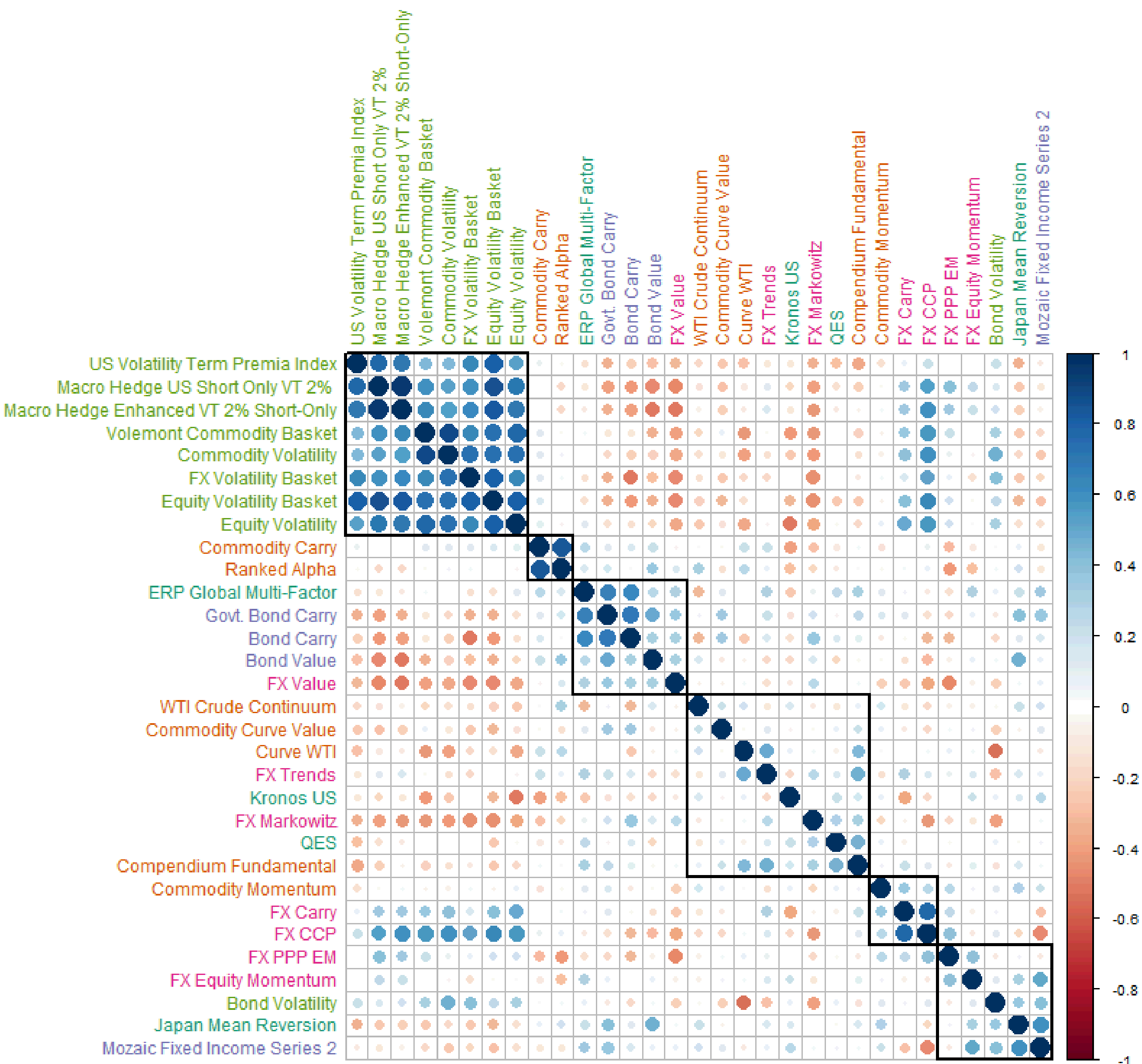
31 JPM cross asset risk premia indices

Figure 32: Correlation clusters based on monthly returns



Source: J.P. Morgan Quantitative and Derivatives Strategy

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Table 8: Daily returns statistics of the 31 JPM risk premia indices, sorted by Information Ratio

	start date	CAGR (%)	Vol (%)	Information Ratio	max drawdown (%)	hit ratio (%)
Commodity Carry	2001-02-01	5.7	3.1	1.82	4.3	54.1
FX Trends	2001-02-01	4.7	2.7	1.77	3.9	51.5
Curve WTI	2001-02-01	9	5.7	1.6	7.6	53.2
Commodity Curve Value	2001-02-01	2.2	1.4	1.53	2.7	49.9
Ranked Alpha	2002-01-01	6.3	4.4	1.44	6.7	53.6
Govt. Bond Carry	2001-02-01	4.1	3.5	1.17	6.8	52.6
Kronos US	2001-02-01	15.1	14	1.08	20	29.8
Compendium Fundamental	2001-02-01	6.7	6.3	1.05	9.6	50.9
Commodity Momentum	2001-02-01	3.1	3	1.05	6.8	50.8
Volemont Commodity Basket	2009-01-05	4.1	4.2	0.98	16.8	60.3
Commodity Volatility	2010-01-01	3.1	3.3	0.93	8.6	59.5
Bond Value	2001-02-01	4.1	4.9	0.84	15.1	51.6
QES	2007-01-01	6.5	7.9	0.82	10.8	23.5
US Volatility Term Premia Index	2008-06-02	8.6	11.3	0.76	15	47
FX Value	2001-02-01	3.1	4.3	0.74	7.3	48
Macro Hedge US Short Only VT 2%	2013-05-02	17	23.4	0.73	27.9	55.2
Equity Volatility	2008-02-18	7.3	11.3	0.65	29.1	59.7
Macro Hedge Enhanced VT 2% Short-Only	2013-05-02	7.9	12.1	0.65	13.4	49.8
ERP Global Multi-Factor	2004-08-23	3.6	5.6	0.64	23.9	52.1
WTI Crude Continuum	2001-02-01	14.9	23.6	0.63	44.2	49.8
FX PPP EM	2006-01-02	3.7	6.1	0.61	14.8	47.2
FX Volatility Basket	2008-01-03	3.4	5.9	0.58	17.9	53.9
FX Equity Momentum	2014-12-02	4	8.2	0.49	9.1	45.6
Bond Volatility	2010-01-05	1.8	3.7	0.48	4.2	59.3
FX CCP	2001-02-01	4.9	10.5	0.47	33.6	49.8
Mozaic Fixed Income Series 2	2001-02-02	5	11	0.45	22.7	52.2
Bond Carry	2001-02-01	2.1	5.5	0.39	6.2	50.5
FX Carry	2001-02-01	3.4	9	0.37	28	49.1
Equity Volatility Basket	2008-02-18	2.9	7.8	0.37	34.3	58.9
Japan Mean Reversion	2006-01-05	4.5	14.5	0.31	42.2	22.9
FX Markowitz	2006-03-01	1.4	7.1	0.2	17.5	47.4

Source: J.P. Morgan Quantitative and Derivatives Strategy

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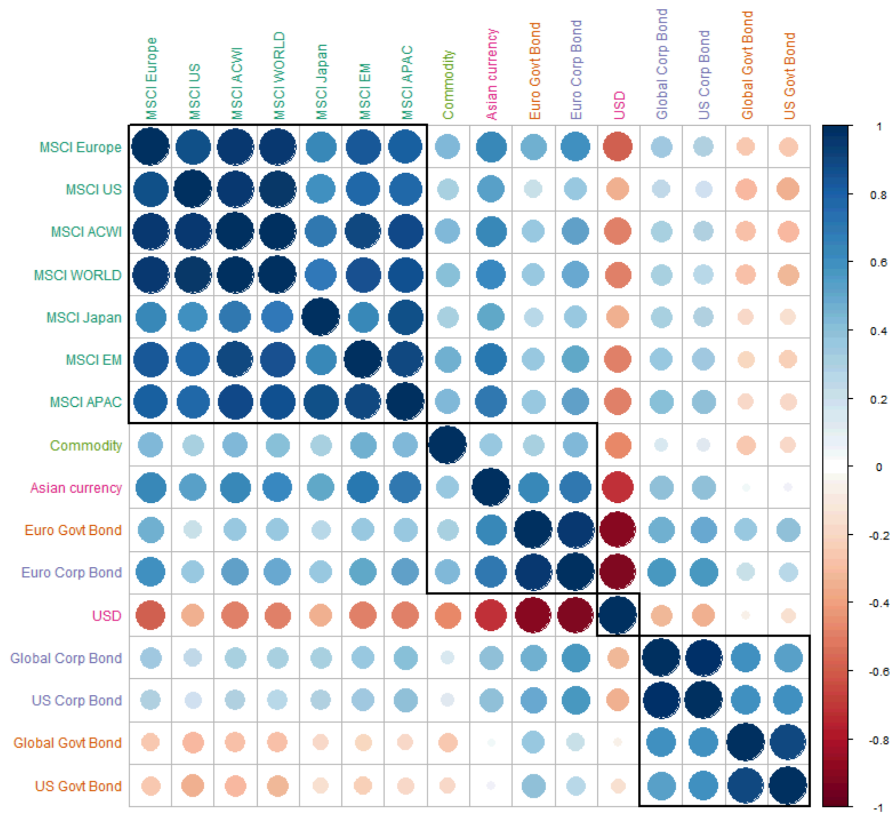
16 asset class indices

Figure 33: Correlation clusters based on monthly returns



Source: J.P. Morgan Quantitative and Derivatives Strategy

Table 9: Daily returns statistics of the 16 asset class indices, sorted by Information Ratio

	start date	CAGR (%)	Vol (%)	Information Ratio	max drawdown (%)	hit ratio (%)
Global Govt Bond	2001-02-01	4.3	2.5	1.74	4.7	55.1
Global Corp Bond	2001-02-01	5.1	3.4	1.48	11.8	54.6
US Corp Bond	2001-02-01	5.6	5.1	1.08	16	52.7
US Govt Bond	2001-02-01	4.1	4.2	0.98	6	52.3
Euro Corp Bond	2001-02-01	5.5	10.2	0.54	26.7	50.9
Euro Govt Bond	2001-02-01	5.6	10.6	0.53	19.9	51
MSCI EM	2001-02-01	8.5	19.2	0.44	65.1	54.6
MSCI ACWI	2001-02-01	4.9	16	0.31	58.1	53.9
MSCI WORLD	2001-02-01	4.8	16.2	0.3	57.5	53.6
MSCI US	2001-02-01	5.3	19.1	0.28	54.9	51.9
MSCI APAC	2001-02-01	4.9	18.6	0.26	57.8	52.8
MSCI Europe	2001-02-01	4	21.9	0.18	62.7	52.1
MSCI Japan	2001-02-01	2.5	22.5	0.11	53.1	50.3
Asian currency	2001-02-01	0.4	3.6	0.11	14.6	51
USD	2001-02-01	-1.5	8.2	-0.18	44.8	48.9
Commodity	2001-02-01	-4.3	23.3	-0.18	83.1	48.5

Source: J.P. Morgan Quantitative and Derivatives Strategy, Bloomberg

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Number of uncorrelated exposures

Meucci (2009) introduces the concept of uncorrelated exposures as a measure of diversification. Given a covariance matrix Σ, we use spectral theory to decompose it into a product

$$\Sigma = EDE'$$

where E is a column matrix of eigenvectors, and D is a diagonal matrix of eigenvalues $\lambda_1, \ldots, \lambda_n$.The eigenvectors E help us to define a new set of uncorrelated portfolios in terms of linear combinations of the original assets. The weights of these uncorrelated "principal" portfolios are given by

$$\hat{w} = E'w$$

where w is the weight of the assets. The proportion of variance of each principal portfolio is

$$v_i = \hat{w}_i^2 \lambda_i$$

Meucci (2009) defined the diversification distribution as

$$p_i = v_i / \sum_i v_i$$

The number of uncorrelated exposures is defined from an information theoretic perspective. It is defined as the exponential of the negative of Shannon's entropy:

$$N_{bet} = \exp\left(-\sum_{i=1}^{N} p_i \log p_i\right)$$

which ranges from 1 to the number of assets N.

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Risks of Common Option Strategies

Risks to Strategies: Not all option strategies are suitable for investors; certain strategies may expose investors to significant potential losses. We have summarized the risks of selected derivative strategies. For additional risk information, please call your sales representative for a copy of "Characteristics and Risks of Standardized Options." We advise investors to consult their tax advisors and legal counsel about the tax implications of these strategies. Please also refer to option risk disclosure documents.

Put Sale: Investors who sell put options will own the underlying asset if the asset's price falls below the strike price of the put option. Investors, therefore, will be exposed to any decline in the underlying asset's price below the strike potentially to zero, and they will not participate in any price appreciation in the underlying asset if the option expires unexercised.

Call Sale: Investors who sell uncovered call options have exposure on the upside that is theoretically unlimited.

Call Overwrite or Buywrite: Investors who sell call options against a long position in the underlying asset give up any appreciation in the underlying asset's price above the strike price of the call option, and they remain exposed to the downside of the underlying asset in the return for the receipt of the option premium.

Booster : In a sell-off, the maximum realized downside potential of a double-up booster is the net premium paid. In a rally, option losses are potentially unlimited as the investor is net short a call. When overlaid onto a long position in the underlying asset, upside losses are capped (as for a covered call), but downside losses are not.

Collar: Locks in the amount that can be realized at maturity to a range defined by the put and call strike. If the collar is not costless, investors risk losing 100% of the premium paid. Since investors are selling a call option, they give up any price appreciation in the underlying asset above the strike price of the call option.

Call Purchase: Options are a decaying asset, and investors risk losing 100% of the premium paid if the underlying asset's price is below the strike price of the call option.

Put Purchase: Options are a decaying asset, and investors risk losing 100% of the premium paid if the underlying asset's price is above the strike price of the put option.

Straddle or Strangle: The seller of a straddle or strangle is exposed to increases in the underlying asset's price above the call strike and declines in the underlying asset's price below the put strike. Since exposure on the upside is theoretically unlimited, investors who also own the underlying asset would have limited losses should the underlying asset rally. Covered writers are exposed to declines in the underlying asset position as well as any additional exposure should the underlying asset decline below the strike price of the put option. Having sold a covered call option, the investor gives up all appreciation in the underlying asset above the strike price of the call option.

Put Spread: The buyer of a put spread risks losing 100% of the premium paid. The buyer of higher-ratio put spread has unlimited downside below the lower strike (down to zero), dependent on the number of lower-struck puts sold. The maximum gain is limited to the spread between the two put strikes, when the underlying is at the lower strike. Investors who own the underlying asset will have downside protection between the higher-strike put and the lower-strike put. However, should the underlying asset's price fall below the strike price of the lower-strike put, investors regain exposure to the underlying asset, and this exposure is multiplied by the number of puts sold.

Call Spread: The buyer risks losing 100% of the premium paid. The gain is limited to the spread between the two strike prices. The seller of a call spread risks losing an amount equal to the spread between the two call strikes less the net premium received. By selling a covered call spread, the investor remains exposed to the downside of the underlying asset and gives up the spread between the two call strikes should the underlying asset rally.

Butterfly Spread: A butterfly spread consists of two spreads established simultaneously – one a bull spread and the other a bear spread. The resulting position is neutral, that is, the investor will profit if the underlying is stable. Butterfly spreads are established at a net debit. The maximum profit will occur at the middle strike price; the maximum loss is the net debit.

Pricing Is Illustrative Only: Prices quoted in the above trade ideas are our estimate of current market levels, and are not indicative trading levels.

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