Risk Premia Portfolio Construction via Uncorrelated Clusters

Introducing Autoencoders as an extension of Principal Components

Autoencoders as a Machine Learning tool for clustering
Last year, we introduced a new methodology to construct cluster risk premia portfolios using Autoencoders, which is a special type of a neural network. We re-visit the idea in this report, providing more insights and update the cluster portfolio as we enter 2021.

Advantage over Principal Components or Hierarchical clustering
We estimate linear autoencoders to ensure tradable cluster portfolios, and impose long-only constraints that are not guaranteed in PCAs. We can also constrain the clusters to be uncorrelated out-of-sample, which cannot be easily controlled in Hierarchical clustering. Moreover, regularization techniques in machine learning could improve cluster robustness.

Performance in 2020 demonstrated its resilience to drawdowns
The cluster portfolio achieved better diversification benefit and suffered from smaller drawdowns than a typical risk parity portfolio in 2020.

Latest risk premia cluster constituents
We estimate two clusters which may roughly be identified as more aggressive vs more defensive. In the more aggressive cluster, we have short vol strategies in FX, rates, credit and equity. In the more defensive cluster, we have rates and equity momentum, quality and FX value.

Global Quantitative and Derivatives Strategy

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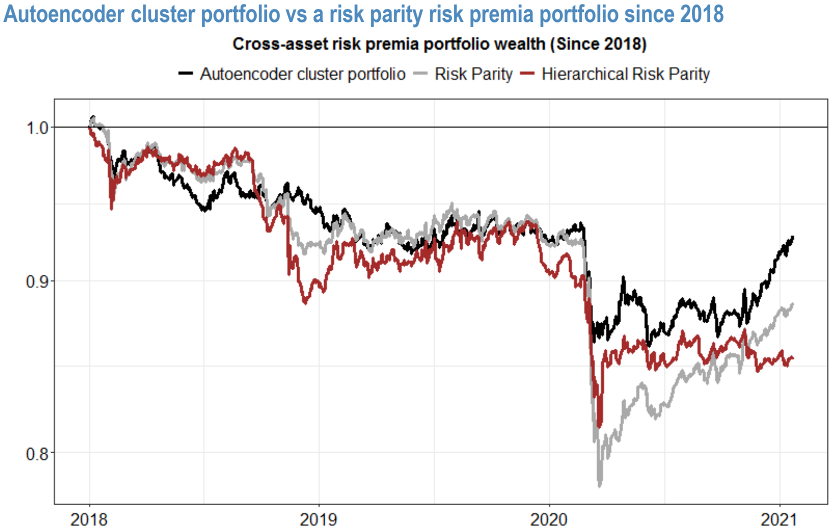
Autoencoder cluster portfolio vs a risk parity risk premia portfolio since 2018



Source: J.P. Morgan Quantitative and Derivatives Strategy; Bloomberg Finance L.P.

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Rationale

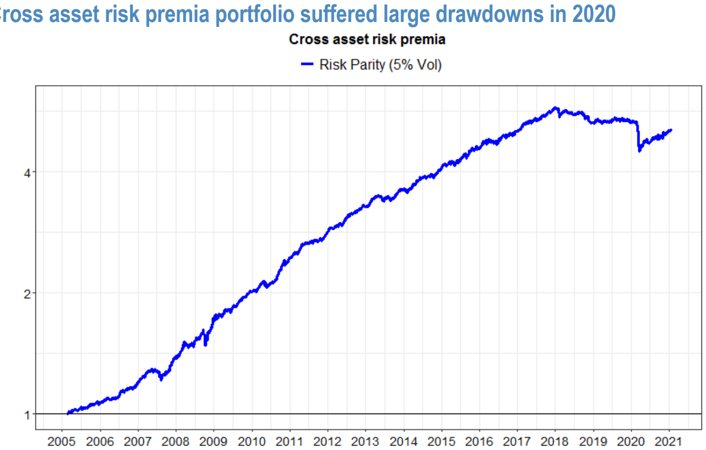
Last year, in one of our issues of Quantitative Perspectives on Cross asset risk premia, we introduced a [novel methodology to construct cluster risk premia portfolios using Autoencoders](). We re-visit the idea in this report, and update the portfolio composition as we enter 2021.

Selecting risk premia candidates

Our portfolio construction methodology not only helps us to assign weights to our "selected universe of assets", but also assists managers to pick a smaller subset of assets out of a potentially large number of candidates. We achieve the latter via the fact that our clustering algorithm essentially assigns zero weights to assets that are "redundant", which could essentially be represented by holding other "similar" assets in the portfolio.

This is particularly useful for alternative risk premia investors as there is a plethora of risk premia indices on the market due to various factor definitions and implementations. How could one choose a "proper" universe into a cross asset risk premia portfolio? Simply judging from historical performance will likely sacrifice diversification benefits. In the case where an investor does not have much constraints, we do find that a simple risk parity portfolio with a large number (>20) of risk premia indices tends to deliver higher Sharpe ratios than more concentrated counterparts. Nevertheless, this selection of a large number of risk premia can be rather heuristic. Moreover, as we have seen in 2020, such portfolios could experience large drawdowns as well (Figure 1), highlighting that the (apparent) diversification benefit maybe overstated when it is most needed.

Figure 1: Cross asset risk premia portfolio suffered large drawdowns in 2020



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

Identifying lowly correlated clusters

In light of the possible lack of diversification during market sell-offs, one of the key goals for risk premia investors is to identify blocks of lowly correlated risk premia as their portfolio constituents – blocks which remain lowly correlated even when there are bouts of market turmoil. Intuitively, we can think of two groups of risk premia that should be largely uncorrelated, one being "Aggressive" and the other "Defensive". While individual risk premia may become more correlated across certain market regimes, one could have more confidence that Aggressive and Defensive risk premia are largely uncorrelated (or even negatively correlated) at all times (we looked heuristically at aggressive and defensive risk premia here). As such, we frame our objective as to "systematically classify risk premia into two lowly correlated clusters" such that we may interpret later that one is more aggressive and the other more defensive. Finally, we assign the same risk budgets to the two uncorrelated clusters (rather than the same risk budgets to each risk premia), and we expect such a cluster portfolio to outperform, especially during regimes when correlations spike.

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Autoencoder as a clustering tool

We introduce a Machine Learning model called Autoencoders to construct lowly correlated clusters for portfolio construction. When it comes to clustering techniques, the first idea quants could think of is Principal Components Analysis (PCA). It is widely used to reduce the dimension of a problem. We may apply PCAs to form uncorrelated clusters, but there are some drawbacks:

1. The solutions for clusters from PCAs are linearly combinations of risk premia, where the weights could be either positive or negative. For long-only portfolios (like typical risk premia allocations), it is not ideal to have negative weights. We may ensure positive weights using constrained optimizations[1], but autoencoder is a more flexible framework

2. One can always flip the signs of the principal components as this will not change the variances. But this is a bit heuristic and we may not know in advance which sign corresponds to a portfolio that would go up

Idea

Autoencoders are special types of neural network which maps the inputs into itself:

$$f(X) = X + \varepsilon$$

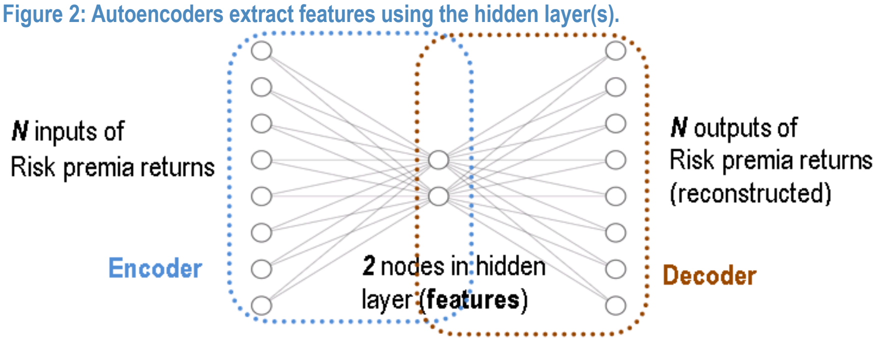
Such mapping can be broken down into two parts (Figure 2):

1. An encoder is applied on the inputs to compress information into a lower dimension, i.e. maps from N inputs to K features

2. A decoder is applied on the compressed features and aims to reconstruct the original information, i.e. maps from K features to N outputs

An autoencoder is a combined network of an encoder followed by a decoder. One could regard the neurons in the hidden layer as "features" to be identified. The hidden layer "condenses" information from a large number of inputs into a smaller dimension of key features, which correspond to our cluster portfolios.

Figure 2: Autoencoders extract features using the hidden layer(s).



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

[1] For instance, non-negative matrix factorization is a popular tool to decompose facial images into sparse, meaningful features (e.g., eyes, nose, mouth)

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A flexible extension of Principal Components

Principal Components are just a special case of Autoencoders when we consider one hidden layer with linear activations and minimize the mean squared errors. More generally, autoencoders could be non-linear extensions of PCAs if we consider non-linear activation functions or a larger number of hidden layers. As autoencoders are a type of neural network, existing tools such as Tensorflow help us to easily impose constraints on the weights, for instance to ensure that they are always positive and correspond to long only positions of risk premia. Moreover, we could easily define alternative objectives in the optimizations instead of minimizing MSEs, e.g. to impose custom penalties or regularizations to control the number of free parameters.

In summary, autoencoders are more flexible than PCAs:

- Autoencoders may handle non-linear relationships via hidden layers and non-linear activation functions (although we will not look at non-linearity here, they could be useful for feature engineering)
- Autoencoders can easily be constrained with positive weights
- Autoencoders can easily be regularized to prevent overfitting
- We may use cross-validations to improve robustness of our model

Note that the features extracted by autoencoders may not always be uncorrelated, which is guaranteed in the case of Principal Components. Nevertheless, we can put it as a constraint to ensure uncorrelated features. This will not be easily achieved if we construct clusters based on another Machine Learning technique called Hierarchical clustering[2].

Figure 3 compares different approaches of constructing cluster portfolios.

Figure 3: Comparison between different methods to construct cluster portfolios

	Principal Components	Hierarchical Clustering	Autoencoders
Long-only	No	Yes	Yes (via constraints)
Output asset weights	Yes	No	Yes
Uncorrelated features	Yes (by construction)	No	Yes (via constraints)
Cross-validation	No	No	Yes

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

[2] **We have applied hierarchical clustering to construct portfolios in Lau et al (2017) Cross Asset Portfolios of Tradable Risk Premia Indices: Hierarchical Risk Parity: Enhancing Returns at Target Volatility**

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Application in Risk Premia portfolio

In the below, we estimate the weights in an autoencoder in order to define two uncorrelated clusters of risk premia, where we will construct a risk parity cluster portfolio. We consider 23 J. P. Morgan risk premia indices as inputs (see our regular risk premia publication). To ensure the features are not dominated by the most volatile risk premia, we scale the returns to target at the same volatility before feeding them as inputs.

Although autoencoders are capable of handling non-linear features, **we keep the linearity so as to ensure the clusters are tradable portfolios**. We fit a linear autoencoder with:

- One hidden layer of two neurons (i.e., features)
- Linear activation function

As such, our autoencoder can be written as a linear function

$$(X \times W_{Encoder}) \times W_{Decoder} = X + \varepsilon$$

where *Ws* are matrix weights. We further impose the following constraints:

- Encoder weights are the transpose of decoder weights: This can help to reduce the number of parameters, and to make our autoencoder resemble principal components
- All weights are positive $\omega_{j,k} \geq 0$
- The column vectors have unit norm, i.e.

$$\sum_{j=1}^{N} \omega_{j,k}^2 = 1 \qquad (k = clusters\ 1,2)$$

- Encoder weights are orthogonal: This ensures that each risk premia only falls into one of the clusters

$$W_{Encoder}{}' W_{Encoder} = \boldsymbol{I}$$

- The features, i.e. cluster portfolios $(X \times W_{Encoder})$ are uncorrelated

We run through a parameter grid search and finalize a model at the beginning of each year starting from 2007, using an expanding window and the most recent 20% of data as the test set for validation. We also include weight regularizations, which leads to a relatively sparse representation and some risk premia may not fall into any cluster.

The estimated weights of the encoder are used to construct a long-only portfolio of risk premia, where we fix the composition in the next 12 months until the next model estimation.

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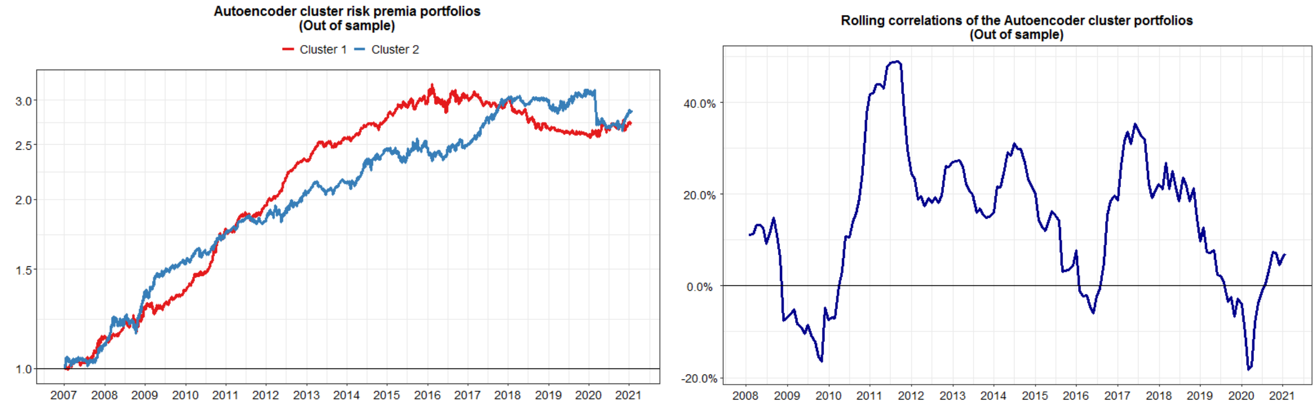
Autoencoder clusters

As we constrain the features to be uncorrelated, the clusters do exhibit relatively low level of correlations, except in 2011 when apparently most risk premia returns were positive (Figure 4).

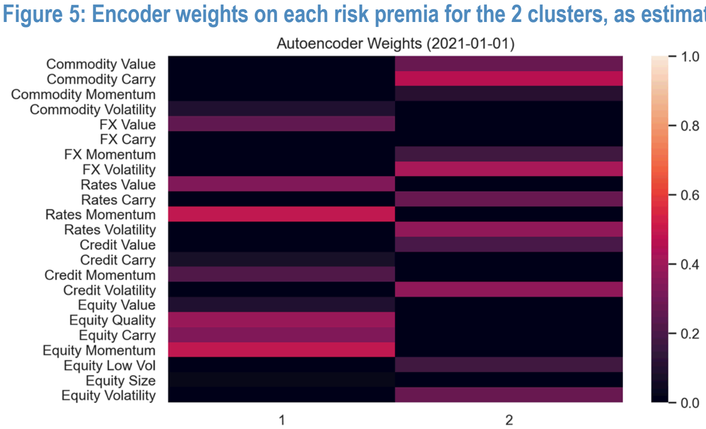
Figure 4: Performance of the AE cluster portfolios (re-estimated every year), and rolling correlations between the AE cluster portfolio returns



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

Latest encoder weights estimated in the beginning of 2021 are shown in Figure 5.

Figure 5: Encoder weights on each risk premia for the 2 clusters, as estimated in the beginning of 2021



	Cluster 1	Cluster 2
Commodity Value		28%
Commodity Carry		46%
Commodity Momentum		11%
Commodity Volatility	10%	
FX Value	26%	
FX Carry		
FX Momentum		18%
FX Volatility		42%
Rates Value	34%	
Rates Carry		28%
Rates Momentum	49%	
Rates Volatility		37%
Credit Value		20%
Credit Carry	7%	
Credit Momentum	22%	
Credit Volatility		37%
Equity Value	9%	
Equity Quality	40%	
Equity Carry	33%	
Equity Momentum	49%	
Equity Low Vol		17%
Equity Size	3%	
Equity Volatility		27%

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

Apparently, we may still interpret Cluster 1 as more defensive and Cluster 2 as more aggressive, although this is not totally intuitive. In Cluster 1, we have Quality, FX value, rates value and momentum. In Cluster 2, we have more short vol strategies, and credit value.

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Figure 6: Interpretation of the 2 clusters

Cluster 1 (More defensive)		Cluster 2 (More aggressive)	
Rates Momentum	48.9%	Commodity Carry	45.9%
Equity Momentum	48.8%	FX Volatility	42.3%
Equity Quality	39.5%	Rates Volatility	37.1%
Rates Value	33.7%	Credit Volatility	36.6%
Equity Carry	33.3%	Commodity Value	27.9%
FX Value	26.4%	Rates Carry	27.7%
Credit Momentum	21.9%	Equity Volatility	27.0%
Commodity Volatility	10.1%	Credit Value	20.2%
Equity Value	9.4%	FX Momentum	17.6%
Credit Carry	6.8%	Equity Low Vol	16.8%
Equity Size	2.5%	Commodity Momentum	10.6%

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

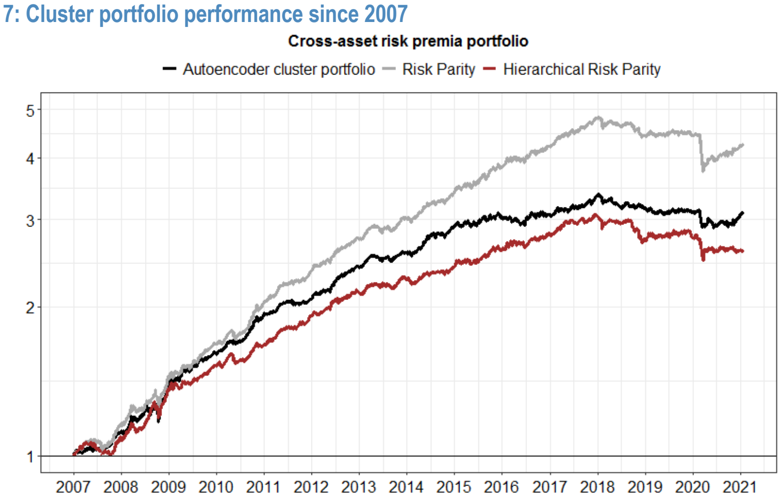
Cluster portfolio backtests

Finally, we assign a risk parity weight on the 2 autoencoder cluster portfolios based on their historical volatilities, and target the overall portfolio to 5% vol. We compare 3 portfolios:

- **Autoencoder cluster portfolio**: inverse volatility on 2 autoencoder clusters
- **Risk parity:** inverse volatility with 23 individual risk premia
- **Hierarchical risk parity:** apply hierarchical clustering and allocate iteratively to the sub-clusters[3] which are assumed to be uncorrelated (see Lopez de Prado[4])

Figure 7 compares the performances since 2007. The autoencoder cluster portfolio appears to have better control on skewness, kurtosis and drawdowns, although this also leads to some sacrifice of high returns during the good days. This is similar for Hierarchical risk parity, although the trade-off in returns seem to be larger.

Figure 7: Cluster portfolio performance since 2007



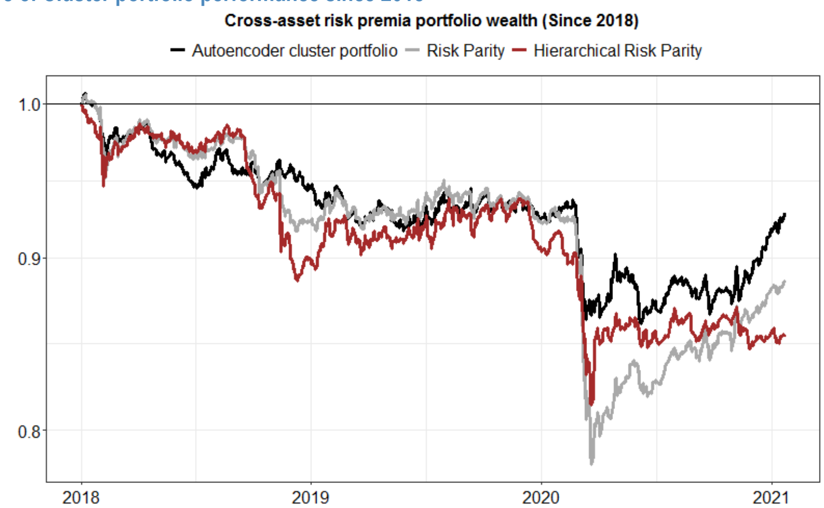
Source: J.P. Morgan Quantitative and Derivatives Strategy.

[3] We applied hierarchical clustering to construct portfolios in Lau et al (2017) Cross Asset Portfolios of Tradable Risk Premia Indices: Hierarchical Risk Parity: Enhancing Returns at Target Volatility

[4] Lopez de Prado, Marcos (2016), Building Diversified Portfolios that Outperform Out-of-Sample. Journal of Portfolio Management, 2016

Interestingly, during market sell-offs in March 2020, the autoencoder cluster portfolio demonstrated better resilience than the risk parity benchmark. The Hierarchical risk parity portfolio also suffered from a smaller drawdown than risk parity, but unlike the autoencoder cluster portfolio, it does not enjoy the subsequent rebound in Q2 2020 (Figure 8).

Figure 8: Cluster portfolio performance since 2018



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

Figure 9: Daily returns statistics

	Start Date	End Date	Annualized Returns	Annualized Vol	Sharpe Ratio	t-stat	Skewness	Excess Kurtosis	Max Drawdown	Hit Ratio	Sortino Ratio	Calmer Ratio
	Since 2007											
Autoencoder cluster portfolio	2007-01-02	2021-01-21	8.1%	5.3%	1.54	5.73	-0.41	4.40	14.5%	56.6%	0.14	0.56
Risk Parity	2007-01-02	2021-01-21	10.5%	5.6%	1.87	6.88	-1.47	15.21	22.3%	58.9%	0.16	0.47
Hierarchical Risk Parity	2007-01-02	2021-01-21	6.8%	5.6%	1.21	4.59	-0.87	8.72	19.5%	55.9%	0.11	0.35
	Since 2018											
Autoencoder cluster portfolio	2018-01-01	2021-01-21	-2.4%	5.2%	-0.45	-0.77	-1.07	5.44	14.5%	52.1%	-0.03	-0.16
Risk Parity	2018-01-01	2021-01-21	-3.8%	6.6%	-0.57	-0.98	-3.08	28.07	22.3%	55.3%	-0.04	-0.17
Hierarchical Risk Parity	2018-01-01	2021-01-21	-4.9%	6.4%	-0.77	-1.34	-1.21	11.03	18.6%	51.4%	-0.06	-0.26

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

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