Zürcher Hochschule
für Angewandte Wissenschaften

School of
Management and Law

Interpretable Machine Learning for Diversified Portfolio Construction

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Munich RE

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ML-based concept for benchmarking robustness of portfolio strategies

For return time series:
Bootstrapping, GANs
For correlation matrices:
«Matrix Evolutions», CorrGAN

Alternative systematic portfolio strategies:
Equal risk contribution (ERC)
Hierarchical Risk Parity (HRP)

Explainable machine learning (XAI):
Train explanation model (XGBoost)
Discuss Shapley values (TreeSHAP)

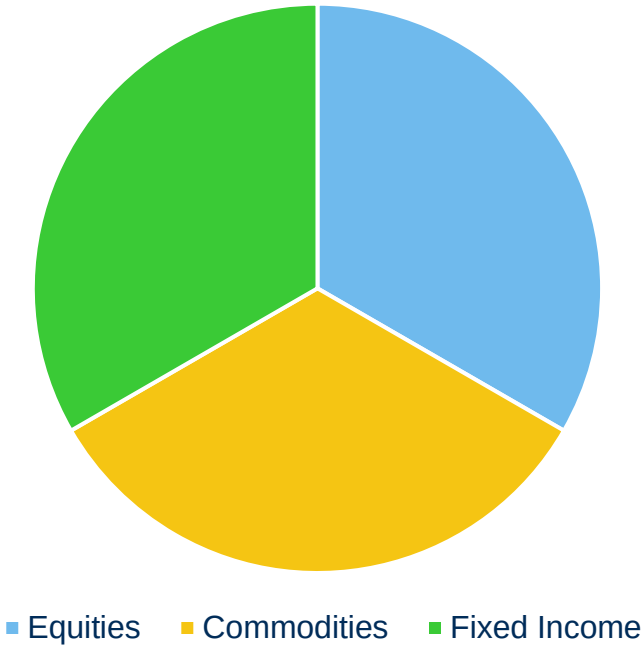
Risk-Controlled Diversified Portfolios: The Risk Parity idea

Risk parity idea:

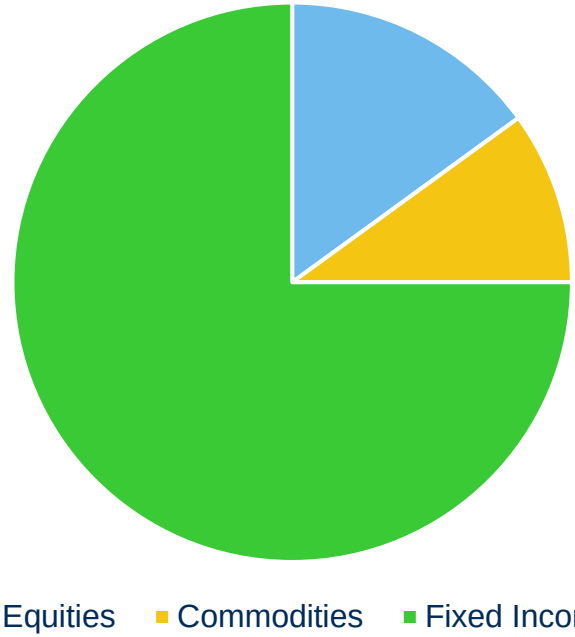
- Long positions in the most liquid futures markets across asset classes.
- Lever up low-risk assets to achieve similar risk contributions across asset classes.
- Rebalance regularly, i.e. monthly or quarterly.
- Control risk at portfolio level using dynamic leverage («volatility target»).

Risk Parity idea: an Example

Equal Risk Contributions



Fixed Income dominates Market Value Allocation



Fixed income has low volatility, but it is levered up to achieve a similar risk contribution as equities and commodities.

Negative correlations from fixed income to other asset classes allows a higher portfolio leverage.

March 2020: equities and bonds show a correlated correction, causing losses for risk parity funds.

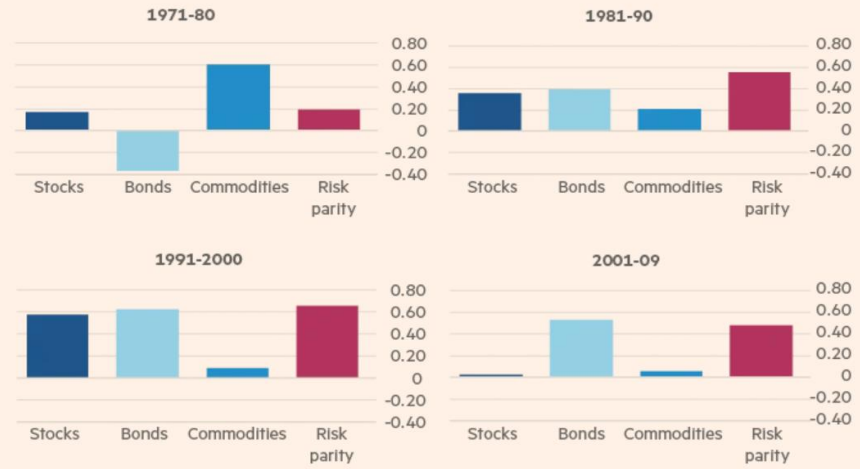
Analysts point finger at 'risk parity' strategy in market rout

Funds are designed to perform well at all times but some say they exacerbate sell-offs

Robin Wigglesworth MARCH 20 2020

A simple risk parity strategy has historically delivered better, steadier returns than most individual asset classes

Sharpe ratio



Source: AQR
© FT

Treasuries have sold off in tandem with stocks lately, pushing yields higher

Source: Refinitiv
© FT

Risk parity funds pummelled by bond and stock sell-off

S&P index showing performance of typical risk parity fund with a 10% volatility target

Source: Refinitiv
© FT

Ref: Danilo Vassallo, Lieven Hermans and Thomas Kostka, "Volatility-targeting strategies and the market sell-off", Financial Stability Review, May 2020
https://www.ecb.europa.eu/pub/financial-stability/fsr/focus/2020/html/ecb.fsrbox202005_02~f6616db9be.en.html

Can HRP achieve more robust portfolios despite unstable correlations?

ERC
Equal Risk Contribution

Distributes the risk evenly among the assets.

HRP
Hierarchical Risk Parity

Uses ML (Hierarchical Clustering) for asset allocation

- Volatility target 5%
- Monthly rebalanced portfolio
- Half-turn transaction cost of 2 bp (flat)
- 17 futures markets (equities, commodities, fixed income)
- 20 years of data 5/2000 – 6/2020

Equal Risk Contribution (ERC)

The risk contribution of the i-th asset in the portfolio is

$$\mathcal{RC}_i = \frac{w_i \left[\Sigma w\right]_i}{\sqrt{(w'\Sigma w)}}$$

where Σ is the VCV matrix, and w the portfolio weights.

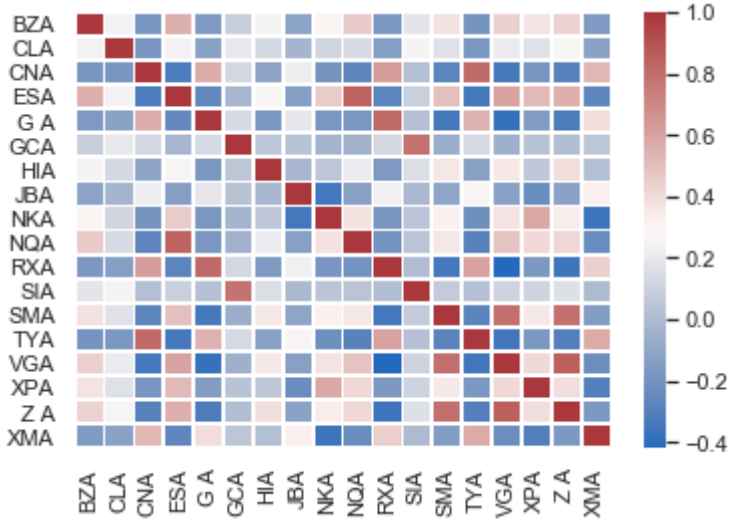
The ERC portfolio weigths are the solution of the optimization

$$\underset{w}{\operatorname{argmin}} \left[\sum_{i=1}^{N} \left(\frac{\mathcal{RC}_i}{\sqrt{(w'\Sigma w)}} - \frac{1}{N} \right)^2 \right].$$

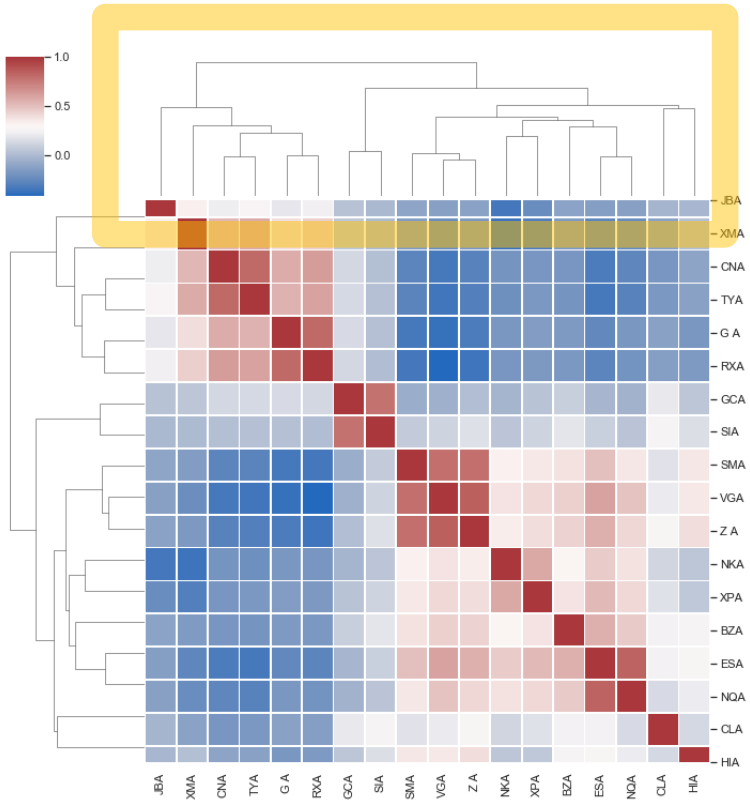
“minimize deviations from equal risk contributions across assets”

T. Roncalli 2013. Introduction to Risk Parity and Budgeting. Chapman & Hall. CRC Financial Mathematics Series.

Hierarchical Risk Parity (HRP) – first step



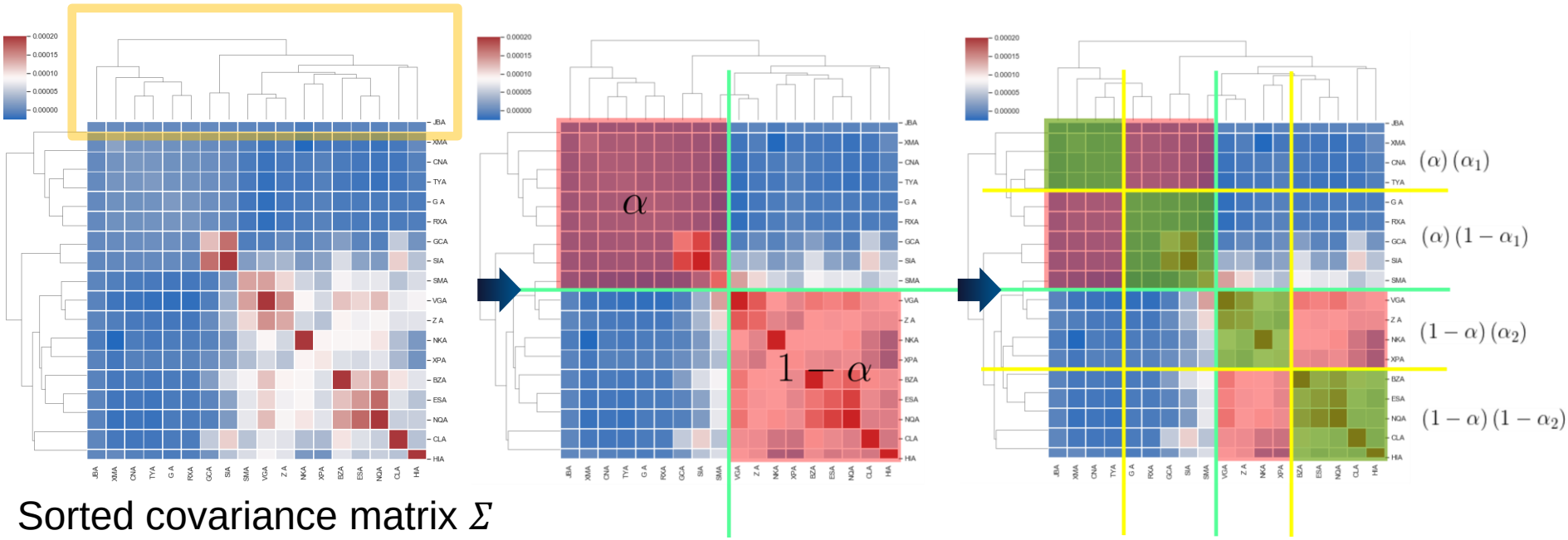
Clustering



Correlation matrix gets sorted by similarity
(Gowers + Euclidean distance)

Hierarchical Risk Parity (HRP) – second step

Recursive bisection of the covariance (not correlation!) matrix



Sorted covariance matrix Σ

$$\alpha = 1 - \frac{\sigma^2\left(w^{(1)}\right)}{\sigma^2\left(w^{(1)}\right) + \sigma^2\left(w^{(2)}\right)}$$

$$\sigma^2\left(w^{(j)}\right) = w^{(j)T}\,\Sigma^{(j)}\,w^{(j)} \text{ and } w^{(j)} = \frac{1/\text{diag}\left[\Sigma^{(j)}\right]}{\text{tr}\left(\text{diag}\left[\Sigma^{(j)}\right]^{-1}\right)}$$

(CAL)MAR Ratio

A practitioners' method to measure risk-adjusted returns:

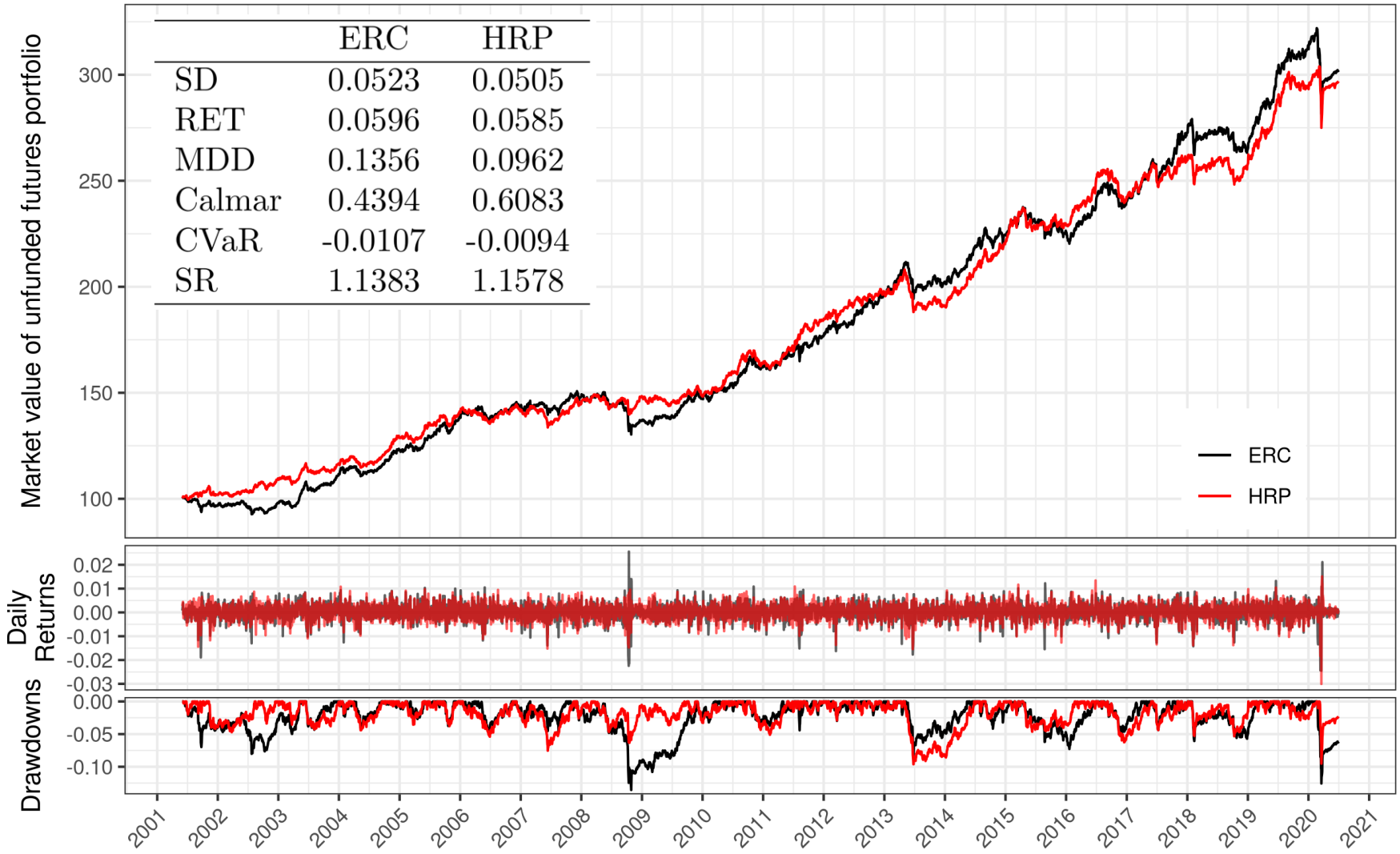
$$\text{Calmar} := \frac{\text{annualized avg return}}{\text{worst drawdown}}$$

- Asymmetric: focus on the worst drawdown, not on volatility like in Sharpe ratio.
- Institutional investors often have to divest a specific strategy at a high drawdown (10%-15%).
- Inverse Calmar ratio: number of years it takes for the average return to make for the worst drawdown

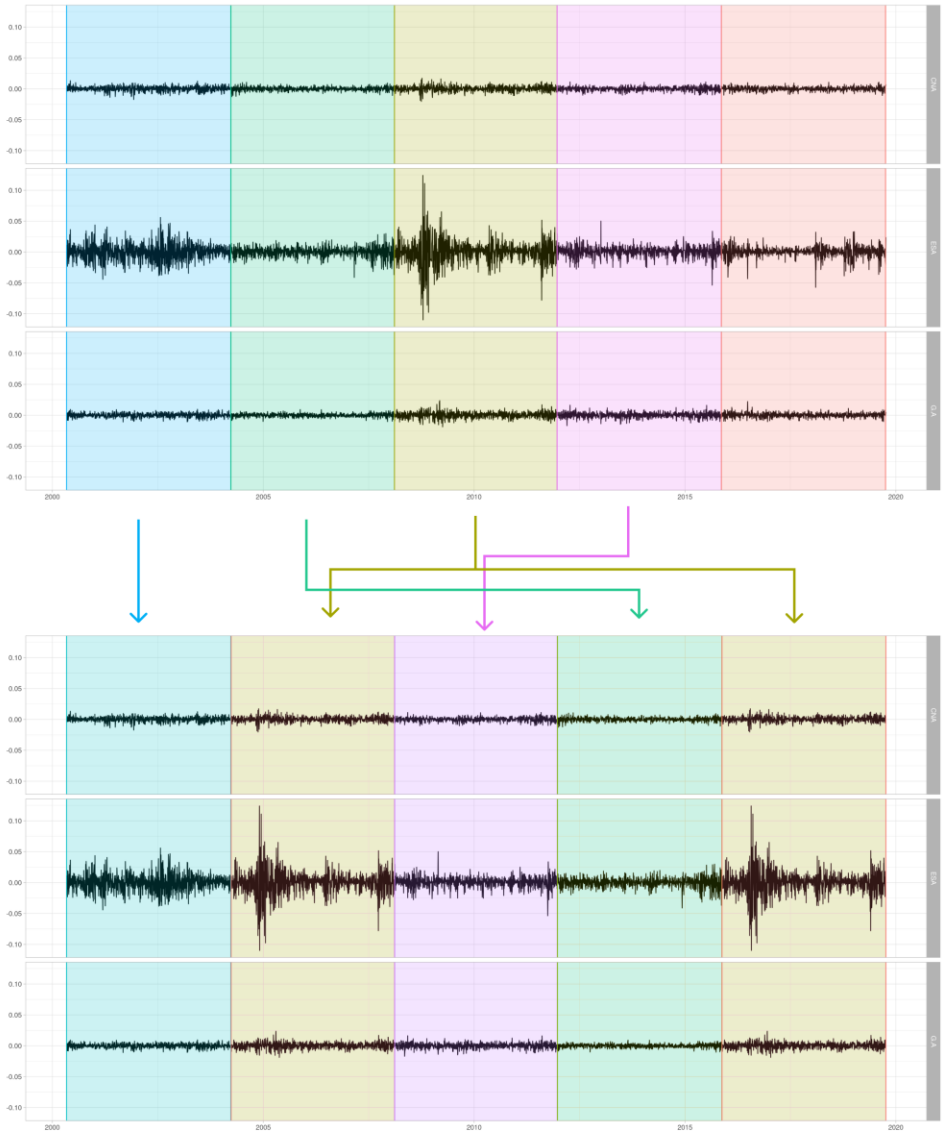
MAR ratio: «Managed Account Reports», a 70's investment newsletter from Leon Rose
Calmar ratio: Young, Terry W. (1991), "Calmar Ratio: A Smoother Tool", Futures magazine

HRP shows less drawdowns in historical data. But elsewhere?

	ERC	HRP
SD	0.0523	0.0505
RET	0.0596	0.0585
MDD	0.1356	0.0962
Calmar	0.4394	0.6083
CVaR	-0.0107	-0.0094
SR	1.1383	1.1578



Data augmentation - Bootstrap



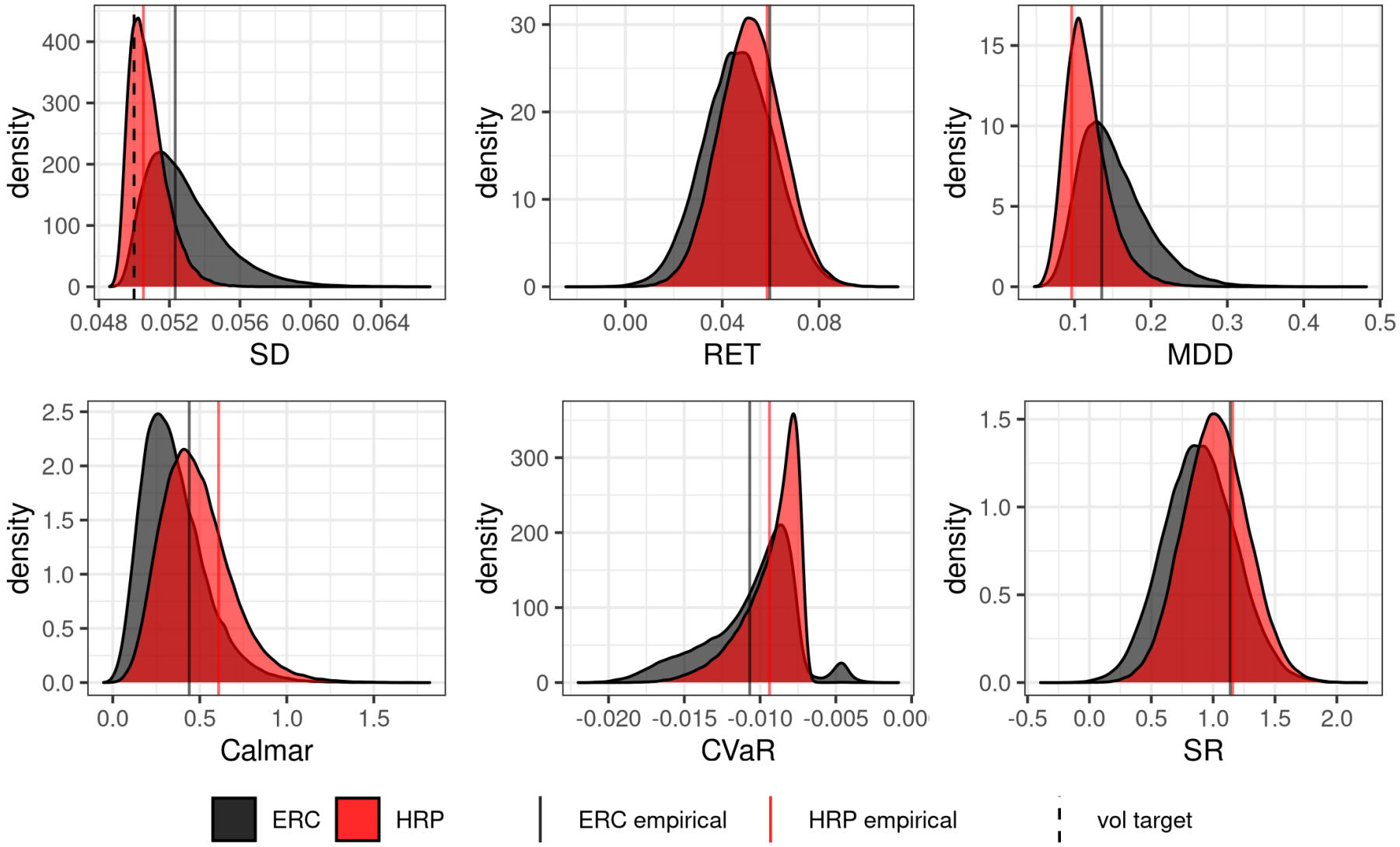
We want to test multiple scenarios:

Block bootstrap

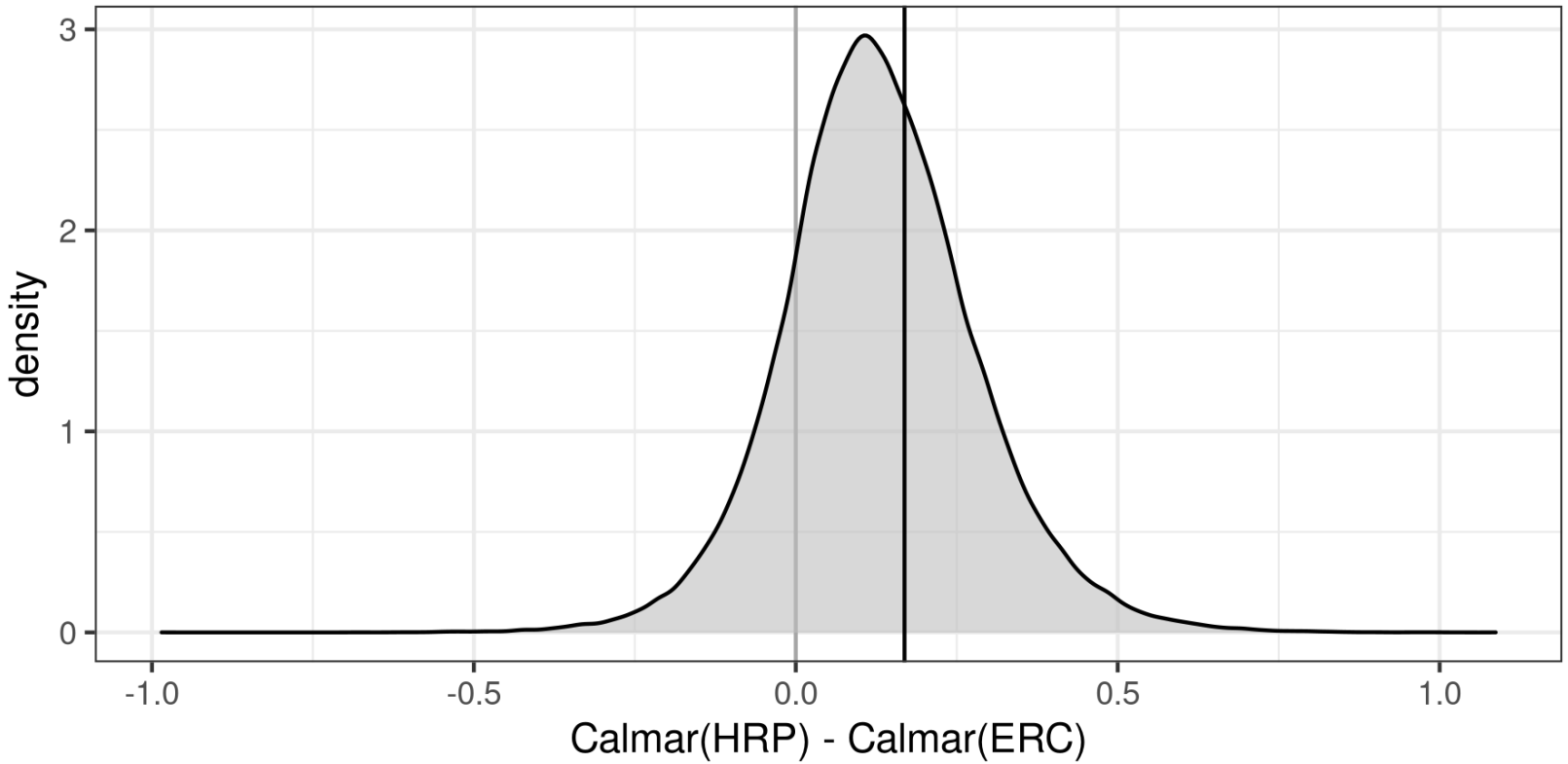
blocks of 60 business days

100k - portfolio universes

Performances – 100k bootstrap portfolios



What dataset features make HRP perform better than ERC?



We use **XGBoost** ⟷ trained over a set of features (global properties of the portfolios), then we exploit Machine Learning explanations.

96 features: statistical properties of the bootstrapped portfolio

[(sd.)] maxDD (_futures) _mean

(sd.): over time; maxDD: statistical measure; (_futures): asset class; _mean: aggregated

Traditional Measures
40 x 2

statistical measure	
mean	mean
sd	standard deviation
corr	correlation coefficients
maxxDD	maximum drawdown
maxDDminus	maxxDD of minus log-returns

asset class
futures
FixedIncome
Commodities
Equities

aggregated
_mean
_sd

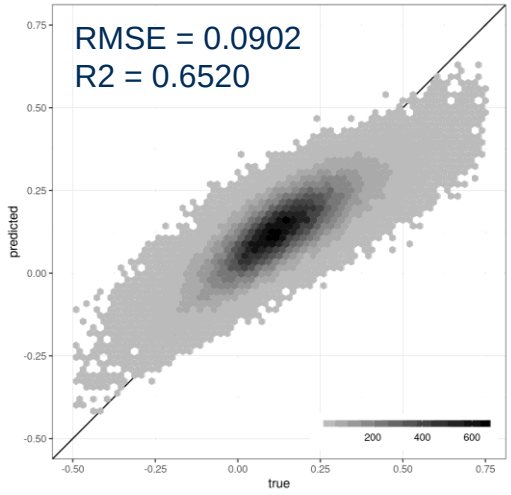
Clustering Measures
2 x 4 x 2

statistical measure	
ClusterCoefficientssingle	specifies the agglomerative coefficient as defined in Kaufman and Rousseeuw (2009) measuring the clustering structure of the dataset
CopheneticCorrelationCoefficientsingle	correlation between the distance matrix and the ultrametric distance matrix

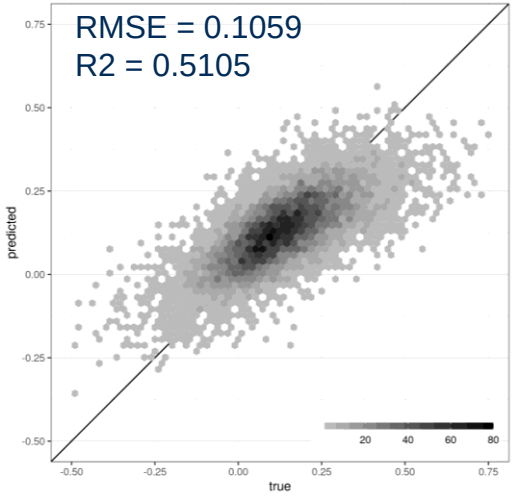
asset class
futures
FixedIncome
Commodities
Equities

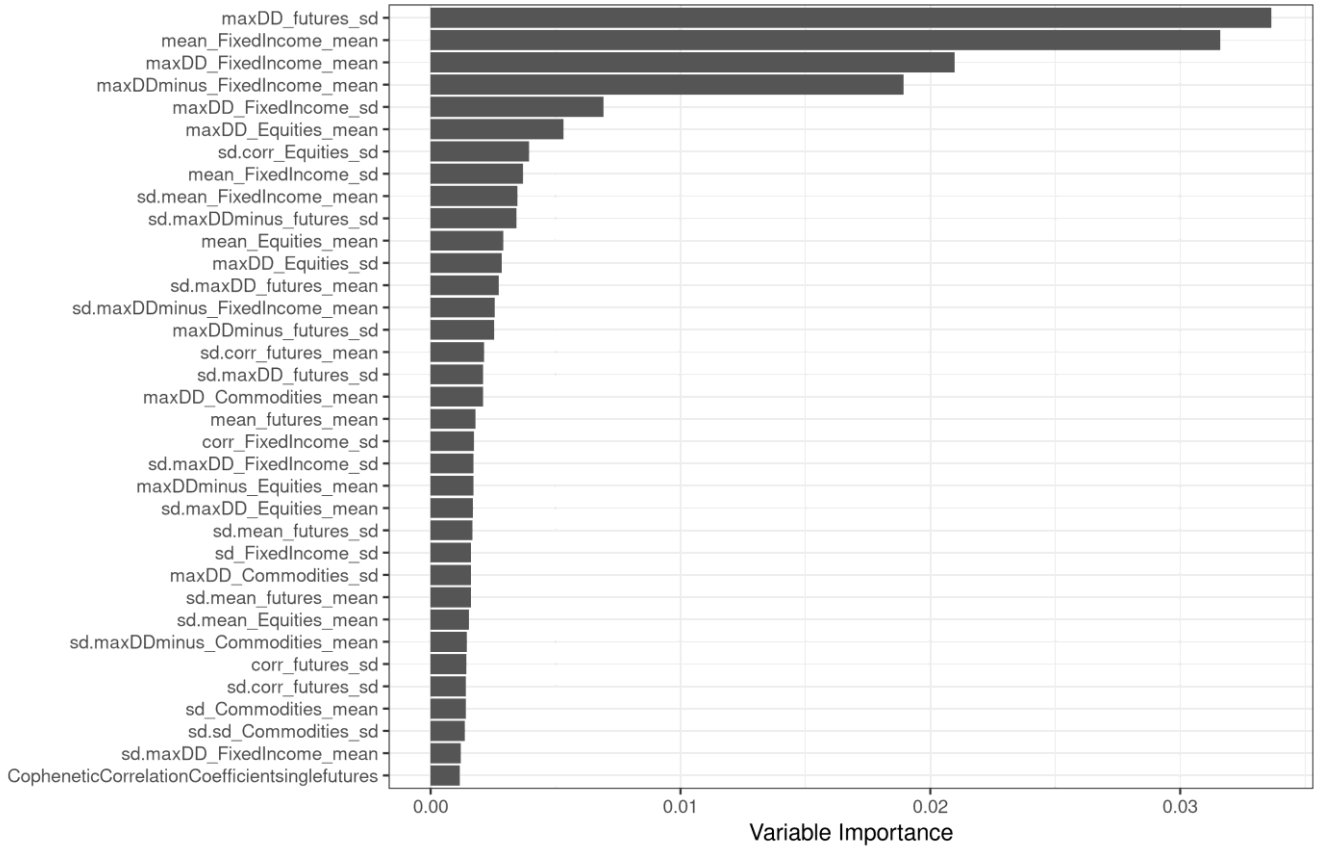
XGBoost outcomes

Train



Test





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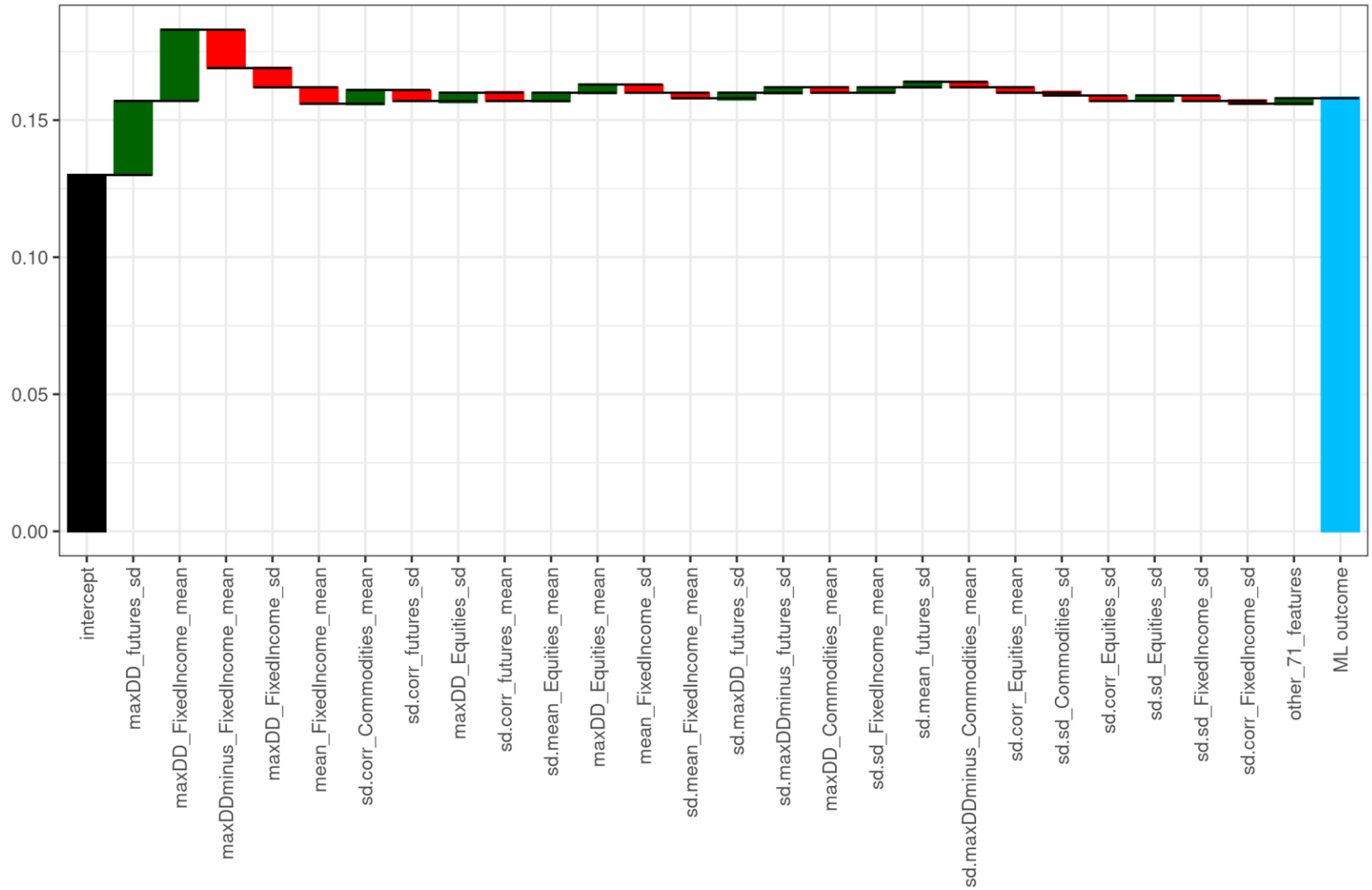
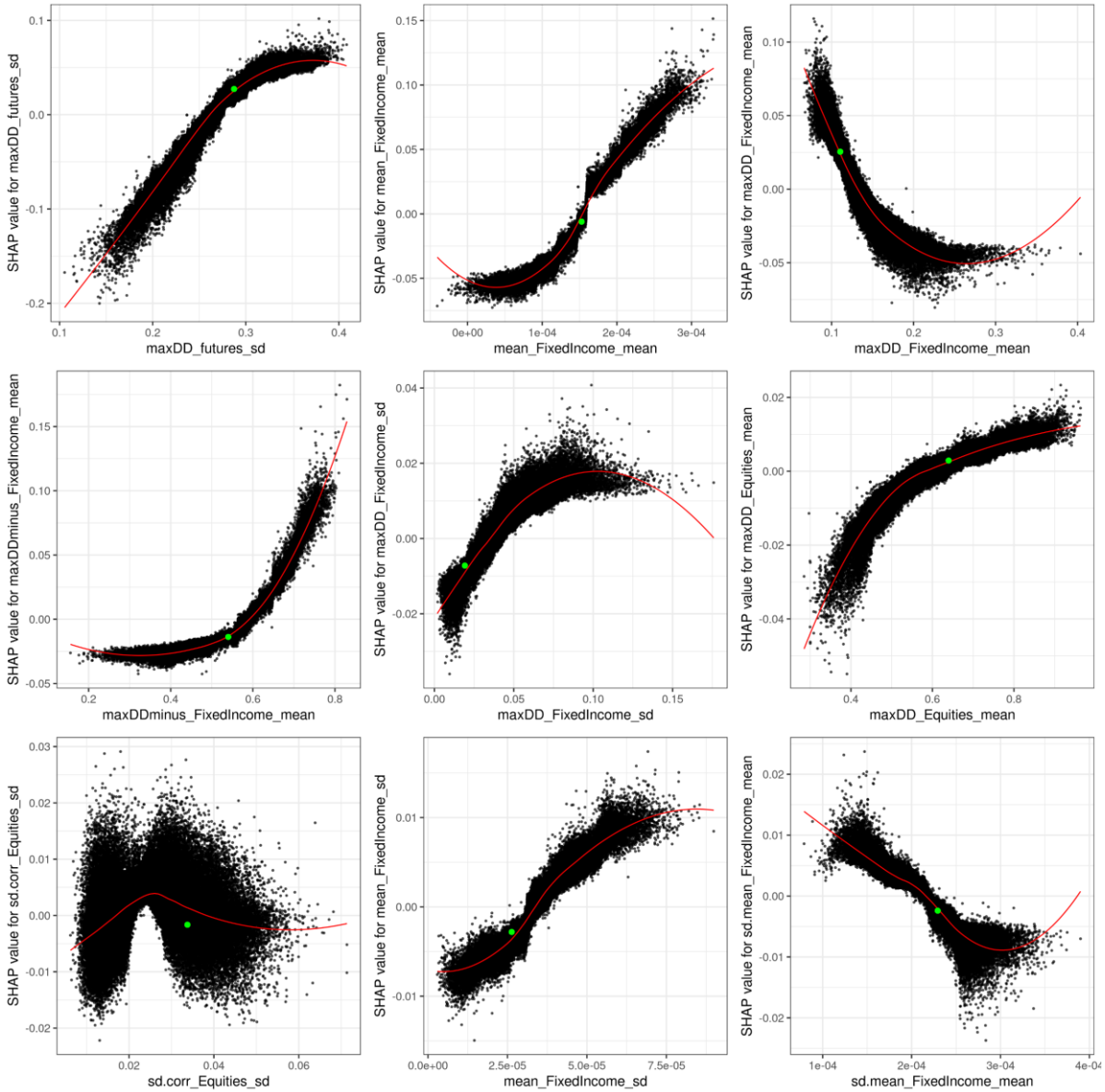
SHAP Explanation for the empirical portfolio



ML Explanations of the performance spread between HRP and ERC



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Conclusions and Extensions

- We find HRP (Hierarchical Risk Parity) to show less drawdowns than Equal Risk Contribution (ERC) using empirical and bootstrapped data.
- We train an explanation model to link the performances with features of bootstrapped market data.
- Out of sample, the Calmar ratio spread can primarily be explained by asset-specific measures of the bootstrapped dataset, especially by the fixed income performance.
- Extensions:

  Matrix Evolutions: Synthetic Correlations and Explainable Machine Learning for Constructing Robust Investment Portfolios. https://doi.org/10.3905/jfds.2021.1.056

  'Adaptive Seriational Risk Parity' and other Extensions for Heuristic Portfolio Construction using Machine Learning and Graph Theory, https://dx.doi.org/10.2139/ssrn.3806714

Appendix: Risk Parity Portfolio

- 17 futures
- 3 asset classes
  - Fixed income
  - Equities
  - Commodities
- Time-series from 2000-05-03 to 2020-06-30 with daily prices

Ticker	Asset class	Currency	Name
CLA Comdty	Commodities	USD	NYMEX WTI Light Sweet Crude Oil
GCA Comdty	Commodities	USD	COMEX Gold
SIA Comdty	Commodities	USD	COMEX Silver
BZA Index	Equities	BRL	BM&F IBOVERSPA
ESA Index	Equities	USD	CME E-mini S&P 500
HIA Index	Equities	HKD	HKFE Hang Seng
NKA Index	Equities	JPY	OSE Nikkei 225
NQA Index	Equities	USD	CME E-mini NASDAQ-100
SMA Index	Equities	CHF	Eurex SMI
VGA Index	Equities	EUR	Eurex EURO STOXX 50
XPA Index	Equities	AUD	ASX SPI 200
Z A Index	Equities	GBP	ICE FTSE 100
CNA Comdty	Fixed Income	CAD	10Y Canadian GB
G A Comdty	Fixed Income	GBP	ICE Long Gilt
RXA Comdty	Fixed Income	EUR	Eurex 10Y Euro-Bund
TYA Comdty	Fixed Income	USD	CBOT 10Y US T-Note
XMA Comdty	Fixed Income	AUD	ASX 10Y Australian T-Bonds