Notes on Feng & Palomar 2016: *Portfolio Optimization with Asset Selection and Risk Control*

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Notation

Vectors are represented by bold, small-case letters, *e.g.*, $\boldsymbol{x}$. All vectors are column vectors. Given a vector $\boldsymbol{x}$, both $(\boldsymbol{x})_i$ and x_i represent the i-th component of $\boldsymbol{x}$.

1 Background

Risky parity is a portfolio design technique which aims to promote diversification of risk contributions amongst assets. This approach often leads to a dense portfolio, *i.e.*, a portifolio which has contributions from all its assets. However, investing in all assets is impractical because of, *e.g.*, high transaction costs. The problem of jointly designing a sparse risk-parity portfolio is precisely the subject of study of Feng & Palomar.

Consider a collection of n assets with random returns $\boldsymbol{r} \in \mathbb{R}^n$ such that $\mathbb{E}[\boldsymbol{r}] \triangleq \boldsymbol{\mu}$ and $\mathbb{E}\left[(\boldsymbol{r}-\boldsymbol{\mu})(\boldsymbol{r}-\boldsymbol{\mu})^T\right]$ are its mean vector and its (positive definite) covariance matrix. Also, let $\boldsymbol{w} \in \mathbb{R}^n$ denote the normalized portfolio (*e.g.* $\boldsymbol{w}^T\mathbf{1} = 1$), which represents the distribution of capital budget allocated over the assets.

Then, for every normalized portfolio $\boldsymbol{w}$, define the portfolio volatility as $\sigma(\boldsymbol{w}) \triangleq \sqrt{\boldsymbol{w}^T\boldsymbol{\Sigma}\boldsymbol{w}}$. Intuitively, the portfolio volativity is a measure of the risk contributions, i.e., the loss contributions from each asset. Besides, the proper definition of a measure of risk contribution is a paramount step before actually advancing on the study of risk parity portfolio.

Note that the portfolio volatility is a positively homogenous function, which implies that it can be expressed as

$$\sigma(\boldsymbol{w}) = \sum_{i=1}^{n} w_i \frac{\partial \sigma(\boldsymbol{w})}{\partial w_i}, \tag{1}$$

in fact, the RHS of (1) is

$$\sum_{i=1}^{n} w_i \frac{\partial \sigma(\boldsymbol{w})}{\partial w_i} = \sum_{i=1}^{n} w_i \frac{(\boldsymbol{\Sigma w})_i}{\sqrt{\boldsymbol{w}^T \boldsymbol{\Sigma w}}}. \tag{2}$$

From (2), $w_i \dfrac{\partial \sigma(\boldsymbol{w})}{\partial w_i}$ can be thought as the risk contribution of the i-th asset. Additionally, the risk contributions of every asset in a risk-parity portofolio are the same, therefore

$$w_i \frac{(\boldsymbol{\Sigma w})_i}{\sqrt{\boldsymbol{w}^T \boldsymbol{\Sigma w}}} = w_j \frac{(\boldsymbol{\Sigma w})_j}{\sqrt{\boldsymbol{w}^T \boldsymbol{\Sigma w}}} \ \forall i, j. \tag{3}$$

2 Problem formulae

$$\begin{array}{ll} \underset{\boldsymbol{w},\theta}{\mathsf{minimize}} & F(\boldsymbol{w}) + \lambda_1 ||\boldsymbol{w}||_0 + \lambda_2 R(\boldsymbol{w}, \theta) \\ \mathsf{subject\ to} & \boldsymbol{w}^T \mathbf{1} = 1, \boldsymbol{w} \in \mathcal{W}, \end{array} \tag{4}$$

where

- $F(\boldsymbol{w}) \triangleq \boldsymbol{w}^T(\nu \boldsymbol{\mu} + \Sigma \boldsymbol{w})$