

# Robust Methods of Portfolio Optimization Exemplified by the Swiss Market Index

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## Abstract

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**Keywords:** Portfolio optimization, Robust optimization, Markowitz model, Covariance matrix, Shrinkage, Sharpe ratio

## 1 Introduction

Markowitz' Optimization and other models of Finance require estimates of the expected return, the standard deviation and the correlations of individual assets. These estimates are subject to estimation errors, especially when they are based on short historical time series. This leads to the danger of over-fitting historical data and - in the case of portfolio optimization - of producing portfolios that perform well in backtesting, but perform poorly in the future. To overcome these problems, several approaches have been proposed. This includes Bayesian approaches, including shrinking Estimators for historical returns, volatilities and correlations. It also includes resampling/bootstrapping approaches, where expected returns, volatilities and correlations are modelled as random variables. We will analyze a variety of such approaches, identify those that add most value in the context of investment management, and combine/improve them. The goal is a recommended methodology for computing the strategic asset allocation of pension funds and other institutional investors.

Lange, min. eine halbe Seite

## 2 Data

**SMI and its constituents instead of just SMI for better clarification** For this paper historical data from the Swiss Market Index or (SMI) and its constituents were used, the data are from the period from 23.05.2001 to 15.10.2020. The SMI is the most important stock index in Switzerland and contains the 20 largest companies traded on the Swiss stock exchange. The SMI covers approximately 80% of the total capitalization of the Swiss stock market. It is also a price index, which means that dividends are not included in the index. The SMI is always reviewed twice a year and, if necessary, reassembled. In our case, we use the composition per end of 2018. The reason for the 2018 composition is, that enough historical data for all those companies is available. The results shown in table 2 are calculated with following two equations, daily logarithmic return (1) and volatility (2). [1] [2]

### 2.1 Logarithmic return

**stock returns are generally assumed to be log-normally, not normally distributed** The reason for using logarithmic returns is that the numbers take smaller values than discrete returns. Due to smaller values there is also a smaller variance, which influences fitting positively. For later calculations the risk-free return has to be subtracted from the returns. For the sake of simplicity the risk-free rate is already deducted now. For the risk-free return  $R_f$ , shown in table 1, the LIBOR interest rate is commonly used. Due to several negative incidents in the past the Swiss Average Rate Overnight (SARON) is used for the time period 2014-2020. SARON is a rate that is based on daily transactions and is therefore considerably more transparent compared to the LIBOR. [3] [4]

$$R = R_{ln} - R_f = \ln\left(\frac{x_t}{x_{t-1}}\right) - R_f \quad (1)$$

$R$  = return

$R_{ln}$  = natural logarithmic return

$R_f$  = risk-free rate of return

$x_t$  = closing stock price at time  $t$

Table 1: Average overnight risk-free return per year in %

Year	Rate [%]
2001	3.037
2002	1.083
2003	0.277
2004	0.357
2005	0.722
2006	1.354
2007	2.245
2008	2.035
2009	0.104
2010	0.064
2011	0.049
2012	0.016
2013	-0.005
2014	-0.014
2015	-0.697
2016	-0.736
2017	-0.738
2018	-0.737
2019	-0.729
2020	-0.691

### 2.2 Volatility (standard deviation)

**sample standard deviation instead of standard deviation** Volatility describes the risk of a stock or market index and is a statistical measure of the dispersion of the calculated logarithmic returns (1). In general, the higher the volatility, the riskier the security.

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (R_i - \bar{R})^2}{n-1}} \quad (2)$$

$\sigma$  = volatility (standard deviation)

$R_i$  = each return from the sample

$\bar{R}$  = sample mean return

$n$  = sample size

Table 2: SMI constituents with expected return and volatility

Stock	Return [%]	Volatility [%]
ABB	-0.003	2.947
Adecco	-0.017	2.282
Credit Suisse	-0.044	2.465
Geberit	0.050	1.664
Givaudan	0.042	1.336
Julius Baer	-0.014	2.333
LafargeHolcim	-0.019	2.064
Lonza	0.035	1.825
Nestle	0.021	1.186
Novartis	0.003	1.310
Richemont	0.013	2.074
Roche	0.016	1.438
SGS	0.035	1.669
Sika	0.068	1.975
Swatch	-0.001	2.066
Swiss Life	-0.014	2.417
Swiss Re	-0.021	2.258
Swisscom	0.001	1.105
UBS	-0.032	2.325
Zurich Insurance	-0.017	2.202

### 2.3 Covariance and correlation

The covariance is a numerical measure that describes the linear statistical relationship between two variables. In this case, it represents the strength of the relationship between two return time series. The correlation is the standardized covariance. By definition, the correlation ranges in an interval of  $[-1, 1]$ . A value of 1 or -1 means that the returns of two shares move in the same direction respectively in opposite directions. In Markowitz' portfolio theory the dependency (correlation) of two individual stocks is an important matter, which will be discussed later on in chapter [Markovitz Model].

$$\text{cov}(x, y) = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{n-1} \quad (3)$$

$\text{cov}_{x,y}$  = covariance between  $x$  and  $y$

$x$  = variable  $x$

$y$  = variable  $y$

$n$  = sample size

$$\rho_{i,j} = \frac{cov_{i,j}}{\sigma_i * \sigma_j} \quad (4)$$

$\rho_{i,j}$  = correlation coefficient between return  $i$  und  $j$

$cov_{i,j}$  = covariance between return  $i$  und  $j$

$\sigma_i$  = volatility of return  $i$

$\sigma_j$  = volatility of return  $j$

The matrix in figure 1 shows the correlations of all 20 stocks included in the SMI. By definition, the diagonal values are always 1. As the SMI only contains shares that are traded on the Swiss stock exchange, there is a rather high correlation between the individual companies. The correlation between companies from the same sector is also higher than that between companies from different sectors or which have less in common. From this it can be concluded that economic similarities are reflected in a higher correlation of stock returns. Another way to demonstrate a connection between two companies is the t-statistic which is described in chapter 2.4.1.

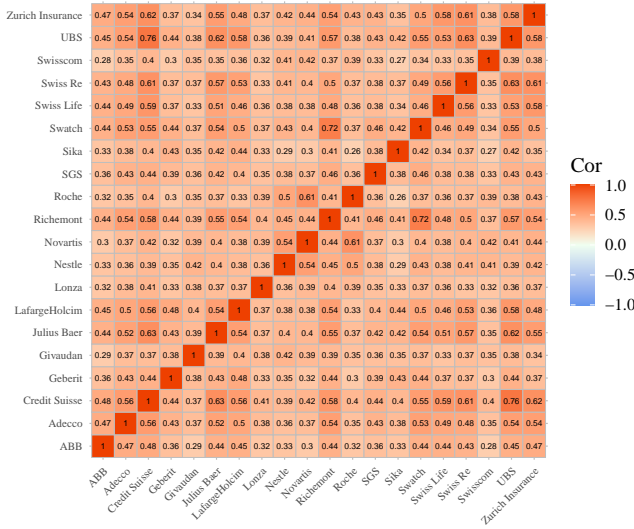


Figure 1: SMI correlation

## 2.4 Statistical key numbers

### 2.4.1 T-statistic

$$t = \frac{\rho_{i,j} * \sqrt{n-2}}{\sqrt{1-\rho_{i,j}^2}} \quad (5)$$

$t$  = t-statistic

$\rho_{i,j}$  = correlation coefficient

$n$  = sample size

To show that each correlation coefficient is significantly different from zero, the t-test is performed for the two shares with the correlation closest to zero, which are Sika and Roche.

$$t = \frac{0.264 * \sqrt{4815-2}}{\sqrt{1-0.264^2}} = 18.951 \quad (6)$$

The probability of measuring this correlation would be 0, IF the true correlation was zero. So we can be sure that the observed correlation is not just an estimation error. The students t-distribution with 4815 degrees of freedom tells us that the probability of getting a test-statistic in the interval of  $[-18.951, 18.951]$  equals 1. Therefore, the probability of getting a test-statistic out of the interval equals 0. Since the P-value is smaller than 0.05, we can reject the null hypothesis. There is sufficient statistical evidence at the  $\alpha = 0.05$  level to conclude that there is a significant linear relationship between Sika and Roche.

### 2.4.2 Standard error of expected return

In statistics the standard deviation of the sampling distribution is known as the standard error and it provides a statement about the quality of the estimated parameter. The more individual values there are, the smaller is the standard error, and the more accurately the unknown parameter can be estimated. The standard error for the expected return and the volatility are explained in the following two chapters.

$$\sigma_R = \frac{\sigma}{\sqrt{n}} \quad (7)$$

$\sigma_R$  = standard error

$\sigma$  = standard deviation of sample

$n$  = sample size

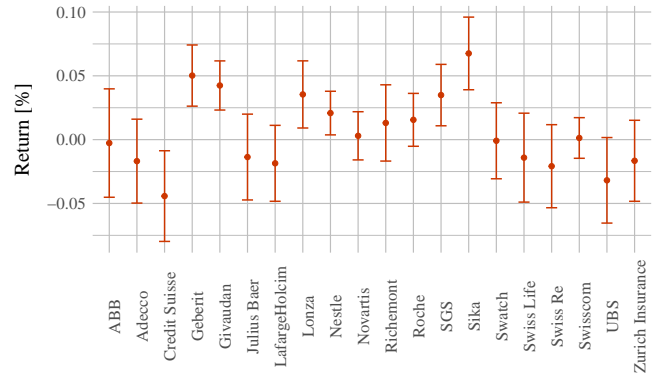


Figure 2: Expected mean return with standard error

In the plot above (figure 2) you can see the logarithmic mean return with the standart errors for each stock. It is easy to see that stocks such as *Swisscom* and *Nestle* with low volatility also have a lower standard error. As well *ABB* and *Credit Suisse* show a high volatility and accordingly have higher values for the standard error. Figure ?? and table 2 can therefore be compared well together.

### 2.4.3 Standard error of volatility (standard deviation)

This formula is an approximation for the standard error of volatility, which is appropriate for  $n > 10$ . [8]

$$\sigma_{\sigma} = \sigma * \frac{1}{\sqrt{2 * (n - 1)}} \quad (8)$$

$\sigma_{\sigma}$  = standard error

$\sigma$  = standard deviation

$n$  = sample size

As shown in table 3 the values of the standard error of volatility are much lower as the one of the mean returns. This behavior will be clearly visible later in the chapter bootstrap. Furthermore, we will neglect the values for any further calculations. **wir können die Volatilität praktisch exakt schätzen, als vernachlässigen wir den Schätzfehler im folgenden**

Table 3: Standard error of volatility

Stock	Standard error [%]
ABB	0.03004
Adecco	0.02325
Credit Suisse	0.02513
Geberit	0.01695
Givaudan	0.01362
Julius Baer	0.02378
LafargeHolcim	0.02104
Lonza	0.01860
Nestle	0.01208
Novartis	0.01335
Richemont	0.02113
Roche	0.01466
SGS	0.01701
Sika	0.02012
Swatch	0.02106
Swiss Life	0.02463
Swiss Re	0.02301
Swisscom	0.01126
UBS	0.02370
Zurich Insurance	0.02244

### 3 Review of classical markovitz optimization

**Markowitz optimization assumes that the return ... is known.** Modern portfolio theory is a theory that deals with the construction of portfolios to maximize the expected return based on a given market risk. Markowitz' portfolio theory shows that efficient risk reduction is only possible if the extent of the correlation of the individual investments is taken into account when putting together the portfolio. Risk reduction through risk diversification is a key finding of the aforementioned portfolio theory. Harry Markowitz pioneered this theory in his article "Portfolio Selection". The main point is that the risk and return characteristics of an investment should not be considered in isolation, but should be evaluated according to how the investment affects the risk and return of the overall portfolio. It is shown that an investor can construct a portfolio of multiple assets that maximizes returns for a given level of risk. Similarly, an investor can construct a portfolio with the lowest possible risk at a desired level of expected return. Based on statistical measures such as volatility and correlation, the performance of an individual investment is less important than how it affects the portfolio as a whole. [5]

The return, volatility and covariance matrix is known. The portfolio volatility is accordingly given as a function of the covariance matrix and the weight vector and it can be minimized as much as desired by sufficient diversification. Also the sum of all weights equals 1. The portfolio weights being searched for are described by the vector  $\vec{w} = (w_1, \dots, w_n)$ . The weights that are calculated are those weights that match the portfolio with minimal volatility (variance) to a given expected portfolio return  $R_p$ . This is a linear optimization problem, as well a formulation of the fundamental problem of balancing return and risk. Furthermore, negative weightings are defined as short sales. [9]

$$\text{minimize} : \frac{1}{2} \vec{w}^T \Sigma \vec{w} \quad (9)$$

With the following two constraints:

$$I. \quad 1 = \vec{w}^T \vec{1} \quad (10)$$

$$II. \quad R_p = \vec{w}^T \vec{R} \quad (11)$$

According to the method of the Lagrange Multiplier, the Lagrange function is formed with the factors  $\lambda$  and  $\epsilon$ .

$$L(\vec{w}) = \min \frac{1}{2} \vec{w}^T \Sigma \vec{w} - \lambda (\vec{w}^T \vec{R} - R_p) - \epsilon (\vec{w}^T \vec{1} - 1) \quad (12)$$

The disappearance of the gradient is the necessary condition for a minimum. This is together with the two constraints ((10), ((11) an inhomogeneous linear system of equations of the dimension  $n + 2$  with  $n + 2$  variables. The solution is a known standard problem from linear algebra.

$$\nabla_w L = \Sigma \vec{w} - \lambda * \vec{R} - \epsilon * \vec{1} = 0 \quad (13)$$

$\vec{w}$  = weight vector

$\Sigma$  = covariance matrix

$\vec{1}$  = all-ones vector

$\vec{R}$  = return

$R_p$  = total portfolio return

### 3.1 Problem

**overfitting** Markowitz' optimization only works under certain assumptions and conditions. Apart from the assumptions concerning particular investors and the capital market, which will not be discussed here, there are also mathematical assumptions that must be made. First assumption is an approximate normal distribution of log-returns. Since it is a stock price over 20 years, it is almost impossible to describe the log-returns as normally distributed. In historical data over a long period of time there are strong stock price movements which can be clearly identified as outliers and therefore reject the assumption of an exact normal distribution. However, a quantile-quantile plot can be used to show that the majority of the data is normally distributed. The y-axis describes the quantiles of the data and the x-axis the quantiles of the normal distribution. The majority of the data is linear near the middle which speaks for a normal distribution. At both ends clear deviations and individual outliers are to be recognized, which is a strong indication of a heavy left tail. This behavior results from stronger stock price volatilities, as they occur for example in times of crisis and uncertain markets.

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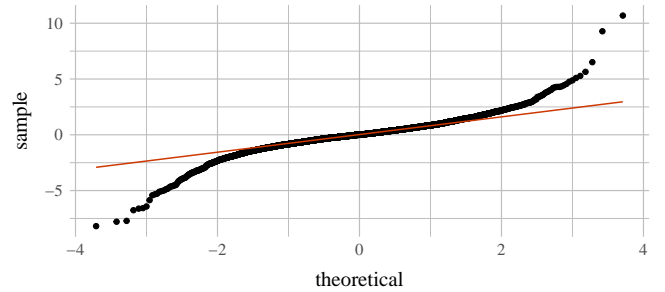


Figure 3: Q-Q plot of daily log-returns for Swisscom

A second condition applies to the linear relationship of the stocks. The log-returns cannot show a perfect correlation between themselves, neither negative nor positive. This is described by a correlation coefficient of -1 respectively 1. If the determinant is 0, the system cannot be solved exactly. This situation occurs if shares have a correlation coefficient of 1 or -1. The system must be uniquely solvable to form the inverse of the covariance matrix  $\Sigma^{-1}$ .

### 3.2 Minimum variance portfolio

The Minimum Variance Portfolio, or MVP for short, describes the portfolio of all possible weightings with the minimum volatility. Since only the volatility is minimized, constraint II. is not included in the equation.

$$\vec{w}_{mvp} = \frac{1}{\vec{1}^T \Sigma^{-1} \vec{1}} * \Sigma^{-1} \vec{1} \quad (14)$$

$\vec{w}_{mvp}$  = weights

$\vec{1}$  = all-ones vector

$\Sigma$  = covariance matrix

Table 4: Weights of minimum variance portfolio

Stock	Weight
ABB	-0.016
Adecco	-0.013
Credit Suisse	-0.057
Geberit	0.096
Givaudan	0.164
Julius Baer	-0.023
LafargeHolcim	-0.007
Lonza	0.026
Nestle	0.233
Novartis	0.105
Richemont	-0.039
Roche	0.068
SGS	0.072
Sika	0.046
Swatch	-0.001
Swiss Life	-0.004
Swiss Re	-0.001
Swisscom	0.389
UBS	-0.019
Zurich Insurance	-0.019

It is clear to see that returns which have a negative value also have a negative weighting. In practice, this would lead to a short selling. : **negative return bedeutet nicht unbedingt negatives Gewicht und umgekehrt. Es kommt noch auf die Korrelationen an**

### 3.3 Tangency portfolio

The tangency portfolio results from the tangent of the capital market line and the efficient frontier, which will be shown more detailed in chapter Efficient Frontier. The capital market line is an important component of the Capital Asset Pricing Model. The slope of the capital market line indicates how much more return is expected per additional volatility, therefore a steeper slope of the capital market line gives a better Sharpe ratio. This is exactly the situation when the capital market line is tangential to the efficient frontier. Therefore, the best possible diversified portfolio results from the weightings of the tangency portfolio.

In this paper the MVP and TP serve as useful reference points to compare the Sharpe ratio of different optimizations. The tangency portfolio is often referred to in the literature as the market portfolio. In the equation for the capital market line, shown as equation (15), the expected return of the market portfolio respectively the tangency portfolio is written as  $R_{tp}$ .

*Capital Market Line:*

$$R_P(\sigma_P) = R_f + \frac{R_{tp} - R_f}{\sigma_{tp}} * \sigma_P \quad (15)$$

$R_P$  = total portfolio return as a function of  $\sigma_P$

$R_f$  = return of risk-free asset

$R_{tp}$  = return of tangency portfolio

$\sigma_P$  = total portfolio volatility

$\sigma_{tp}$  = tangency portfolio volatility

*Tangency Portfolio:*

$$\vec{w}_{tp} = \frac{1}{\vec{1}\Sigma^{-1}(\vec{R} - R_f\vec{1})} * \Sigma^{-1}(\vec{R} - R_f\vec{1}) \quad (16)$$

$\vec{w}_{tp}$  = weights

$\vec{1}$  = all-ones vector

$\Sigma$  = covariance matrix

$\vec{R}$  = return

Table 5: Weights of tangency portfolio

Stock	Weight
ABB	-0.001
Adecco	-0.190
Credit Suisse	-0.307
Geberit	0.533
Givaudan	0.592
Julius Baer	-0.085
LafargeHolcim	-0.344
Lonza	0.222
Nestle	0.339
Novartis	-0.321
Richemont	0.200
Roche	0.165
SGS	0.301
Sika	0.505
Swatch	-0.194
Swiss Life	-0.029
Swiss Re	-0.062
Swisscom	-0.143
UBS	-0.141
Zurich Insurance	-0.038

### 3.4 Efficient Frontier

The efficient frontier is a set of points that extends in the return-volatility diagram (figure 4) between the minimum variance portfolio at the left edge of the reachable area and the tangency portfolio. All possible weightings of portfolios on this line are efficient because they have the maximum return at a defined level of volatility.

$$\vec{w}_{tp} = \alpha * \vec{w}_{mvp} + (1 - \alpha) * \vec{w}_{tp} \quad (17)$$

$\vec{w}_{tp}$  = weights

$\alpha$  = scale factor

$\vec{w}_{mvp}$  = weights of minimum variance portfolio

$\vec{w}_{tp}$  = weight of tangency portfolio

$$R_P = \vec{w}^T * \vec{R} \quad (18)$$

$R_P$  = total portfolio return

$\vec{w}$  = weights

$\vec{R}$  = mean return

$$\sigma_P = \sqrt{\vec{w}^T \Sigma \vec{w}} \quad (19)$$

$\sigma_P$  = total portfolio volatility

$\vec{w}$  = weights

$\Sigma$  = covariance matrix

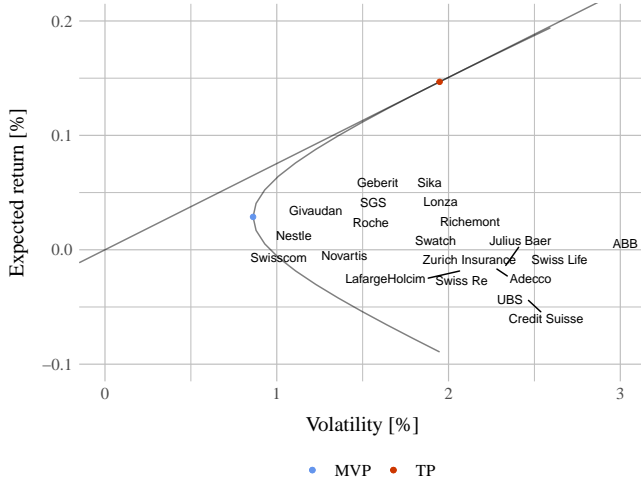


Figure 4: Efficient frontier with stocks

**text umschreiben, SMI nicht erwahnen** In figure ?? it is clearly visible that the SMI shows a significantly higher return with almost the same volatility and vice versa. This leads to a larger in sample Sharpe ratio of the SMI compared to the groups. The reason for a higher in sample Sharpe ratio of the individual stocks is due to the higher amount of data. There are 20 stocks in the SMI for which the weighting can be optimized, but only four in the grouping. However, it will become apparent in chapter ?? that this no longer applies to the out of sample Sharpe ratio, which in our case is much more important than the in sample.

### 3.5 Sharpe ratio

The Sharpe ratio measures the performance of an investment which means the return of an investment compared to its risk. Generally, the greater the value of the Sharpe ratio, the more attractive the risk-adjusted return. In practice, the value of the Sharpe Ratio is not only positively received. In this paper, however, we will rely on the Sharpe ratio because it is a key figure by which performance can be measured. It is calculated by the average return earned in excess of the risk-free rate per unit of volatility. In this case it is the natural logarithmic return per day  $R$  divided by  $\sigma$ .  $R$  is already calculated in equation (1). [6] [7]

$$\text{Sharperatio} = \frac{R_{ln} - R_f}{\sigma} = \frac{R}{\sigma} \quad (20)$$

$R$  = natural logarithmic return per day

$R_{ln}$  = mean logarithmic return

$R_f$  = risk-free rate of return

$\sigma_i$  = volatility of return

Before any weighting of a portfolio is optimized, the Sharpe ratio of the SMI is calculated. This is done by weighting all stocks equally, 1/20 each, and then applying the weightings to the actual returns of the historical data. This results in a Sharpe ratio of XX. Note that the Sharpe ratio is annualized, which means that it is multiplied by  $\sqrt{252}$ . As mentioned above, the Sharpe ratio is used as a measure of the optimization and robustness. A robust optimization leads to a lower volatility which results in a higher Sharpe ratio. The higher the value the better the optimization.

## 4 Methodology

### 4.1 Grouping

Grouping of stocks is an approach to reduce the noise given by individual assets and therefore increase the Sharpe ratio. A more qualitative approach and a mathematical approach are applied in this paper.

#### 4.1.1 Grouping by industry

An intuitive approach to group stocks is to do so by industry. In the case of the SMI the stocks can be grouped as follows resulting in four groups:

**Consumer:** Adecco, Nestle, Richemont, Swatch, Swisscom

**Finance:** Credit Suisse, Julius Baer, Swiss Life, Swiss Re, UBS, Zurich Insurance

**Industrial:** ABB, Geberit, Givaudan, LafargeHolcim, SGS

**Pharma:** Lonza, Novartis, Roche, Sika

To obtain the group returns, the daily mean value of the daily returns of all stocks within the group is calculated. Therefore, the group returns are a time series equaling the length of the historical data and all stocks within the group are weighted equally. From this time series the mean returns, volatility and correlation matrix can be calculated from which the first two are shown in table 6.

Table 6: Mean returns and Volatility of groups

Group	Return [%]	Volatility [%]
Consumer	0.003	1.342
Finance	-0.024	1.902
Industrial	0.021	1.397
Pharma	0.030	1.189

#### 4.1.2 Grouping with cluster analysis

In a second approach the grouping is made by sorting the euclidean distance. The group formation is based on the similarity measure, which is calculated here with Euclidean distances between two correlation coefficients. The formula is illustrated below.

$$d_{1,2} = \sqrt{\sum_{j=1}^p (x_1 - x_2)^2} \quad (21)$$

$d_{1,2}$  = euclidean distance between stock 1 and stock 2

$x_1$  = stock 1

$x_2$  = stock 2

The Formula takes all column values of a first stock and calculates the squared difference to the column values of the second stock. These 20 values are summed up and the root is extracted from them. The result is the distance between the two stocks, and if it is done for all 20 stocks it results in a distance matrix. The algorithm sorts the values of the distance matrix with the method "complete". The first step is (independent of methods) grouping the two stocks with the smallest distance. The second step is comparing the created group to single stocks or groups. The distance between a group  $(x_1, x_2)$  and a stock  $x_3$  is the maximum distance between a stock of the group and the single stock.  $d(\{x_1, x_2\}, x_3) = \max(d(x_1, x_3), d(x_2, x_3))$ .

For distances between groups, the maximum value is taken from the distances between each object of a group with the object of

another group. For distance between group  $(x_1, x_2)$  and  $(x_3, x_4)$  with two objects (stocks) applies  $d(\{x_1, x_2\}, \{x_3, x_4\}) = \max(d(x_1, x_3), d(x_1, x_4), d(x_2, x_3), d(x_2, x_4))$ . The third step is repeating the procedure with the new created distance matrix until only two groups remain. The outcome is a dendrogram which is also part of the illustration in figure 5. It can be seen that the first step of grouping is the connection which is drawn lowest. [10] **die farben sind die distanzen**

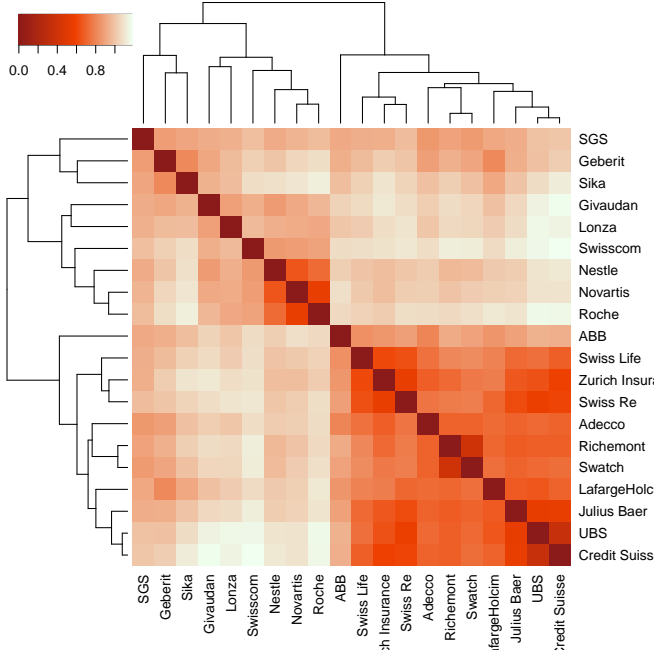


Figure 5: Grouped by euclidean distance for stocks

**Group 1:** ABB, Adecco, Credit Suisse, Julius Baer, LafargeHolcim, Richemont, Swatch, Swiss Life, Swiss Re, UBS, Zurich Insurance

**Group 2:** Givaudan, Lonza, Nestle, Novartis, Roche, Swisscom

**Group 3:** Geberit, SGS, Sika

unterschiedliche gruppengroessen beschreiben und was das bedeutet eine 3er und eine 11er gruppe eher wenig sinnvoll

plot von eingefarbten gruppen zeigen analog shiny

Table 7: groups with expected return and volatility

Group	Return [%]	Volatility [%]
Group 1	-0.015	1.752
Group 2	0.020	0.978
Group 3	0.051	1.371

Further methods like k-means or PAM etc. could be considered but are not discussed in this paper.

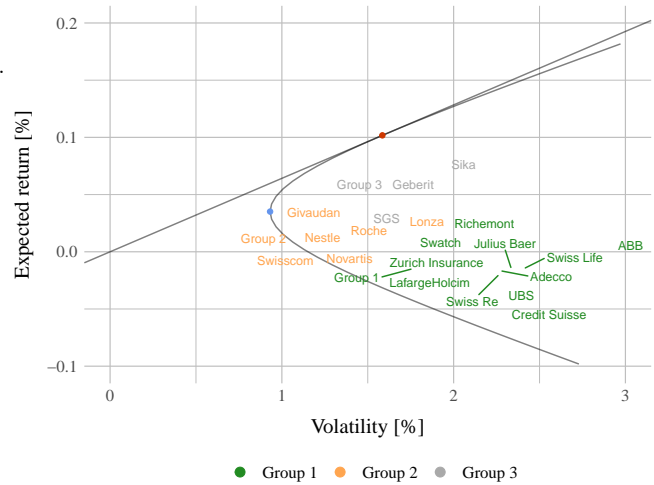


Figure 6: Efficient frontier with stocks

## 4.2 Bootstrap

Bootstrapping is a statistical method of resampling. It allows to create a new sample with drawing from the existing sample. With 100 or more resampled data, each mean and variance of the samples can be analyzed. This method can be used to draw conclusion about a population from its sample.

In this method a bootstrap process was made to analyze the robustness of the tangency portfolio weights when resampling all historical returns.

**Step 1** The dates of the historical data is being sampled (using `sample()`) in the same dimension, with replacing included. In other words, the row numbers of the historical is being sampled. With the argument `replace = TRUE` ensures, that certain dates, respectively rows can occur multiple times. If replacing would not be included in the sampling method, the correlation matrix would remain constant to the one of the original data.

**Step 2** A new dataset is created with the new sorted dates or row numbers. From each sampled date or row, the corresponding returns of each stock are added to the new dataset, consequently maintaining the daily differences between stocks. This new dataset is one Bootstrap sample.

**Step 3** From the Bootstrap sample, new mean return of each stock and the corresponding covariance matrix is being calculated. Those two variables are now used as input of the optimization function to calculate minimum variance portfolio, tangency portfolio of the stocks. The weights of this two portfolios are now being saved in a mvp-weights-matrix and a tp-weights-matrix.

**Step 4** Repeat the steps 1-3 100 times. This results in two matrices with each 100 rows of weights. Those MVP and TP weights can now be compared and analyzed. Additionally, the standard deviation of the resulting weights over those number of bootstrap samples can be studied. The standard deviation is computed with the 84-Quantil minus the 50-Quantil to achieve a more robust result, because this calculation is less vulnerable to outliers.

: the extended cloud of red dots demonstrates the huge estimation error of the risk and return of the TP



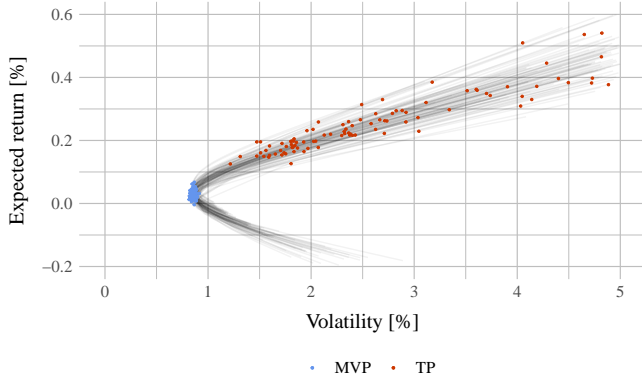


Figure 7: Bootstrap samples efficiency frontier

In figure 7 all bootstrap samples can be seen with their minimum variance portfolio, tangency portfolio and their efficiency frontier. Noticeable is the variance of the tangency portfolio in comparison to the minimum variance portfolio. This is due to the high standard errors of returns. Since the return is included in the calculation of the TP, but not in the MVP, a larger deviation can be seen.

### 4.3 Cross validation

Cross validation is a model validation technique for assessing how a model will generalize to an independent data set, i.e., in another time period. The data set is split into a training set used to train the model and a test set to evaluate its performance. This procedure is replicated multiple times until all data was once in the test set.

In this case, the historical data is split into five sections and consequently five models are trained as depicted in figure 8. The gray sections are the training sets and the red ones the test sets.

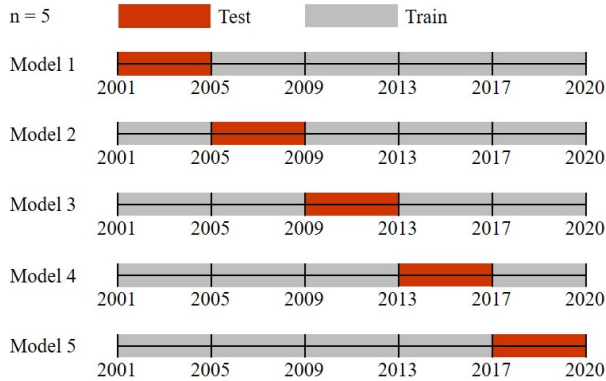


Figure 8: Cross validation training and test sets

In the case of the Markovitz model, the mean returns and covariance matrix of the training set are used to calculate the asset weights. These weights are then applied to the test set asset returns according to (22).

$$R_{i,w} = \vec{w}^T * \vec{R}_i \quad (22)$$

$R_{i,w}$  = weighted return day  $i$

$\vec{w}$  = asset weights

$\vec{R}_i$  = asset returns day  $i$

At the end of the cross validation, all five test sets are combined into one time series consisting of the daily weighted returns and equaling the length of the historical data. This time series is completely out of sample and is used to calculate the Sharpe ratio and hence measure the performance of the model. The implicit assumption behind this procedure is that the returns at different points in time are independent random variables (and, in particular, do not “remember” the past).

It is to note that the training and test sets of the five sections vary significantly in some cases. To give one cause for this, the financial crisis from 2007–2008 can be looked at. During this period, most assets yielded negative returns. For example, model two in figure 8 includes this time period as part of the test set and model four of the training set. This results in fluctuating asset weights across the five models which are illustrated in figure 9.

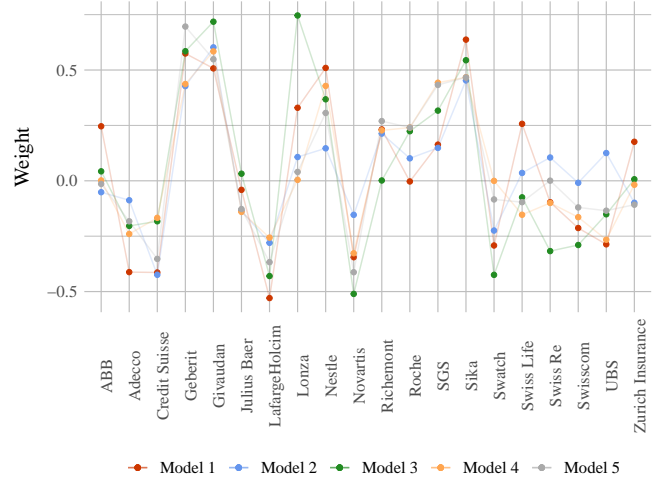


Figure 9: Tangency portfolio weights by model

Stocks like *Julius Baer* and *Sika* have similar weights across all models while *Lonza* for example varies significantly.

## 4.4 Shrinkage

Shrinkage is an approach with the goal to increase the out of sample Sharpe ratio by altering the inputs of the Markovitz optimization, namely the mean returns and covariance matrix.

### 4.4.1 Shrinkage of mean returns

The shrunk mean returns are calculated as in (23).

$$\vec{R}(\lambda) = \lambda * \vec{R} + (1 - \lambda) * \vec{\bar{R}} \quad (23)$$

$\vec{R}(\lambda)$  = mean returns as a function of  $\lambda$

$\lambda$  = shrinkage factor

$\vec{R}$  = mean returns

$\vec{\bar{R}}$  = mean of mean returns

When the shrinkage factor  $\lambda$  is set to one, the mean returns remain unchanged. When it is decreased from one towards zero, the mean returns converge towards their mean value. Once the shrinkage factor  $\lambda$  is zero and therefore all mean returns are equal, the tangency portfolio (16) obtains the same asset weights as the minimum variance portfolio (14).

There is an important constraint in mean returns shrinkage. Take the scaling factor of the tangency portfolio (16) and replace  $\vec{R}$  with (23) as in (24).

$$\vec{w}_{tp, sf} = \frac{1}{\vec{1}\Sigma^{-1}(\lambda * \vec{R} + (1 - \lambda) * \vec{\bar{R}})} \quad (24)$$

It is clear that for some value of  $\lambda$  the denominator becomes zero. Computationally, it is already problematic if the denominator is close to zero. When setting the denominator equal to zero, the value of  $\lambda$  at the zero crossing can be calculated as in (25).

$$\lambda_0 = \frac{-\vec{1}\Sigma^{-1}\vec{\bar{R}}}{\vec{1}\Sigma^{-1}\vec{R} - \vec{1}\Sigma^{-1}\vec{\bar{R}}} \quad (25)$$

If the zero crossing is in the shrinkage interval of  $[0, 1]$ , this results in extreme asset weights. As the denominator approaches zero, the scaling factor (24) becomes very large which carries over to the weights. To illustrate this effect, the weights of the five cross validation models from figure 8 are plotted as a function of  $\lambda$  in figure 10.

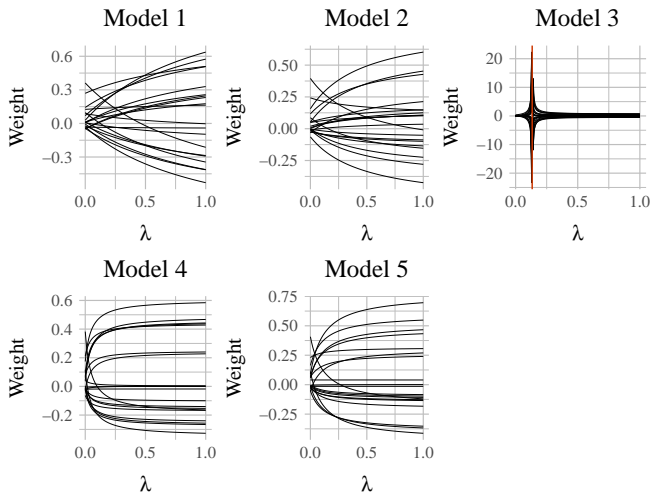


Figure 10: Tangency portfolio weights by model as a function of  $\lambda$

Model three shows such extreme asset weights ranging from about -20 to 20. The asymptote is visualized as a vertical red line. It is not optimal when such extreme weights are applied to returns as done in the cross validation. This can negatively influence further calculations and lead to undesired results. The other four models do show asset weights in a normal scale.

The scaling factor as a function of  $\lambda$  is shown in figure 11.

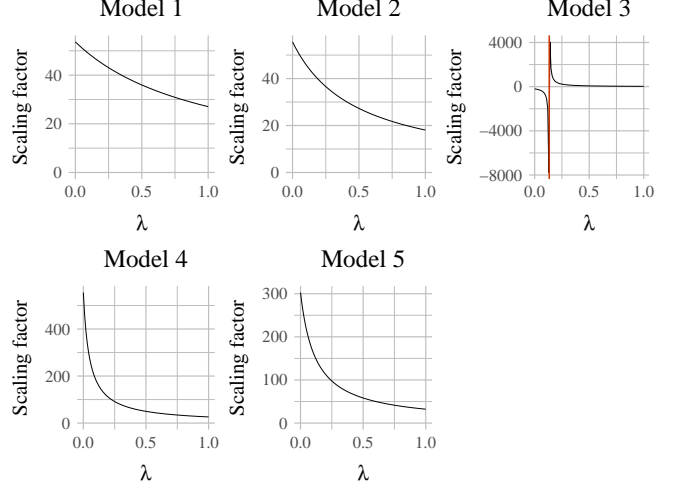


Figure 11: Tangency portfolio weights scaling factor by model as a function of  $\lambda$

The zero crossing of the scaling factor in model three can be seen clearly. When working with mean returns shrinkage one has to be aware of this behavior.

### 4.4.2 Shrinkage of correlation matrix

The shrunk correlation matrix is calculated as in (26).

$$\rho_{i,j}(\epsilon) = I_{i,j} + \epsilon * \tilde{\rho}_{i,j} \quad (26)$$

$\rho_{i,j}(\epsilon)$  = correlation matrix at  $i,j$  as a function of  $\epsilon$

$\epsilon$  = shrinkage factor

$I_{i,j}$  = identity matrix at  $i,j$

$\tilde{\rho}_{i,j}$  = correlation matrix with diagonal zero at  $i,j$

When the shrinkage factor  $\epsilon$  is set to one, the correlation matrix remains unchanged. When it is decreased from one towards zero, the correlation coefficients converge towards zero, except for the diagonal which always remains one. As the tangency portfolio (16) requires the covariance matrix, it is first standardized to the correlation matrix according to (4), then shrunk with (26) and scaled up to the covariance matrix again according to (4).

There can also arise the case where for some shrinkage factor  $\epsilon$  the scaling factor denominator of the tangency portfolio (16) becomes zero or close to zero. However, this is not further elaborated on.

## 5 Results

In this section the different approaches which were described in chapter 4 methodology are applied on the historical data. Section 5.1 optimizes the entire SMI with 20 stocks. Section 5.2 includes the optimization of the different grouping methods. Section 5.3 applies the shrinkage.

### 5.1 Sharpe ratio of SMI as a portfolio

Table 8: Sharpe ratio

	In sample	Out of sample
SMI	1.196	0.489

The table 8 describes the results of the cross-validation (4.3) method of 20 stocks. As it can be seen and might be expected the in-sample performs much better than the out-of-sample. This is related to the fact that in-sample has the same testing section as training section. which logically results in a high performance considering that the testing data is part of the previous optimized training data. Contrary to the out-of-sample where the testing section is not included in the training section. If a stock behaves differently in this one test section compared to the 4 training sections flowing into the optimization, this stock can be easily over- or underfitted. This leads to a worse Sharpe ratio than the in-sample one. The consequences that can be drawn from this insight is, that firstly the in-sample Sharpe ratio should always be higher than the out-of-sample Sharpe ratio. Secondly, if the two Sharpe ratio differ clearly, the returns of each model differ as well. That means if we have similar returns over 20 years, in- and out-of-sample Sharpe ratio should be closer together, which is not the case here.

In the following two illustrations part of the bootstrap results can be seen. In the graphics the mean weights and the standard deviation over the 100 samples are shown. Figure 12 shows the MVP weights of the 20 stocks and figure 13 the TP weights.

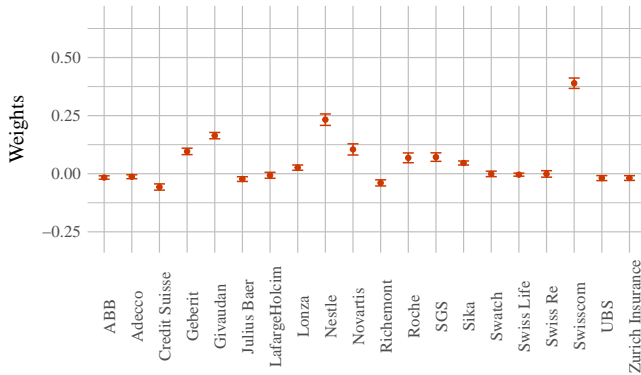


Figure 12: MVP weights with standard error

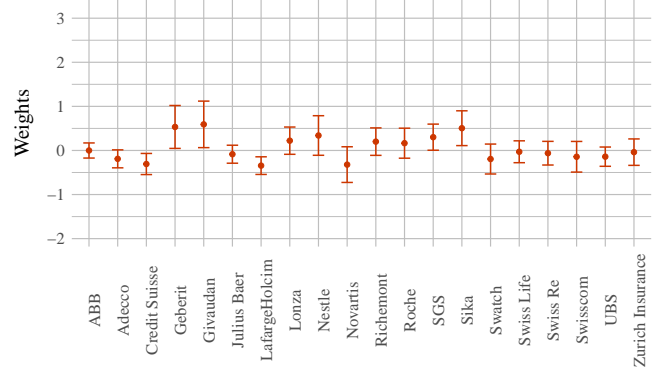


Figure 13: tangency portfolio weights with standard error

### 5.2 Results of grouping and bootstrapping method

Table 9: Sharpe ratio

	In sample	Out of sample
Group by industry	0.811	0.608
Groups by correlation	1.019	0.991

Here in table 9 the Sharpe ratio of in- and out-of-sample of the formed groups are presented. The first observation is, that the in-sample value decreased after the grouping method was applied. Optimizing 20 Parameters lead to higher possible variations, therefore this portfolio performs well in-sample. Between the two grouping methods though, the difference in parameters is too small to affect the Sharpe ratio in the way as mentioned before. Other impacts are more significant to the outcome. However the SMI should have the highest in-sample Sharpe ratio because of the numerous parameters.

Nevertheless, the out-of-sample Sharpe ratio has increased. This is because with forming groups, stock returns of companies within the group are being averaged. Consequently, the group return is more stable over the whole time period. As described more detailed in results 5.1, this leads to a better performance respectively a better Sharpe ratio. Therefore, also in- and out-of-sample are here closer together.

In chapter 4.1.2, cluster analysis is used to optimize the group collocation. Hence, more correlating stocks are put together to have a more diversifying portfolio. Consequently, the correlation between the groups shrunk in comparison to the correlation between the groups by industry. Further seen in table 9, the Sharpe ratio of the new grouping method is much higher than grouping by industries which is a logical consequence of the diversification. In reality though, it is unlikely to invest in such a compiled portfolio, however it was made to find a method for grouping, which affects the Sharpe ratio positively.

Below the second part of bootstrapping results is depicted. As mentioned in section 5.1, the same is shown for the groups. Figure 14 illustrates the MVP weights and figure 15 the TP weights.

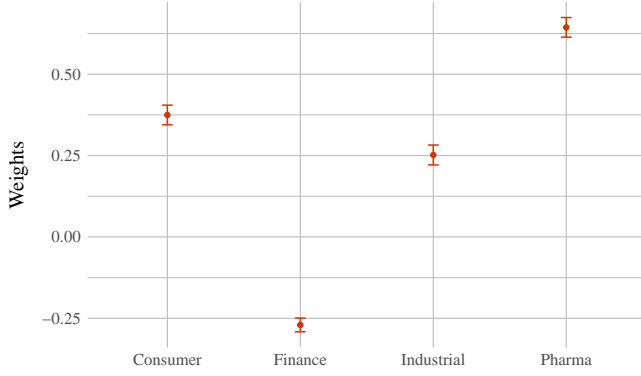


Figure 14: MVP weights with standard error

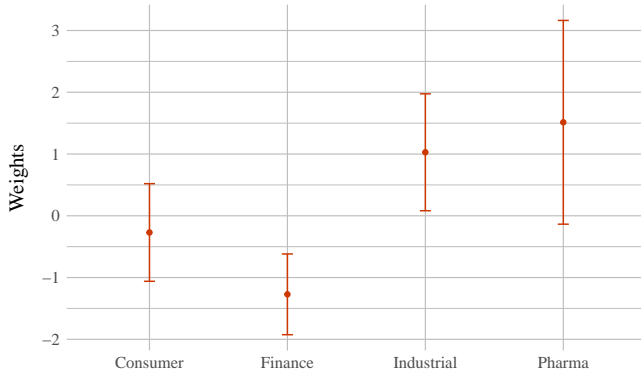


Figure 15: Tangency portfolio weights with standard error by group

As it is obvious to see and also visualized in figure 7, is that TP weights have a higher standard deviation than MVP weights. That means the TP is more sensible to changes of returns than the MVP is. If the equation (14) of MVP and the equation (16) of TP are considered, the MVP does not depend on the returns directly. Consequently different returns samples have not a large impact on the MVP. The small differences arise from the varying covariance matrix. But it can also be noticed that this matrix has not large deviations following the standard deviation of the MVP. Therefore bootstrap sampling of the returns does not influence the covariance matrix as much as the returns itself.

## 5.3 Results of shrinkage method

### 5.3.1 Shrinkage factors analyzed separately

The Sharpe ratio can be visualized as a function of the shrinking factor. Figure 16 shows such a plot for the mean returns shrinkage factor.

When looking at the SMI curve it can be seen that the highest Sharpe ratio is achieved with a shrinkage factor of about 0.05. This means that the mean returns are shrunk almost completely and therefore there is not much trust in them. This result is plausible, as the returns are very noisy. Further can be seen that the Sharpe ratio has a sharp bend and drop below zero. This is caused by the close to zero denominator of the tangency portfolio (16) as described in chapter 4.4

For the two group curves the result is inverted. As the grouping of the stocks already reduces the noise significantly, shrinkage does

show almost no improvement over non-shrunk mean returns. The groups by correlation do show a significantly higher Sharpe ratio than the grouping by industry and it is also higher than the one of the SMI.

o Single stock optimization: clear maximum for return shrinking factor 0.05. If past returns are taken too seriously (higher shrinking factor), the out-of-sample Sharpe drops. If they are not considered at all (shrinking factor 0), it also drops. We see that they can be trusted to about 5%. o Single stock optimization with 5% return shrinking is better out-of-sample than the best result from forming groups o Single stock optimization: clear maximum for correlation shrinking factor 0.4. If past correlations are taken too seriously (higher shrinking factor), the out-of-sample Sharpe drops. If they are taken less seriously (shrinking factor 0), it also drops. We see that they can be trusted to about 40%. o Single stock optimization with 40% correlation shrinking is better out-of-sample than the best result from forming groups

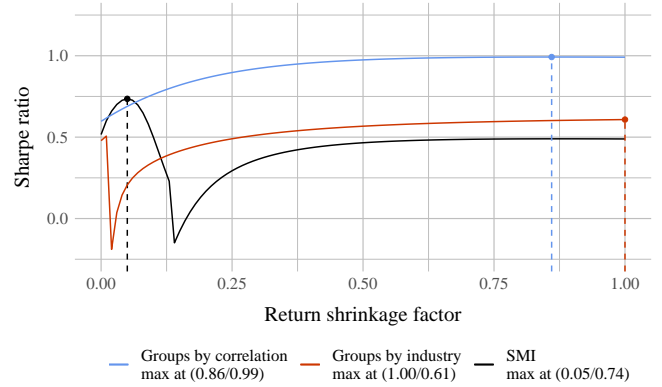


Figure 16: Sharpe ratio as a function of return shrinking factor

Figure 17 shows the same plot for the correlation shrinkage factor. The highest Sharpe ratio for the SMI is achieved with a shrinkage factor of about one third. This result is similar to the one obtained in figure 16 as for the groups shrinkage does not have a great impact. The highest Sharpe ratio is again achieved by the groups by correlation.

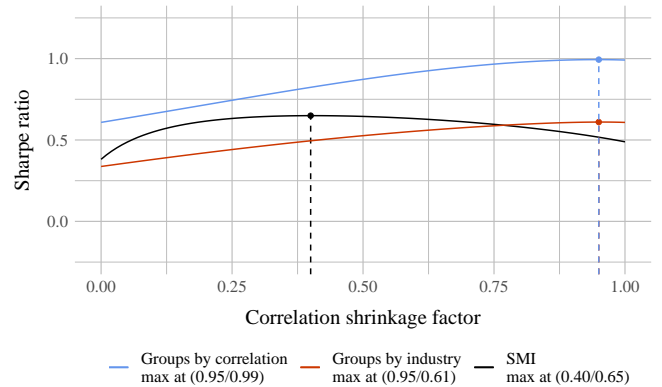


Figure 17: Sharpe ratio as a function of correlation shrinking factor

### 5.3.2 Shrinkage factors analyzed simultaneously

A further visualization is a three dimensional plot where the Sharpe ratio is plotted as a function of both shrinkage factors. The darker the area, the higher the Sharpe ratio.

Figure 18 shows such a plot for the SMI. In the lower and left part of the plot the contour lines are very chaotic which is caused by the Sharpe ratio dropping quickly and below zero. The highest Sharpe ratio is achieved with a mean returns shrinkage factor of about 0.05 and a correlation shrinkage factor of close to one. This matches the result of the previous plots where the mean return shrinkage is better at improving the Sharpe ratio.

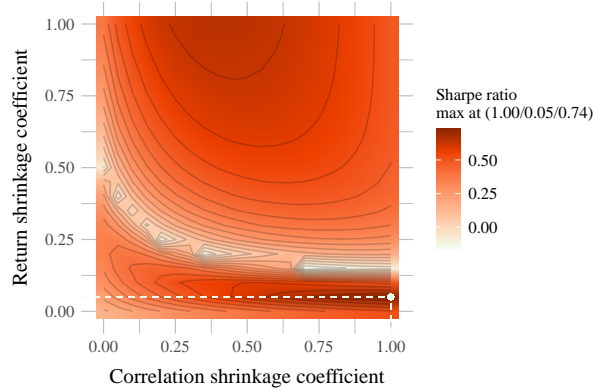


Figure 18: SMI Sharpe ratio as a function of return and correlation shrinking factor

Figure 19 shows the three dimensional plot for the groups by industry and figure 20 for the groups by correlation. Both plots are very similar in their general structure. The groups by industry also show a drop in Sharpe ratio in the lower portion while the groups by correlation does not. Overall, latter do show a Sharpe ratio which is about 0.3 greater than the groups by industry.

**simultaneous shrinking: if returns are shrunk to 5%, then correlation shrinking does not add more value**

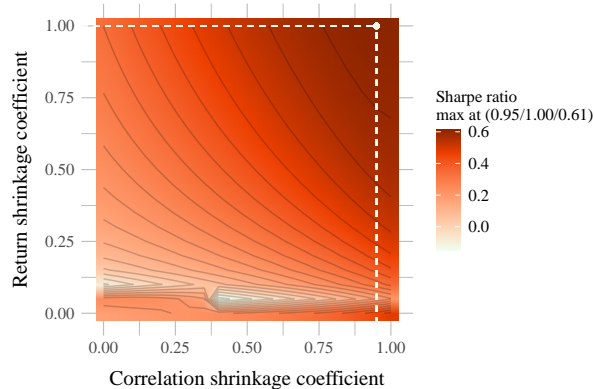


Figure 19: Groups Sharpe ratio as a function of return and correlation shrinking factor

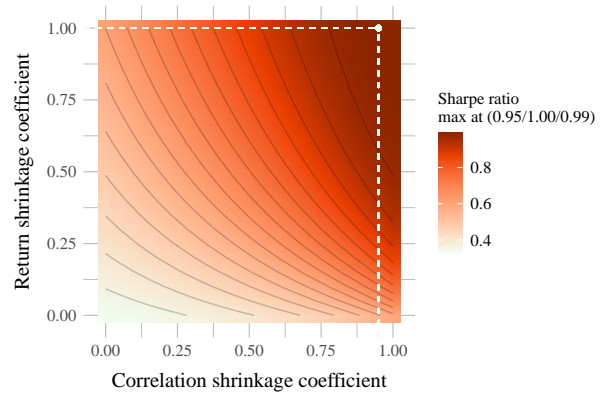


Figure 20: Groups Sharpe ratio as a function of return and correlation shrinking factor

Table 10 provides an overview over all Sharpe investigated Sharpe ratios, namely in sample (IS), out of sample (OS) and out of sample with applied Shrinkage (OS Shrinkage).

Table 10: Sharpe ratio

	IS	OS	OS Shrinkage
SMI	1.196	0.489	0.735
Groups 4	0.811	0.608	0.610
Groups 3	1.019	0.991	0.994

optimale gewichtungen

## 6 Conclusion

It can be concluded, that the best improvement of Sharpe ratio is achieved by grouping by correlation with the help of cluster analysis methods. Shrinkage can also improve the Sharpe ratio slightly on already optimized groups and more significantly on ungrouped assets as in the case of the SMI.

Kapitel noch ausbauen, aber Kernaussage ist jene von oben

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