Sustainability Aware Asset Management

Project: Asset Allocation with a Carbon Objective

Due Friday May 24, 2024, at midnight

The goal of this project is to implement some climate aware asset management concepts seen in class. The first part of the project consists in building a portfolio based on the mean-variance criterion. The second part focuses on the climate dimension of the portfolio. You are given a certain freedom within the framework, provided you explain the methodology that seems the most relevant to you.

Please submit a PDF-report with the details of your methodology and an analysis of the results, and a folder containing your code files such that I can replicate your results by running the code. You are graded based on your report and, to a lesser extent, on your code.

You must use the strategy assigned to your group, i.e., the region and the climate strategy. Projects provided after the deadline will not be graded.

Data

In the "Static.xlsx" file, you are given the following information for 2051 firms, i.e., all firms in Trucost with carbon data for all years from 2005 and 2021 and with price data for all years from 2000 to 2022:

- ISIN code
- Name of the company
- Sector
- Country and region

Then you are given additional files containing time series on carbon data and market values:

- CO_2 emissions (annual) for Scope 1, Scope 2, and Scope 3 (in tonnes CO_2) ($E_{i,Y}$)
- Revenues (annual) (in million USD) ($Rev_{i,Y}$)
- CO_2 intensity (annual) for Scope 1, Scope 2, and Scope 3 (in tonnes CO_2/million USD) ($CI_{i,Y}$)
- Market capitalization (end of year) (in million USD) ($Cap_{i,Y}$)
- Market capitalization (end of month) (in million USD) ($Cap_{i,t}$)

- Total return index (price index, including dividend payments) (end of year) (in USD) ($P_{i,Y}$)
- Total return index (price index, including dividend payments) (end of month) (in USD) ($P_{i,t}$)

Additional important information:

- The data is collected from 2000 to 2022 for market values and from 2005 to 2021 (last year available) for carbon data.
- Price data are collected at the monthly frequency. Prices should be converted into returns using the simple return definition. Returns at date t are collected in the vector $R_t = \{R_{1,t}, ..., R_{N,t}\}$, where N denotes the number of firms. The first 6 years of data (2000 to 2005) are used to initialize the calculation of expected returns and the covariance matrix. See point 1.1 below.
- Revenues and CO_2 emissions are updated annually. Some data might be missing. In such instances, interpolate the missing number using the average of the previous and next year. If the missing number corresponds to 2005, take the number of 2006. The allocation is based on information available at the end of the year (carbon and return data) for the next year. The portfolio is rebalanced only once per year. However, the performance of the portfolio is calculated month by month.
- It is important to distinguish the frequency of returns (monthly) and the frequency of rebalancing (annual). The investment decision is made at the end of a given year for the next year. However, expected returns and the covariance must be calculated based on monthly returns. So, to avoid confusion, I use the index t when the variable is monthly and the index Y when the variable is annual. The reason for computing monthly return is that this allows us to compute some important characteristics of the portfolio, such as its volatility and its Value-at-risk.

Part I - Standard Asset Allocation (Presentation: April 9)

1 Standard Asset Allocation

We start with the construction of a minimum variance portfolio. The region defining the investment set is given in the strategy assigned to the group.

1.1 We compute the minimum variance portfolio out of sample. "Out of sample" means that we use only past data to compute the optimal portfolio for the next period. For instance, we use the first 6 years of monthly returns (from Jan. 2000 to Dec. 2005) to compute the vector of expected returns and the covariance matrix. Therefore, we have $\tau = 6 \times 12 = 72$ months of data available to compute the expected returns and the covariance matrix valid for the allocation at the end of Dec. 2005 for the allocation for Dec. 2006. Dec. 2005 corresponds to year $Y_0 = 2005$ for annual data and to $t_0 = \tau = 72$ for monthly data. Dec. 2006 corresponds to $Y_0 + 1 = 2006$ and $t_0 + 12 = 84$. We associate year Y to month t (Dec. of the year).

    We compute the expected returns as

$$\hat{\mu}_{Y+1} = \frac{1}{\tau} \sum_{k=0}^{\tau-1} R_{t-k}$$

The covariance matrix is

$$\Sigma_{Y+1} = \frac{1}{\tau}\sum_{k=0}^{\tau-1}(R_{t-k} - \hat{\mu}_{Y+1})'(R_{t-k} - \hat{\mu}_{Y+1})$$

The allocation is determined at the end of year Y for year $Y+1$. We compute the optimal allocation of the portfolio using Markowitz's approach. In general, the covariance matrix Σ_{Y+1} is not invertible, so using the optimal weight formula will not work. Instead, we use the following maximization problem, while restricting the optimal weights to be positive:

$$\begin{aligned}
\min_{\{\alpha_Y\}} \quad & \sigma^2_{p,Y+1} = \alpha_Y' \Sigma_{Y+1} \alpha_Y \\
s.t. \quad & \alpha_Y' e = 1 \\
s.t. \quad & \alpha_{i,Y} \geq 0 \qquad \text{for all } i
\end{aligned}$$

Then, we roll the window by one year and iterate until the end of the sample, so that our portfolio is rebalanced every year from Dec. 2005 to Dec. 2021.

We compute the ex-post performance of the portfolio. The portfolio return can be computed every month of year $Y+1$ using monthly stock returns of year $Y+1$ and optimal weights calculated at the end of year Y. This gives: $R_{p,t+k} = \alpha'_{t+k-1} R_{t+k}$, for $k = 1, ..., 12$, where $\alpha_{i,t+k-1} = \alpha_{i,t+k-2} \times (1 + R_{i,t+k-1})/(1 + R_{p,t+k-1})$, with $\alpha_t = \alpha_Y$. We now have a time series of ex post portfolio returns: $\{R_{p,\tau+1}, ..., R_{p,T}\}$, where $T = 276$ denotes the total number of months in the sample.

Compute the characteristics of this portfolio (denoted "$P^{(mv)}_{oos}$") over the sample: annualized average return ($\bar{\mu}_p$), annualized volatility (σ_p), Sharpe ratio (SR_p), minimum, maximum, and maximum drawdown.

Remark: The reason for considering a long-only portfolio is to help interpreting the carbon footprint of the portfolio.

1.2 Compare these properties to those of the value-weighted portfolio (denoted "$P^{(vw)}$") ("benchmark"). The performance of the value-weighted portfolio is

$$R^{(vw)}_{t+1} = \sum_{i=1}^{N} w_{i,t} R_{i,t+1}$$

where $w_{i,t} = Cap_{i,t}/\sum_{j=1}^{N} Cap_{j,t}$ denotes the relative market capitalization of firm i at the end of month t.

In particular, plot the cumulative return series of both strategies and compare their summary statistics.

Part II - Asset Allocation with a Carbon Emissions Reduction (Presentation: May 28)

2 Allocation with a 50% Reduction in Carbon Emissions

We now add a layer in the portfolio construction by taking into account the CO_2 emissions associated to the portfolio. The scope of the CO_2 emissions is given in the strategy assigned to the group.

2.1 We consider the carbon intensity ($CI_{i,Y}$) of all firms in our investment set. It is computed in tons of CO_2 equivalent per million U.S. dollars of revenue. We compute the weighted-average carbon intensity and the carbon footprint of the portfolio as the amount of annual carbon emissions that can be allocated to the investor per million U.S. dollars invested:

$$WACI_Y^{(p)} = \sum_{i=1}^{N} \alpha_{i,Y} CI_{i,Y} \qquad\qquad CF_Y^{(p)} = \frac{1}{V_Y} \sum_{i=1}^{N} o_{i,Y} E_{i,Y}$$

where $o_{i,Y} = V_{i,Y}/Cap_{i,Y}$ measures the fraction of the equity of the firm owned by the portfolio, with $V_{i,Y} = \alpha_{i,Y} V_Y$ the dollar value invested in firm i and $V_Y = \sum_{i=1}^{N} V_{i,Y}$ the dollar value of the portfolio. Compute the carbon footprint of $P_{oos}^{(+)}$ for every year in the sample, assuming a starting wealth equal to V_{2005} =1 million U.S. dollars.

2.2 We now construct an optimal long-only portfolio with a carbon footprint 50% below the carbon footprint of the optimal long-only portfolio $P_{oos}^{(mv)}$ determined in point 1.2 (*minimum variance active investor*). For every year in the sample, compute the optimal weights of the long-only portfolio with a carbon footprint lower or equal to $0.5\times$ the carbon footprint of $P_{oos}^{(mv)}$. This can be done by solving the problem:

$$\begin{aligned} &\min_{\{\alpha_Y\}} \quad \sigma_{p,Y}^2 = \alpha_Y' \Sigma_{Y+1} \alpha_Y \\ &s.t. \qquad CF_Y^{(p)} \leq 0.5 \times CF_Y^{(P_{oos}^{(mv)})} \\ &s.t. \qquad \alpha_{i,Y} \geq 0 \qquad \text{for all } i \end{aligned}$$

We call this portfolio "$P_{oos}^{(mv)}(0.5)$". Compute the characteristics of this out-of-sample portfolio over the sample. As before, plot the cumulative return series of both strategies and compare summary statistics.

2.3 Another interesting decarbonization strategy consists in designing the portfolio that is as close as possible to the benchmark, while reducing the carbon footprint by 25% (*otherwise passive investor*). This is done by maximizing the minimum variance criterion for the tracking error every year:

$$\begin{aligned} &\min_{\{\alpha_Y\}} \quad (TE_{p,Y})^2 = (\alpha_Y - \alpha_Y^{(vw)})' \Sigma_{Y+1} (\alpha_Y - \alpha_Y^{(vw)}) \\ &s.t. \qquad CF_Y^{(p)} \leq 0.5 \times CF_Y^{(P^{(vw)})} \\ &s.t. \qquad \alpha_{i,Y} \geq 0 \qquad \text{for all } i \end{aligned}$$

where $CF_Y^{(P^{(vw)})} = \frac{1}{Cap_Y} \sum_{i=1}^{N} E_{i,Y}$ denotes the carbon footprint of the value-weighted portfolio, with $Cap_Y = \sum_{i=1}^{N} Cap_{i,Y}$ the total market value of the investment set.

We call this portfolio "$P_{oos}^{(vw)}(0.5)$". Compute the characteristics of the portfolio over the sample. Again, plot the cumulative return series of both strategies and compare summary statistics.

2.4 Comment on the trade-off between the financial performance of the portfolio and the reduction in its carbon footprint. Elaborate on the difference between portfolios "$P_{oos}^{(mv)}$" and "$P_{oos}^{(mv)}(0.5)$" and between portfolios "$P_{oos}^{(vw)}$" and "$P_{oos}^{(vw)}(0.5)$".

3 Allocation with a Net Zero Objective

Finally, we want to construct a minimum variance portfolio, while cumulatively reducing its carbon emissions.

3.1 Finally, we implement a decarbonization strategy in which the carbon footprint of the portfolio is reduced by $\theta = 10\%$ per year every year from Dec. 2005 to Dec. 2021.

We adopt the point of view of the otherwise passive investor. The optimization problem is the same as in point 2.3 except that the carbon emissions reduction constraint is now defined as

$$CF_Y^{(p)} \leq (1-\theta)^{Y-Y_0+1} \times CF_{Y_0}^{(P^{(vw)})} \qquad \text{for } Y = 2005, \cdots, 2021$$

with $Y_0 = 2005$.

We call this portfolio "$P_{oos}^{(vw)}(NZ)$". Compute the characteristics of this portfolio over the sample. Again, plot the cumulative return series of both strategies and compare summary statistics.

3.2 Compare the cumulative performance of the three portfolios "$P_{oos}^{(vw)}$", "$P_{oos}^{(vw)}(0.5)$", and "$P_{oos}^{(vw)}(NZ)$". Comment on the possible cost of constructing a net zero portfolio.