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The Effect of Including Weapon Stocks on Performance, Riskiness and Sustainability of an Investment Portfolio

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Preface

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I started writing this thesis at the end of summer 2022, in Offenbach am Main. A keen interest in sustainability, mathematics and finance made me start a journey which would lead me to the end of my academic career, for now. This journey could not have been possible without standing on the shoulders of the giants mentioned below.
First of all, I want to thank my supervisor prof. dr. Wim Schoutens[1] for introducing me to the three elements of ESG investing: risk, return and sustainability. His never ending knowledge and patience guided me in the right direction.
Secondly, I want to thank my parents Hans Bayer, Froukje Andringa and our dear friend prof. dr. Conor Dolan. Without them, I would have never had the courage to start my academic career in a mathematical field. Their never-ending support invited me to always look beyond flaws, to take things lightly and, remain ”Tongue-in-cheek”.
Thirdly, I want to thank my friends who I met at Maastricht University and KU Leuven (and the ones from beyond and before). University life is not (only) about the journey, it is about the company. I want to thank them for the uncontrolled bursts of laughter and joy we have shared in the past and will share in the future. And, Mario, I want to thank you for making your jokes about my ”vegan weapon thesis”.
Lastly, I want to thank all of the other professors that lectured me throughout my journey. Without them, I would have never been fascinated by the first actuarial formulas written by Dutch politician Johan de Witt in 1671. This mathematician and politician was born in the same city as my dear friend Wout de Vos, only half an hour away from my hometown. I would especially like to thank all of my lecturers for their patience: I am sorry I was always (fashionably) late because I was bringing a coffee to-go with me.
Rebecca

[1] And Jingyan Zhang for sharing the ESG database with me

Summary

The 24th of February, 2022, Russia invaded Ukraine [16]. This invasion resulted in a violent shift in Wall Street's stocks. Specifically, weapon industry stocks[2] showed an increase in value while the value of other stock showed a strong decrease in value [7].
In this thesis, I study the effect of including weapon stocks on both profitability and environmental, social, and governance (ESG) ratings, provided by Sustainalytics. These ratings are needed to quantify the level of sustainability.
In the second chapter, the literature review, I zoom in closely on the effects of the use of sustainability ratings on portfolio performance. Specifically, I focus on the question of how rating agencies influence the investor's appetite for sustainable stocks.
Then, in chapter 3.1 an analysis is provided of how Sustainalytics defines ESG Scores, specifically for weapon stocks. I find some questionable results with respect to how Sustainalytics determines its ESG scores. In addition, I conclude that weapon (Aerospace and Defense) have slightly higher ESG risk ratings. However, they perform more than 30% better with respect to the raw score of their human rights policy.
To investigate the influence of weapon stocks, I use a specific type of mean-variance analysis: the efficient frontier. Through quadratic programming I optimized different optimal minimum-variance portfolios with different restrictions on the number of weapon stocks allowed. This method is explained in chapter 4.
The algorithm developed in chapter 4 was applied on both the STOXX50 and Dow Jones in chapter 5[3]. The European and Northern American market give different results. In chapter 6, I included an upperbound on the algorithm developed to transform the mean-variance analysis into a mean-variance-weapon analysis. Then, in chapter 7, I also include a passive strategy to zoom in to the profitability effects discovered in chapter 5.
The effect of the inclusion of weapon stocks is a decrease in volatility, increase in profitability and slight increase in sustainability risk. Therefore, by increasing the sustainability risk only slightly, a portfolio not excluding weapon stocks will ensure an improved lowerbound of profitability and volatility. In addition, by investing in weapon stocks, one can improve on the average human right policy of a portfolio.

[2] Or military industry stocks / defense stocks / companies

[3] For an overview of the data and R code used, please see https://github.com/bekkie-007/ESGthesis.git

Abbreviations

E	Environmental
S	Social
G	Governance
GHG	Greenhouse gases
CDP	Centers for Disease Control and Prevention

List of Symbols

ρ_{ij}	Correlation
σ_i	Volatility
w	Vector of weights
R	Vector of returns
μ	Vector of mean returns
μ_P	Return portfolio
Σ	Covariance matrix
A_{neq}	Matrix for inequality constraints
A_{eq}	Matrix for equality constraints
b_{eq}	Vector for equality constraints

Contents

Chapter 1

Introduction

In this thesis I will investigate the effect of including (or excluding) military[1] stocks on portfolio and Environmental, Social, and Governance (ESG) performance. ESG is defined as an investment philosophy that focuses on long-term value growth while maintaining a proper governance method. Weapons, also when used for defense, are considered both hazardous and they have a negative community impact. Therefore, they are both in conflict with the environmental and social aspects of ESG.

Nowadays, investors increasingly apply non-financial factors relating to ESG in their financial decision making. The focus of most "ESG-investors" has been on (reducing) carbon emissions, with many also excluding defense stocks [2]. However, since this year, defense stocks outperform the S&P500 due to the war in Ukraine [5]. Analysts say that the ongoing war in Ukraine has changed investors' view of the industry, underscoring its role in facilitating international security.

Sustainability is a hot topic, and not only for climate researchers. In the financial world, there has been an increasing appetite for "green" portfolios: financial assets that have a good or non-risky ESG rating. The increased demand for stocks with a good ESG Rating has led to the growth of several large ESG Ratings companies such as Sustainalytics, MSCI ESG Research, ESGI, Yahoo and so on. The role of these ESG Ratings companies can be compared to agencies such as S&P and Moody's. They reduce the non-financial information asymmetry and are considered a regulatory body on sustainability. The European Green Deal, that aims to have Europe climate neutral before 2050, could benefit from these agencies as they enhance market transparency and possibly market efficiency [6]. The view of ESG agencies on military stocks is crucial for sustainable investors in the current climate. It would be interesting to see whether the bigger ESG Credit Agencies have adapted their ESG framework in the light of the current military conflict in the Ukraine.

In addition, it is important to adopt a critical attitude towards the quantitative models behind the ESG ratings. There is as yet no regulation for ESG Rating Agencies as there is for Credit Agencies. The Credit Agencies' regulation was only developed after the financial crisis of 2008, when the ratings turned out to be untrustworthy. The underperformance of portfolios with good ESG Ratings may signal the deceptiveness of their ESG ratings. Therefore, to allow for a more quantitative approach, it is more elegant to con-

[1] Or defense/weapons

[2] Especially those of companies that manufacture controversial weaponry, such as nuclear and cluster bombs

sider the mass of total green house gas (GHG) emission or the percentage of total weapon stocks per portfolio as a measure of sustainability. The aim of this thesis is therefore to investigate the impact on sustainability and profitability of including and excluding weapon stocks in index portfolios such as STOXX or Dow Jones.

Chapter 2

Literature Review

Presently, with the ongoing war in Ukraine, it is expedient to update our believes about the ESG Rating of weapon stocks. At this moment, weapon stocks are not usually included in green portfolios [5]. However, as international defense can be considered as an important factor to contribute to the social aspect of ESG, there is room for change. Due to the war in Ukraine, I have already seen a tendency among investors to invest in (sustainable) energy related sources. Also, many countries have announced that they will invest more in aerospace and defense. This year, sustainable "greener" funds showed lower returns than the less sustainable "browner" funds, which has been attributed to their lower involvement in weapons (and fossil fuel) stocks. This is the first time in two years that ESG funds underperform non-ESG funds.

ESG research tends to focus on internal governance and includes economic consequences. There is a gap in the literature with respect to "change management" in ESG. Although ESG Rating Companies do not adapt their rating, this should not rule out that defense stocks are sustainable. Also, economic consequences might be inferior to the social consequences of excluding weapon stocks in large investment portfolios. Even though, the common view on the weapon industry is negative, investments are necessary to ensure safety of citizens. ESG investing has been criticised from several sides. The current market-based approach assumes that investors in an efficient market will invest more sustainably because of the "green light effect" of ESG ratings. However, the current ESG regulation may fail to achieve that desired change of investment behaviour that is needed. Also, inferior ESG regulation could lead to "Greenwashing": the practice of misleading investors or consumers with regards to the sustainable credential of a firm's products. ESG rating providers have also failed to spot governance issues at Wirecard and social issues at Boohoo, see e.g. [1] and [11].

Undoubtedly, the ESG rating agencies have been criticized with respect to the different methodologies and factors that are used to develop the different ESG ratings. It is important to learn from the past [1] and to intervene to increase the accuracy, comparability and credibility of the ESG ratings [6]. Especially as these ESG ratings are crucial for the Sustainable Finance Disclosure Regulation (SFDR) of asset managers, pension funds and insurance firms [9].

Besides the critisicm of the rating agencies, one may disapprove of the very use of these ratings. For example, having a less favourable ESG rating might only lead to a stock transfer from a "green" to a "brown" investor. In addition, green strategies have been

[1] The questionable position of Rating Agencies that led to the Crisis of 2008

outperforming brown strategies since April 2019. However, since the war in Ukraine it is clear that weapon stocks outperform green portfolios in profitability aspects, see "ESG: a new dimension in portfolio allocation".
Since February 2022, investors preferences have shifted to "energy" and "aerospace and defense" sectors. Many countries announced an increased investment in defense and military spending. Obviously, this has sparked interest among investors in this sector as well, even though the ESG ratings of aerospace and defense stocks are relatively low. The increased interest in energy (and aerospace and defense) stocks is a result of a return spillover effect from ESG investments [4]. Meaning that because of the lower returns of "greener" portfolios, investors seek "refuge" in "browner" portfolios with higher returns.
In this thesis, both the European and Northern American weapon markets will be discussed. Obviously, there are differences with respect to regulation between the two continents. In Europe, for example, the defense market is dominated by states rather than market supply and demand [13]. In the United States, on the other hand, weapons are easier accessible to the normal market which changes the attitude with respect to the defense market as a whole as well.
To conclude, the current circumstances call for a different approach towards ESG investing. The true effect of including military stocks[2] in "green" portfolios should be investigated from different approaches. Currently, the lower returns of sustainable funds are mainly explained by lower involvement in weapons and fossil fuel stocks [8]. Nevertheless, it is important to look not only at the effects on returns but also to take a critical approach towards ESG Ratings and to create different profitability and sustainability scenarios for "sustainable weapon funds", see "ESG: Research Progress and Future Prospect".

2.1 Research Question

What is the effect of including military stocks on portfolio and ESG performance?

Subquestions

- What are (examples of) military stocks? [3]
- What is the effect of including military stocks in a market-wide used portfolio?

  What is the profitability development of a ESG portfolio without military stocks from 2015 to the present?

  What is the profitability development of a ESG portfolio with military stocks from 2015 to the present?
- What would happen if a third dimension [4], a constraint on weights on weapon stocks, is added to the risk-return portfolio analysis used?
- How have the ESG ratings developed over the past years?

[2]When talking about military stocks, I refer to the shares of listed defense companies
[3]In SP there are 15 military stocks https://www.esganalytics.io/insights/companies-in-the-s-p500-involved-in-weapons-manufacturing
[4]Next to the dimensions of risk and return

2.2 Research Framework

This thesis will follow the approach from Reyners, Schoutens, and Verdonck closely. In order to model the mean-variance analysis, I will use several techniques from Rupert and Mateson [17]. This thesis consists of three parts:

Part 1: Literature Background

In this stage, I report on the relevant literature concerning ESG Investing in times of war. I will also investigate which companies are the weapon players in the European and Northern American market, and analyse the weapon market.

Part 2: Comparing the Tangent Portfolio

In this stage, I will create two types of portfolios. The first type includes weapon stocks, and the second type excludes weapon stocks. I will do this for both the European market (STOXX50) and Northern American market (Dow Jones). I will compare the tangent portfolio, Sharpe ratio, maximal drawdown and profitability of both portfolios. I propose to do this by means of a one month rebalancing method, a method commonly used in asset management.

Part 3: Including Bounds on Weapon Stocks

In this stage, I will transform the two-dimensional tangency portfolio model into a three-dimensional portfolio model including both risk, yield and a bound on weapon stocks.

Part 4: Comparing Passive Investment Strategies

In this stage, I will include a more passive investment strategy which will invest a fixed proportion in weapon stocks. This strategy decides about a portfolio location once, and does not adapt the weights during the portfolio lifetime.

Chapter 3

Preliminary Data Analysis

3.1 ESG Ratings

Like credit ratings, ESG ratings elaborate on the riskiness of a company. ESG ratings[1] are based on three subdivisions, which are elaborated below. Within each subdivision, a range of different factors is considered, which are awarded a score S_i^X, that ranges from 0 to 100. Here, i refers to the number of scores and X to the subdivision "E","S" or "G". Next to these factors, a weight W_i^X is assigned which determines how much the score contributes to the company's rating.

3.1.1 E: Environmental

The "E" scores and weights together describe how risky a company is with respect to its environment. For instance, if a company has a higher carbon intensity or a less developed Green Procurement Policy, it will get a higher environmental sustainability risk rating from Sustainalytics.

3.1.2 S: Social

Sustainability is not related to GHG only. And even though more difficult to quantify than GHG emissions, the societal aspect of sustainability should not be disregarded. Societal aspects include certain incidents, for example, that influence society and/or the local community.

3.1.3 G: Governance

Even though closely related to the "S", the governance aspect also includes the policies in place to ensure sustainability. These policies should include, for example, manuals on how to avoid bribery and sustain the appropriate business ethics. In addition, the amount of women on the board could also influence the governance aspect of sustainability.

[1] from Sustainalytics

3.2 Analysis of ESG Ratings

To investigate the sustainability dimension, I used ESG ratings in time-series format ranging from 2014 to 2019. As I do not have access to the ratings from 2019 to the present, I assume that the ratings did not change in the past 3 to 4 years. In addition, I replaced the missing values in the dataset with the last observed value. For my research, it is more interesting to focus on the most present ESG rating of weapon stocks. Sadly, the ESG ratings from 2019 on are calculated based on the last observed value. Therefore, the results might underestimate or overestimate the sustainability dimension.

3.3 Construction of ESG Ratings

The ESG Ratings from Sustainalytics are constructed from the scores S_i^X and the weights W_i^X. Here, $i_X \in [1, ..., n_X]$ with n_X the number of scores in each subdivision X and $X \in E, S, G$. The ratings R^X and R^{ESG} are then calculated as follows:

$$R^X = \frac{\sum_{i_X=1}^{n_X} S_{i_X}^X W_{i_X}^X}{\sum_{i=1}^{n_X} W_{i_X}^X} \tag{3.1}$$

$$R^{ESG} = \frac{\sum_{i_E=1}^{n_E} S_{i_E}^E W_{i_E}^E}{\sum_{i_E=1}^{n_E} W_{i_E}^E} + \frac{\sum_{i_S=1}^{n_S} S_{i_S}^S W_{i_S}^S}{\sum_{i_S=1}^{n_S} W_{i_S}^S} + \frac{\sum_{i_G=1}^{n_G} S_{i_G}^G W_{i_G}^G}{\sum_{i_G=1}^{n_G} W_{i_G}^G} \tag{3.2}$$

3.4 Military Stocks

	E	S	G	ESG
Aerospace and Defense	59.9	57.8	65.1	60.8
All others	54.4	57.2	61.6	57.1
Difference	10.3%	1.2%	5.8%	6.33%

Table 3.1: Average ESG Ratings from 2009 to 2019

Above, the average ratings for all stocks and Aerospace and Defense stocks are shown. Obviously, it would have been interesting to see the change in ESG Rating since the start of the war in Ukraine. However, I do not have access yet to this data.
In the dataset from Sustainalytics, some environmental aspects of the weapon stocks were given zero weight and therefore did not attribute to the environmental rating of these stocks. I have not been able to find out why Sustainalytics decided to attribute this weight factor to these aspects. It could be a sign of greenwashing. However, I did not find any proof for this. The aspects that were given zero weight are elaborated below:

- Waste Intensity
- Air Emissions Programmes
- Water Management

- ◇ Other Environmental Programmes
- ◇ Fleet Emissions Trend
- ◇ Product Stewardships Programmes

In addition, in Appendix A I listed the elements that have the potential to drive risky environmental scores.

3.4.1 S Side of Military Stocks

From the table below you can see that the ESG risk rating score for human rights for the Aerospace and Defense score outpaced the ESG rating of all other sectors. Meaning that, on average, the Aerospace and Defense sector outperformed with respect to their human rights policy from 2009 to 2019. From the previous subsection I know that the "S" side of military stocks was the best performing side of the Aerospace and Defense ESG rating. Therefore, adding military stocks to a portfolio does not only improve the human rights policy, it would also increase the "S" risk rating only slightly.

	Human Rights Policy-Raw Score
Aerospace and Defense	22.5
All others	26.8
Difference	30.5%

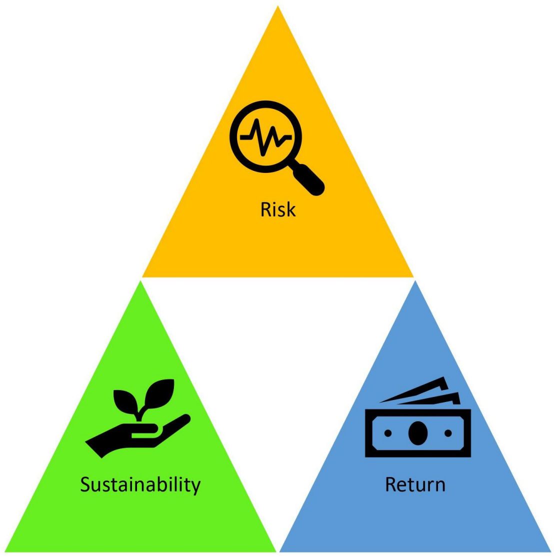
Table 3.2: Average Human Rights Ratings from 2009 to 2019

Chapter 4

Method

Classical portfolio is based on the trade-off between two dimensions: risk and return. Originally, this trade-off is optimized through diversification benefits: by increasing the number of investments for example. Markowitz (1952) was the first to develop such a diversification model. Later on, based on Markowitz' model, Sharpe developed the capital asset pricing model [12]. In this thesis, a third dimension is added to the model of Markowitz: sustainability [1].

Figure 4.1: Three dimensional trade-off



In this chapter, I elaborate on the method used to find the "Optimal portfolio". In 4.1, I will describe how to derive the stock returns R_t, with t indicating the time element, and weights w_i, with i indicating the different stocks, to calculate the portfolio return μ_p. In the next section, 4.2, I will elaborate on the different measures used to quantify risk. Then, in section 4.3, I will describe how to derive the minimum variance portfolio, and how this two-dimensional portfolio serves as the benchmark for the three-dimensional optimisation. Then, in 4.4, I will describe the actual optimisation algorithm. Finally, in 4.6 and 4.7 I will apply the method on the two and three dimensional optimisation.

[1] Or the percentage of weapon stocks

4.1 Portfolio Allocation

To optimize portfolios that include either two or three dimensions, I will use the theory of portfolio allocation. In this thesis, I will focus on equity portfolios: only stocks from the (usually price-weighted) DowJones-index and from the (usually market-value-weighted) STOXX-index are included together with weapon stocks. I want to find weights w (proportions of the initial investment) such that the portfolio consisting of N different assets is optimized initially with respect to two dimensions (adding the defense stock as the third dimension below): risk and return. Therefore I define,

$$w = (w_1, ..., w_N)^t \tag{4.1}$$

with $\sum_{i=1}^{N} w_i = 1$ and $w_i \geq 0$ for all $i \in N$. The latter inequality serves to exclude short-selling. Including short-selling would allow for risk and return approaching either $-\infty$ or ∞. In a later stage, when the third dimension 'sustainability' is added, its actual impact could then become more difficult to define, see the method developed by Reyners. Each weight w_i represents the proportion of a specific risky asset $R_{i,t}$ in the total portfolio. $R_{i,t}$ is a time-series return of a specific stock i. I define Σ to be the covariance matrix of R, and define the vectors R and μ,

$$R = (R_1, ..., R_N)^t \tag{4.2}$$

$$E(R) = \mu = (\mu_1, ..., \mu_N)^t \tag{4.3}$$

Here, R is the time-series return of stock N calculated at all times t. Obviously, the return can be calculated through different methods. Here, I use:

$$R_t = \frac{V_t - V_{t-1}}{V_{t-1}} \tag{4.4}$$

With V_t the value of the stock N at time t. At the same time, I could have also used:

$$r_t = \ln \frac{V_t}{V_{t-1}} = \ln(1 + R_t) \tag{4.5}$$

The advantage of this approach is that the compound return $R_{t,m} = \ln \frac{V_t}{V_{t-m}}$ has an additive structure.
I am interested in finding the weights w_i such that the variance of the portfolio is minimized while still maintaining a target expected return μ_P. The vector of the N different variances can be retrieved from the diagonal of Σ [17]. I can calculate the return μ_P,

$$\mu_P = \sum_{i=1}^{N} w_i \mu_i \tag{4.6}$$

4.2 Risk Measures

Below, several risk measures used will be elaborated. In Appendix B, the Herfindahl-Hirschman Index, Value-at-Risk, Tail Value-at-Risk, Expected Shortfall, Skewness and Kurtosis willl be introduced but they fall out of the scope of this thesis.

4.2.1 Volatility

The volatility of a stock σ_i, which is equal to the square root of the variance, it indicates how much the actual returns vary about the mean return. One can calculate σ_i^2 for each stock i with M periods as follows:

$$\sigma_i^2 = \frac{\sum_{i=1}^{M}(R_i - E[R_i])^2)}{M} \tag{4.7}$$

As I use the daily returns, the formula above will give the daily volatility. In order to transfer the daily volatility into yearly volatility, you can multiply with $\sqrt{2}52$. [2] In addition, by using the square root of the diagonal below, one could calculate the daily volatility per stock:

$$\Sigma = \begin{pmatrix} \sigma_1^2 & \rho_{12} & \rho_{13} & \cdots & \rho_{1N} \\ \rho_{21} & \sigma_2^2 & \rho_{23} & \cdots & \rho_{2N} \\ \rho_{31} & \rho_{32} & \ddots & & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ \rho_{N1} & \rho_{N2} & \rho_{N3} & \cdots & \sigma_N^2 \end{pmatrix} \tag{4.8}$$

From the volatility per stock $i \in N$, the portfolio volatility σ_P can be calculated as follows:

$$\sigma_P = \sqrt{\sum_{i=1}^{N} w_i^2\sigma_i^2 + 2\sum_{i=1}^{N}\sum_{j<i} w_i w_j \rho_{ij}\sigma_i\sigma_j} \tag{4.9}$$

The equation above shows the benefit of diversification, when using portfolio volatility as a risk measure. σ_P will only be equal to the weighted sum of the volatilities if $\rho_{ij} = 1$ for every $i, j \in N$. If $\rho_{ij} < 1$, σ_P will be smaller than the weighted sum of the volatilities.

4.2.2 Sharpe Ratio

The (historical) volatility indicates how the actual returns have been different from the expected returns. The next risk measure, the Sharpe Ratio, assumes there is a risk-free rate. This means that there is an asset, for example the 1 year US treasury yield, with zero volatility. In this thesis, this yield is equal to 4.8% on a yearly basis. Investors are then interested in the standard deviation of excess returns and the risk premium that comes along with it. This means that, by taking on extra risks by investing in stocks and the US treasury yield, these investors require a risk premium which "rewards" them for

[2]As there are 252 trading days per year

taking on extra risks.
This reward-to-volatiltiy measure, known as the Sharpe ratio, is then calculated as follows:

$$\text{Sharpe ratio} = \frac{\text{Risk premium}}{\text{Volatility of excess return}} \tag{4.10}$$

Ideally, a portfolio is characterized by weights that maximize the risk premium over the volatility of excess return. This is different from volatility, a risk measure that should be minimized (and not maximized). The portfolio, with the highest Sharpe ratio, is called the tangency portfolio. While the portfolio with the lowest volatility, is called the minimum-variance portfolio.
Note that when comparing portfolio's Sharpe ratios, its important to convert them to equal investment periods, see Bodie, Kane and Markus (2014).

4.2.3 Maximum Drawdown

The maximum drawdown in a portfolio describes the difference between the highest return for a given set of weights and the lowest return for that set of weights. It is a risk measure commonly used in asset management, and describes the magnitude of the losses of one's fund:

$$\text{Maximum drawdown} = \max\{\text{Return in period}\} - \min\{\text{Return in period}\} \tag{4.11}$$

A fund with a lower maximum drawdown is considered more attractive as it is less volatile to market shocks [10].
One can formalize the formula used as follows:

$$\text{MDD} = \min\left\{ \frac{value_i}{\max\{value_j | j = 1, ..., i\}} \middle| i = 1, ..., n \right\} - 1 \tag{4.12}$$

With:

$$value_j = \prod_{i=1}^{j} (1 + w^T r_i) \tag{4.13}$$

The formalisation uses the cumulative return ($value_j$). This total return describes the profitability of a portfolio of assets over a certain compound period, see "ESG: a new dimension in portfolio allocation". In my analysis, I calculate the maximum drawdown per month. Therefore, I will use equation 4.11 and not 4.12 as I bound myself to a monthly maximum drawdown that does not allow the use of an arbitrary compound period. This maximum drawdown simply looks at the difference between the most profitable day and the least profitable day within one month. Here, the non-cumulative returns are used.

4.3 Minimum-Variance Portfolio

The goal of this thesis is to find weights that minimize risk and maximize returns/sustainability. Obviously, this is a trade-off, and finding the best in three dimensions is mathematically impossible. Therefore, I have the following possibilities to implement:

◇ Tangency portfolio
This portfolio maximizes the Sharpe ratio, see 4.2.

◇ Maximum sustainability portfolio
This portfolio looks for the weights that create the best "green" portfolio while at the same time maintaining some target minimal volatility or target maximum return.

◇ Minimal-variance portfolio
This portfolio minimizes the volatility while maintaining some mean target expected return and some target sustainability rating.

The first option is not as attractive because, as will be shown in 4.7, "green portfolios" are on average riskier than "brown portfolios". Therefore, I want to optimise sustainability through minimizing risk and not maximizing the pay-off for taking extra risk (the Sharpe ratio).
The second option is not as attractive as most investors will consider the dimensions risk and return as more important than the dimension sustainability [8].
The third option will give results with minimum volatility and target sustainability ratings/returns. As this is most in line with investor's risk appetite, this portfolio will be considered for this thesis.

4.4 Quadratic Programming

Quadratic programming is an optimisation method to minimize a quadratic objective function (the variance of the portfolio return) subject to linear constraints (such as $\sum_{i=1}^{N} w_i = 1$ and $w_i \geq 0$). As I have to be consistent with the notation necessary for the 'quadratic programming' in R, I introduce the following matrices and vectors,

$$D = 2\Sigma \tag{4.14}$$

With Σ the N x N covariance matrix such that $\frac{1}{2}w^T Dw = w^T \Sigma w$

$$A_{neq}^T w \geq 0 \tag{4.15}$$

A_{neq}^T is the N x N identity matrix, such that I am able to avoid short-sales. This implies that no weight w_i is smaller than zero.

$$A_{eq}^T = \begin{pmatrix} 1^T \\ \mu^T \end{pmatrix} \tag{4.16}$$

μ^T is a (one-dimensional) vector that stores all of the (monthly) means of the stocks and 1^T is a N-vector of 1's. Therefore:

$$b_{eq} = A_{eq}^T w = \begin{pmatrix} 1 \\ \mu_P \end{pmatrix} \tag{4.17}$$

In order to find the efficient frontier, I want to minimize $w^T\Sigma w$ subject to $A_{neq}^T w \geq 0$ and $A_{eq}^T w = \begin{pmatrix} 1 \\ \mu_P \end{pmatrix}$ In this thesis I focus on the minimum variance portfolio. Therefore, the minimized value of $w^T\Sigma w$, σ_P^2, needs to be calculated for all target portfolio means μ_P. The minimum variance portfolio is then the portfolio with the lowest σ_P^2. In addition, I calculate the Sharpe ratio for each portfolio:

$$Sharpe = \frac{\mu_P - R_f}{\sigma_P} \tag{4.18}$$

To calculate the Sharpe ratio, I need to have the risk-free rate (R_f) as well. This is determined in the input value of the code. The portfolio that gives the highest Sharpe ratio is called the Tangency portfolio. Besides the Sharpe ratio, I am also interested in the Maximum Drawdown. This risk measure is defined as the difference between the highest daily return and lowest daily return in the considered time period.

4.5 Data Used

The data are proxies of the European market (Euro Stoxx 50 index) and Northern American market (Dow Jones). Besides these proxies, I add additional listed stocks that are active in the weapon/defense market. Therefore, the European market consists of 54 stocks ($N = 54$) and the Northern American market consists of 50 stocks ($N = 50$). A complete overview of the stocks used (together with their expected return, volatility and current ESG rating) is included in the Appendix, see section C.

4.5.1 Calculation of ESG Ratings

Part of the analysis will include the (average) ESG ratings of the stocks. To calculate the ESG ratings in time-series format, I use the formula below:

$$ESG_{(i,t)} = \begin{cases} ESG_{(i,t)} & \text{if } ESG_{(i,t)} \neq \emptyset \\ ESG_{(i,t-1)} & \text{if } ESG_{(i,t)} = \emptyset \end{cases} \tag{4.19}$$

Here, $\emptyset$ stands for the empty set: if a data point is missing, it is replaced by the previous known value. The ESG ratings were taken from a Sustainalytics data-set that has not been updated since November 2019. Therefore, I assume that the ESG ratings have been stable since: they are set equal to the last reported value. In addition, I use the formula above to fill in the missing values in the data set.

4.6 Two Dimensional Application

For the two dimensional optimisation I do not set any constraints on the percentage of weapon stocks. Therefore, I only consider the following three sets of constraints:

- $\sum_{i=1}^{N} w_i = 1$
- $\sum_{i=1}^{N} w_i \mu_T = \mu_P$

- ⋄ $w_i \geq 0$ with $i \in 1, 2, 3, ..., N$

I take 300 different values for μ_T, ranging from the smallest expected total stock return and largest expected total stock return. Then, for each value of μ_T, the optimal portfolio is calculated to create the efficient frontier. The optimisation problem looks as follows:

$$\begin{array}{ll} \min\limits_{w} & w^T \ \Sigma w \\ \text{s.t.} & \sum_{i=1}^{N} w_i = 1 \\ & \sum_{i=1}^{N} w_i \mu_T = \mu_P \\ & w_i \geq 0 \end{array} \tag{4.20}$$

With Σ the covariance matrix calculated in R. On the efficient frontier, there is a set of weights w such that the portfolio has the largest Sharpe ratio (the tangent portfolio) or the smallest volatility (the minimum-variance portfolio w_{MV}^T).
Besides the daily returns, I also have the daily ESG ratings. Therefore, I can calculate the (minimum or maximum) return for the minimum-variance portfolio (MV) and I can calculate the (average) ESG rating $E[ESG_{MV}]$:

$$E[ESG_{MV}] = E[w_{MV}^T * ESG^T] \tag{4.21}$$

This method will be repeated for both the portfolio with weapons and the portfolio without weapons.

4.6.1 Monthly Reshuffle

Here, the exact same method from above is repeated for time periods of maximum a month. Through this method, an asset manager can actively manage a fund by selling and buying stocks every month to maintain the new set of optimal weights.
I also store the Sharpe ratio and maximum drawdown per month, these are calculated through Equation (4.10) and Equation (4.12).

4.7 Three Dimensional Application

For the three dimensional optimisation I do set constraints on the percentage of weapon stocks. Therefore, I consider four sets of constraints:

- ⋄ $\sum_{i=1}^{N} w_i = 1$
- ⋄ $\sum_{i=1}^{N} w_i \mu_T = \mu_P$
- ⋄ $w_i \geq -0.01$ with $i \in S$
- ⋄ $w_j \leq$ cap with $j \in M$

  Here, S is the set of all stocks, M is the set of weapon stocks and cap is the maximum weight for each weapon stock in M:
  cap = {0.05,0.045,0.04,0.035,0.03,0.025,0.02,0.015,0.01,0.005}

The optimisation problem is as follows:

$$\begin{aligned} \min_{w} \quad & w^T \ \Sigma w \\ \text{s.t.} \quad & \textstyle\sum_{i=1}^{N} w_i = 1 \\ & \textstyle\sum_{i=1}^{N} w_i \mu_T = \mu_P \\ & w_i \geq -0.01 \text{ with } i \in S \\ & w_j \leq \text{cap with } j \in M \end{aligned} \tag{4.22}$$

Note that I do allow for (partial) short-selling by setting $w_i \geq -0.01$ instead of $w_i \geq 0$. Short-selling is feasible when assuming an efficiently liquid market. The advantage of this approach is that I am able to further decrease the weights of the weapon stocks. By not allowing short-selling, it would be more difficult (or infeasible) to find minimum variance portfolios for stricter constraints on the number of weapon stocks.

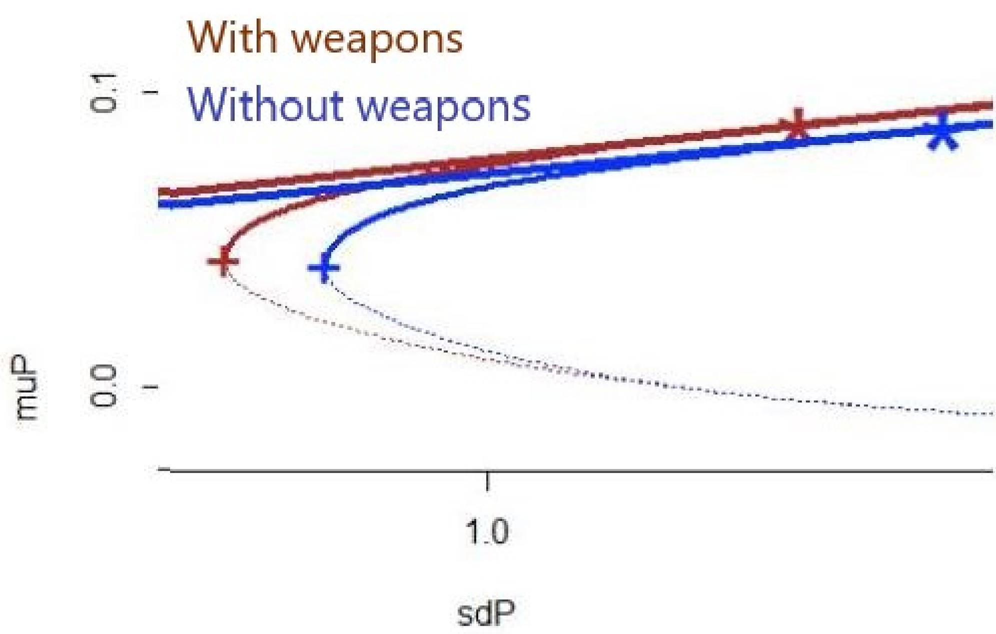
Chapter 5

Two Dimensional Optimisation

5.1 STOXX

In the graph below, we zoom in the efficient frontier for the time period November 2014 till September 2022. As you can see, there is a small difference between the minimum variance portfolio (the "+" in the graph) of the (proxy of the) STOXX50 with and without weapons. Here, the portfolio with weapons consists of 55 stocks and the portfolio without weapons consists of 42 stocks. Apparently, adding these weapon companies does benefit an investment portfolio with respect to decreasing volatility (sdP).

Figure 5.1: The difference between the two efficient frontiers is a decrease in daily volatility (sdP) for a given daily return (muP)



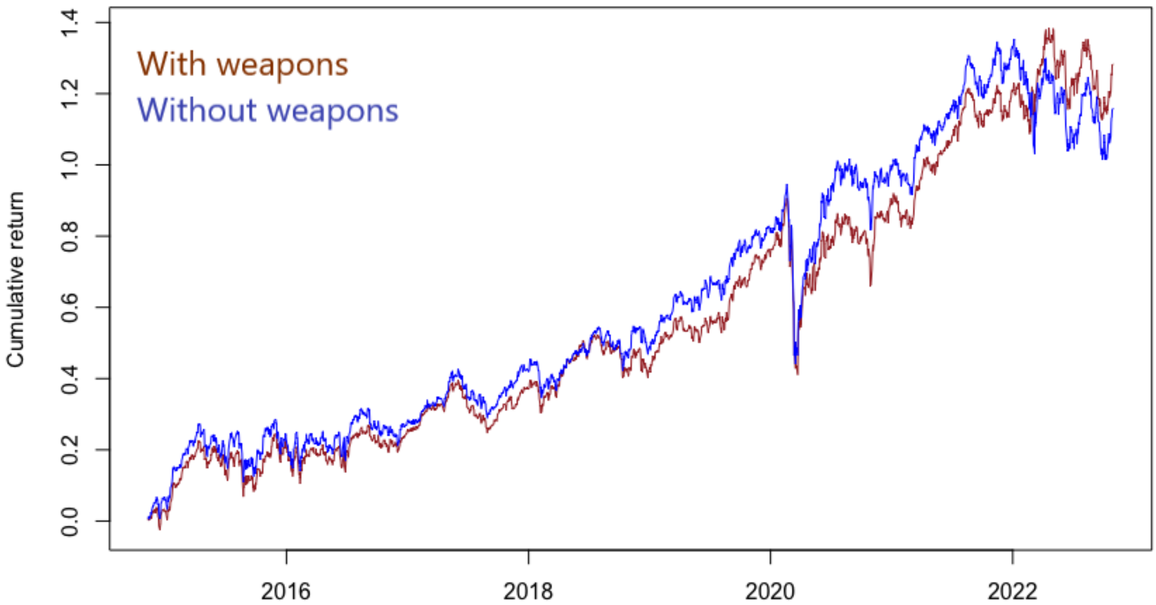
The average ESG risk rating of the minimum-variance portfolio without weapons is 67.93 while the total portfolio has an ESG risk rating of 68.65. This means that by adding weapons, you increase your sustainability risk with 1.1%. In the zoomed in efficient frontier above, you can compare the volatility of the portfolios with and without weapons more closely. In the minimum variance portfolio (the "+" in the graph), the volatility decreases with 3.3% when weapons are included. The difference between the two portfolios is the addition of the following 13 companies:

Name	ESG score	Weight (%)
AIRBUS	70.7	0
BAE SYSTEMS	61.9	9.6
DASSAULT AVIATION	61.7	0
KONGSBERG GRUPPEN	73.7	10.1
LEONARDO	71.5	0
MTU AERO ENGINES	77.6	0
QINETIQ GROUP	83.3	9.4
RHEINMETALL	56.0	0
ROLLS-ROYCE HOLDINGS	71.2	0
SAAB B	76.1	0
SAFRAN	64.3	0
THALES	75.5	0

Table 5.1: Weapon stocks considered in European market

The weights sum up to 29.15%, meaning that the optimal minimum variance portfolio is for almost 30% invested in weapon stocks. All weapon stocks got a weight at least equal to 0%, but due to rounding only three weapon stocks get weights significantly greater than zero.

Figure 5.2: The minimum-variance portfolio including weapon stocks outperformed with respect to cumulative returns from February 2022 onward



The graph above shows how the minimum variance portfolio without weapons behaves similarly to the one with weapons, up to 2022. From 2022 on, the blue line starts to underperform with respect to profitability. This means that the minimum variance portfolio without weapons is counterproductive with respect to both profitability, and volatility, shown above.

5.1.1 Monthly Reshuffle

In the graphs below, the maximum drawdown and Sharpe ratio per month are plotted. Their pattern is similar: a decrease of the Sharpe ratio and increase of the maximum drawdown in March 2020[1] and March 2022 [2]. Their similar behaviour is not surprising as the only difference between the two portfolios are the stocks mentioned in Table 5.1.

[1]Because of COVID-19

[2]Because of the start of the war

Figure 5.3: Both the MD and SR from tangency portfolio with weapons behave similar to the portfolio without weapons

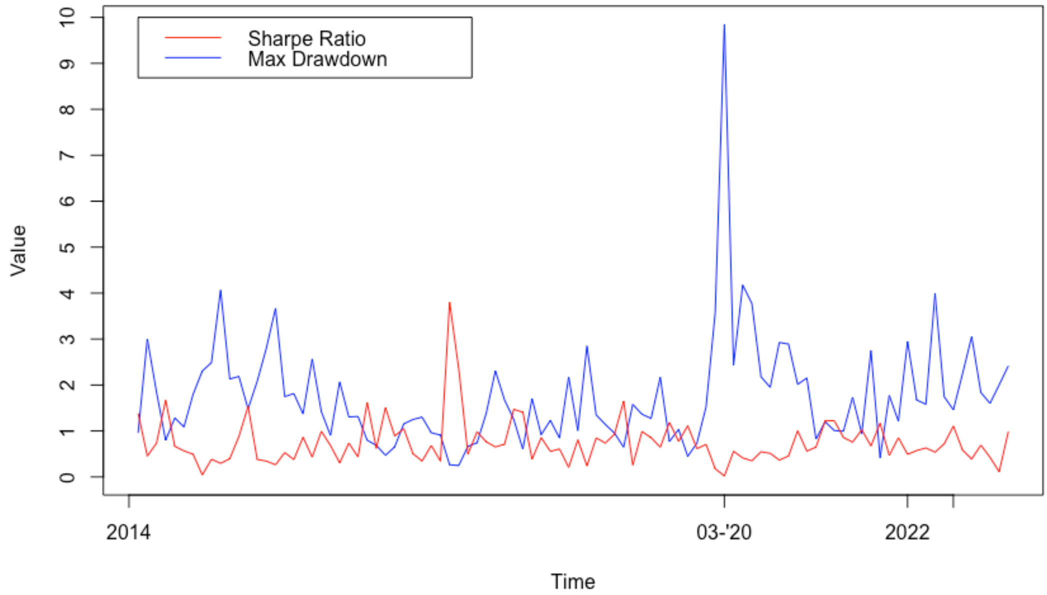
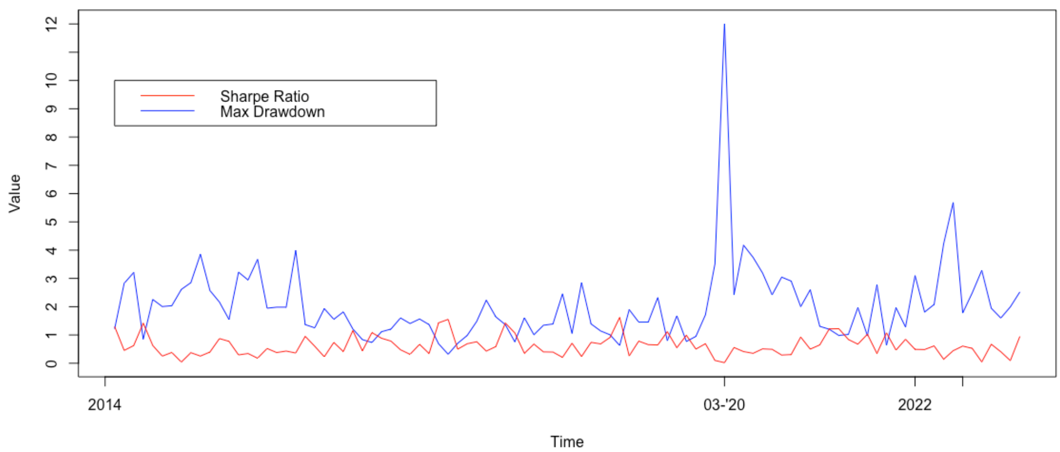


Figure 5.4: MD and SR without weapons



In addition, in the table below, I included the mean (μ) and standard deviation (σ) of the maximum drawdown (MD) and Sharpe ratio (SR) for the portfolio with and the portfolio without weapons. The average monthly maximum drawdown of the portfolio without weapons is 11.4% bigger than the average monthly maximum drawdown of the portfolio with weapons. In addition, the portfolio without weapons has a smaller average monthly Sharpe ratio. Also, the standard deviation of the maximum drawdown of the portfolio without weapons is bigger and the standard deviation of the Sharpe ratio is smaller. The results above therefore show a clear advantage of including weapons into the index.

	μMD	μSR	μESG	$\mu\%Weapons$
Portfolio with weapons	1.76	0.75	70.5	29.3
Portfolio without weapons	2.04	0.62	70.2	
	σMD	σSR	σESG	$\sigma\%Weapons$
Portfolio with weapons	1.22	0.51	4.22	18.2
Portfolio without weapons	1.41	0.35	4.83	

Table 5.2: Summary Statistics Risk Measures

In the graphs in Appendix D you see the development of the ESG ratings of the monthly minimum variance portfolios. For these graphs, the adopted ESG ratings in time series are used, see chapter 3.2. If weapons are not included in the mean-variance analysis, the ESG rating barely improves. In addition, even though there was a strong increase in weapon stocks investments at the beginning of the war in Ukraine, the percentage of weapon stocks in the minimum variance portfolio has been decreasing since 2014.

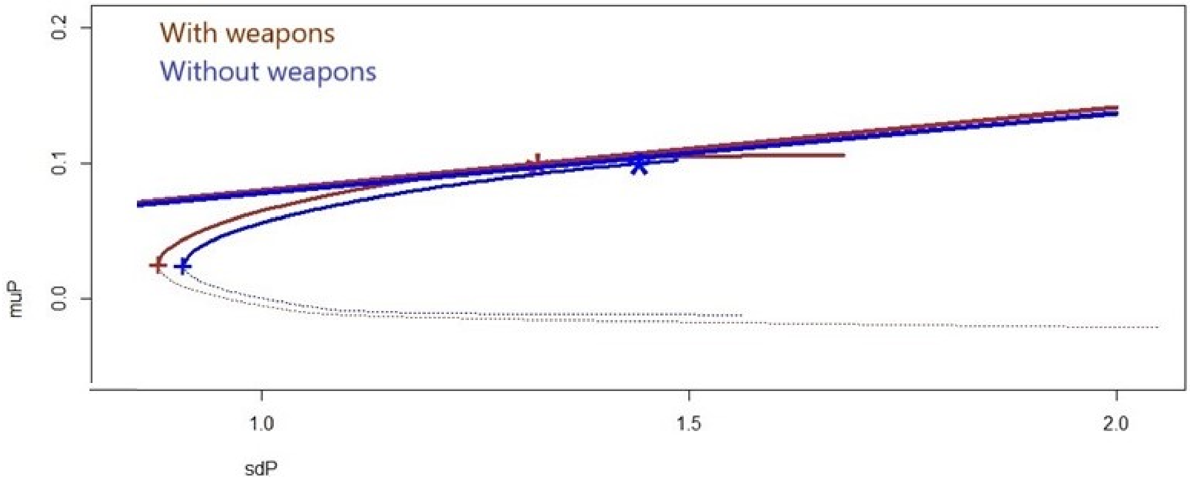
5.1.2 Conclusion

Allowing weapon companies decreases the daily volatility of a minimum variance portfolio with 3.3% while the sustainability risk increases with only 1.1%. Outperformance of portfolios including weapons is a new phenomenon that started in the beginning of 2022, when the war in Ukraine started. Portfolios including weapons also have a Sharpe Ratio that is more than 20% higher than the than a portfolio that excludes weapons.

5.2 Dow Jones

In the graph below, the efficient frontier is plotted for the time period November 2014 till September 2022. Here, the portfolio with weapons consists of 50 stocks and the portfolio without weapons consists of 27 stocks. Apparently, adding these companies only has a small benefit with respect to decrease of portfolio volatility. Because, there is a smaller difference with respect to volatility between the minimum variance portfolio (the "+" in the graph) of the approximation of the Dow Jones index with and without weapons compared to the European market.

Figure 5.5: The difference between the two efficient frontiers is a slight decrease in volatility (sdP) for a given return (muP



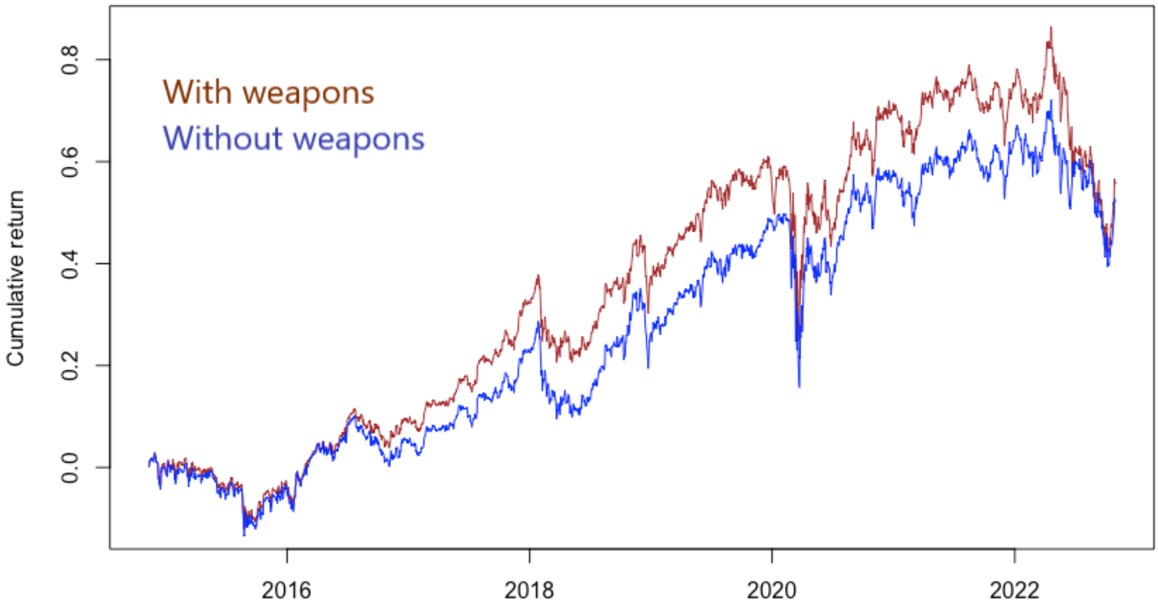
The average ESG rating of the portfolio without weapons is 66.5 while the total portfolio has an ESG of 65.5. The difference between the two portfolios is the addition of the following 23 companies:

Name	ESG score	Weight (%)
AMETEK	47.0	0
AMPHENOL 'A'	56.2	0
BOMBARDIER 'B'	63.3	0.27
CAE	63.9	2.78
CUMMINS	68.6	0.23
CURTISS WRIGHT	52.6	0
EATON	75.3	0
GENERAL DYNAMICS	53.6	0
GENERAL ELECTRIC	63.4	0
HEICO	50.8	1.06
HEXCEL	60.5	0
HONEYWELL INTL.	54.8	0
JACOBS SOLUTIONS	53.2	0
L3HARRIS TECHNOLOGIES	49.9	1.37
LOCKHEED MARTIN	66.8	4.05
MAXAR TECHNOLOGIES	46.7	0
NORTHROP GRUMMAN	67.5	0
RAYTHEON TECHNOLOGIES	62.9	0
SPIRIT AEROSYSTEMS CL.A.	65.8	0
TELEDYNE TECHS.	54.7	0
TEXTRON	57.3	0
THE BOEING COMPANY BDR	54.2	5.78
TRANSDIGM GROUP	50.8	0

Table 5.3: Weapon stocks considered in Northern-American market

The weights sum up to 15.5%, meaning that optimal minimum variance portfolio is for more than 15% invested in weapon stocks. All weapon stocks got a weight at least equal to 0%, but due to rounding only three weapon stocks get significant weights. Also, Eaton acquired Cobham Mission Systems in 2021 and Teledyne acquired FLIR Systems in 2021 [14]. These mergers could have benefited Eaton and Teledyne, however, they both were not included in the minimum variance portfolio.

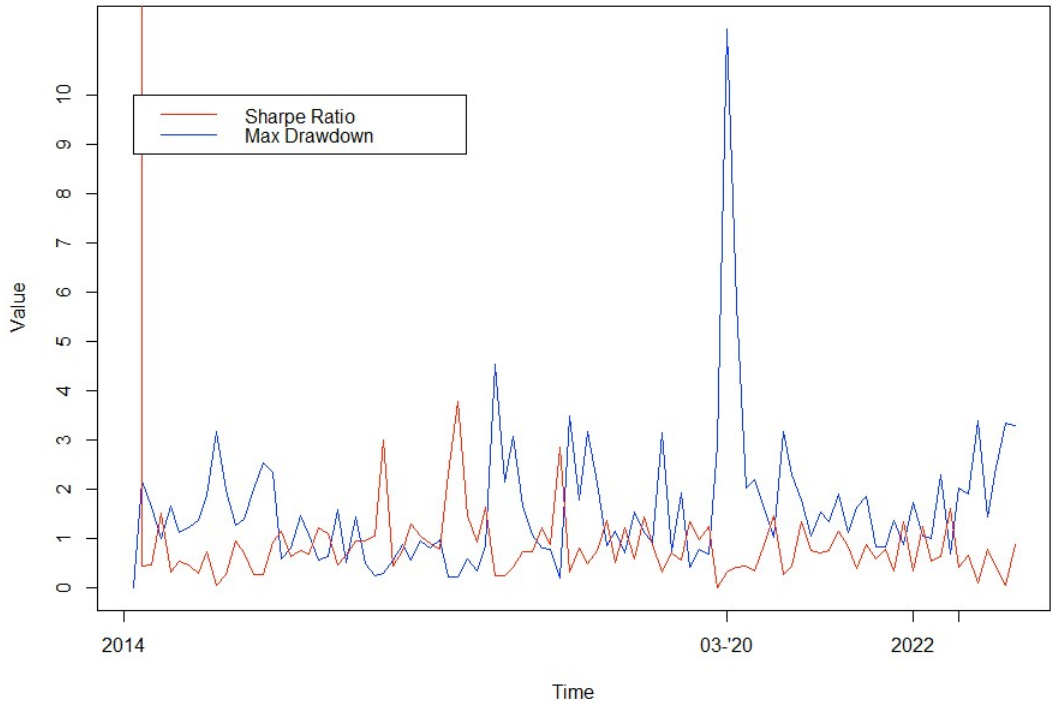
Figure 5.6: Cumulative returns of minimum-variance portfolio with weapons has outperformed the portfolio without weapons since 2017 already



In contrast to section 5.1, here the portfolio with weapons performs better than the portfolio without weapons from 2017 on. For the European market, the phenomenon of outperformance with respect to profitability only started from 2022 on. Therefore, outperformance of weapon stocks in the Northern American market is not only a recent phenomenon. Do note that I have also added more weapon stocks to the Dow Jones than I have done to the STOXX. Hence, the difference between the two lines or portfolios in the graph above is therefore expected to be more emphasized here than in 5.1.

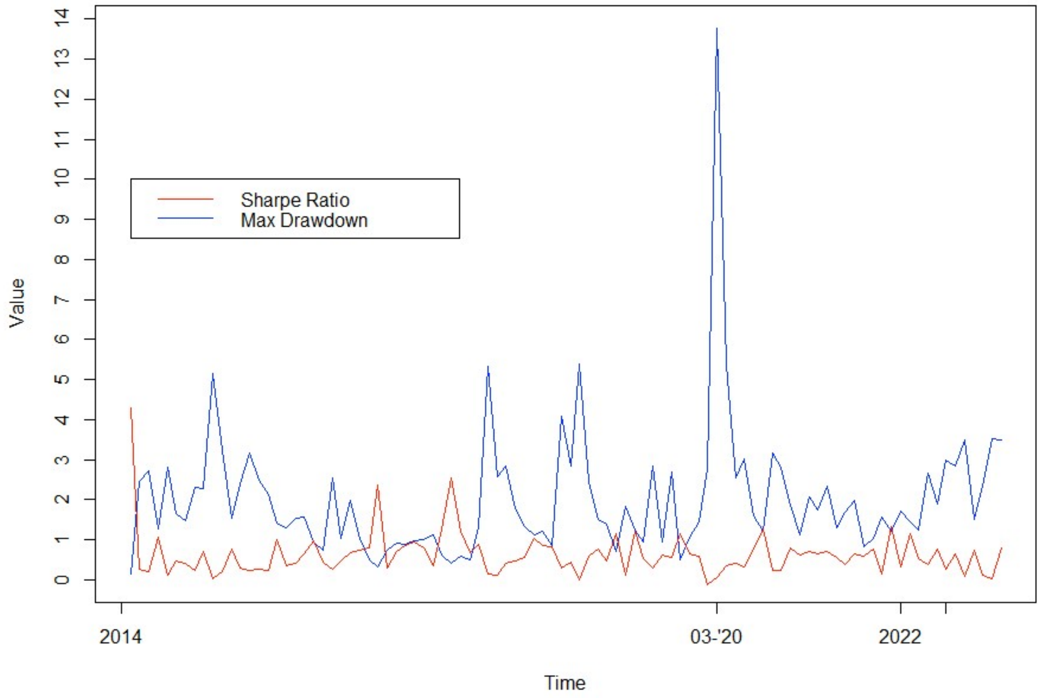
5.2.1 Monthly Reshuffle

Figure 5.7: Both the MD and SR from tangency portfolio with weapons behave similar to the portfolio without weapons



In this graph, and the one below, the maximum drawdown and Sharpe ratio per month are plotted. Again, they follow a similar pattern. A decrease of the Sharpe ratio and increase of the maximum drawdown in March 2020 (because of COVID-19) and March 2022 (because of the start of the war). In addition, the inflated Sharpe ratio in November 2014 is due to an extremely low portfolio volatility in that month ($\sigma_P = 0.0001$ for the tangency portfolio). The efficient frontier of that month is plotted in Appendix E.

Figure 5.8: MD and SR without weapons



In addition, in the table below, I included the mean and standard deviation of the maximum drawdown and Sharpe ratio for the portfolio with and the portfolio without weapons.

	μMD	μSR	μESG	$\mu \% Weapons$
Portfolio with weapons	1.61	0.83	62.7	34.4
Portfolio without weapons	2.02	0.63	65.5	

	σMD	σSR	σESG	$\sigma \% Weapons$
Portfolio with weapons	1.42	0.63	3.84	19.9
Portfolio without weapons	1.64	0.57	3.65	

Table 5.4: Summary Statistics Risk Measures

The average monthly maximum drawdown of the portfolio without weapons is 16.4% bigger than the average monthly maximum drawdown of the portfolio with weapons. In addition, the portfolio without weapons has a smaller average monthly Sharpe ratio. Also, the standard deviation of the maximum drawdown of the portfolio without weapons is bigger and the standard deviation of the Sharpe ratio is smaller. The results above therefore show a clear advantage of including (more) weapons into the index.
In the graph below you see the development of the ESG rating of the monthly minimum variance portfolios with weapons. On the next page, the ESG rating development of the monthly minimum variance portfolios without weapons is shown. For these graphs, the adopted ESG ratings in time series are used, see chapter 3.2.
If weapons are not included in the mean-variance analysis, the ESG risk rating does not increase as much for the portfolio excluding weapons. This is to be expected, as weapon stocks have a higher ESG risk rating on average. However, the percentage of weapon stocks

Figure 5.9: ESG Risk Rating for portfolio with weapons is positively increasing over time

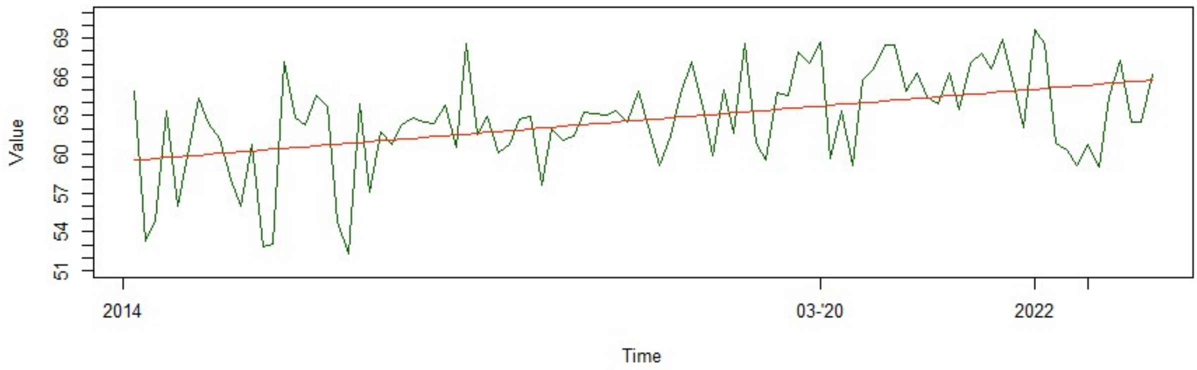
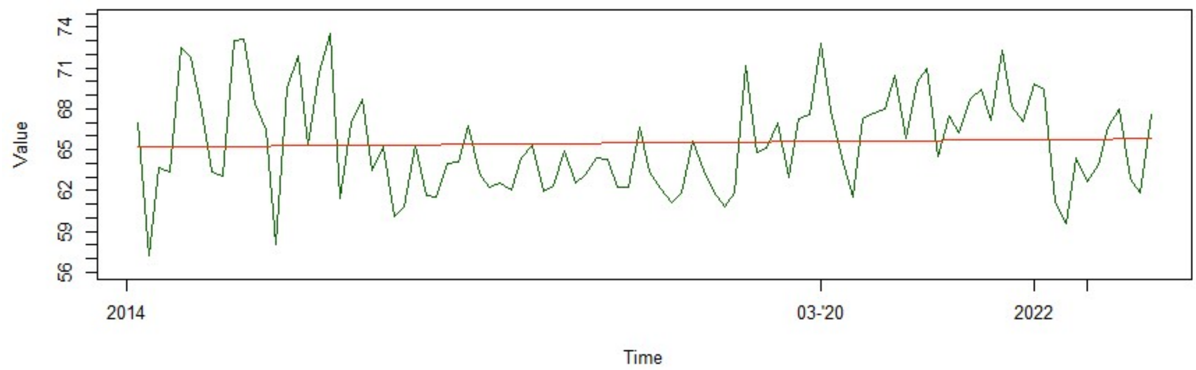


Figure 5.10: ESG Risk Rating for portfolio without weapons is relatively stable over time



decreases in the monthly minimum variance portfolios, see Appendix F. Therefore, the graphs above do not illustrate a clear preference with respect to the addition of weapons from a sustainability perspective.
In addition, there is a very strong increase in weapon stocks at the beginning of the war in Ukraine. This increase is much stronger than the increase in the European weapon stocks from the previous section. However, as mentioned before, the percentage of weapon stocks in the minimum variance portfolio has also been decreasing, on average, since 2014.

5.2.2 Conclusion

Allowing weapon companies decreases the daily volatility less than in the European market. Outperformance of portfolios including weapons is also not a new phenomenon. Portfolios including weapons do have a Sharpe Ratio that is more than 30% higher than those that do not include weapon stocks.

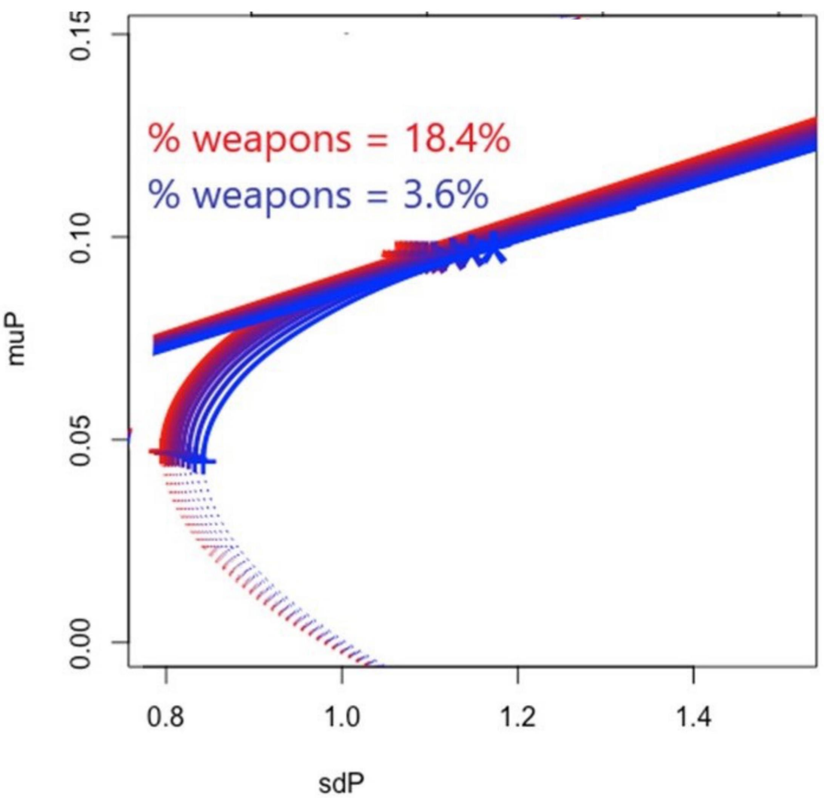
Chapter 6

Three Dimensional Optimisation

6.1 STOXX

From 5.1 I know that approximately 30% of the optimal minimum variance portfolio is invested in weapon stocks. I want to decrease this weight and see the effects on three dimensions: profitability, risk and ESG rating. Note that I do not restrict for short-selling. However, I do not allow short sells that are bigger than (-)1% of the portfolio. Hence, $w_i \geq -0.01$.

Figure 6.1: The efficient frontiers show that the more severe the weapon restrictions, the more volatile (sdP) the minimum-variance portfolio



The figure above describes the behaviour of the efficient frontier when the percentage of weapon stocks is decreased. As expected, the minimum variance portfolio (the "+" in the graph), shows a higher volatility and slightly lower return when the upperbound on weights in total weapon stocks is decreased to 3.6%.

Figure 6.2: Minimum-variance portfolios with less severe weapon restrictions outperform portfolios with more weapon restrictions since February 2022

The outperformance of the red portfolios (with a higher percentage of weapon stocks) to the blue portfolios (with a lower percentage of weapon stocks) becomes more visible in 2022. Before 2022, the portfolio returns behave in a very similar pattern.

Cap	0.05	0.045	0.04	0.035	0.03	0.025	0.02	0.015	0.01	0.005
%Weapon stocks	18.4	17.5	16.3	15.2	13.7	11.5	9.3	6.5	3.6	0.8
%Mean cum. return	64.4	64.7	64.3	64.5	64.8	65.1	64.8	64.3	63.2	62.8

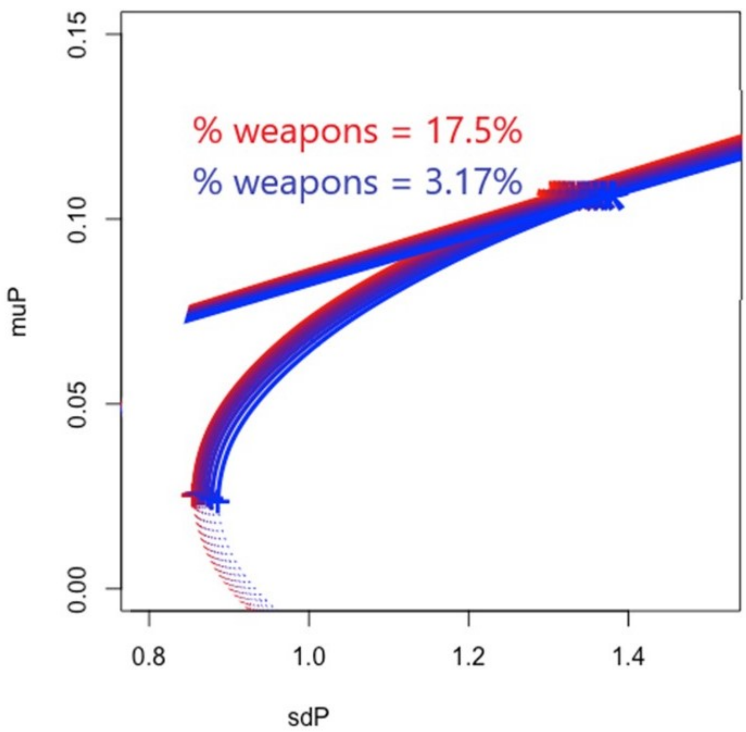
Table 6.1: Effect of an upperbound on weapon stocks

The table above shows how the cumulative return decreases when the percentage of weapon stocks is decreased. However, do take into account that the cumulative return does not strictly decrease.

6.2 Dow Jones

The figure below describes the behaviour of the efficient frontier when the percentage of weapon stocks is decreased. As expected, the minimum variance portfolio (the "+" in the graph), shows a higher volatility and slightly lower return when the percentage is decreased to 3.17%.

Figure 6.3: The efficient frontiers show that the more severe the weapon restrictions, the more volatile (sdP) the minimum-variance portfolio



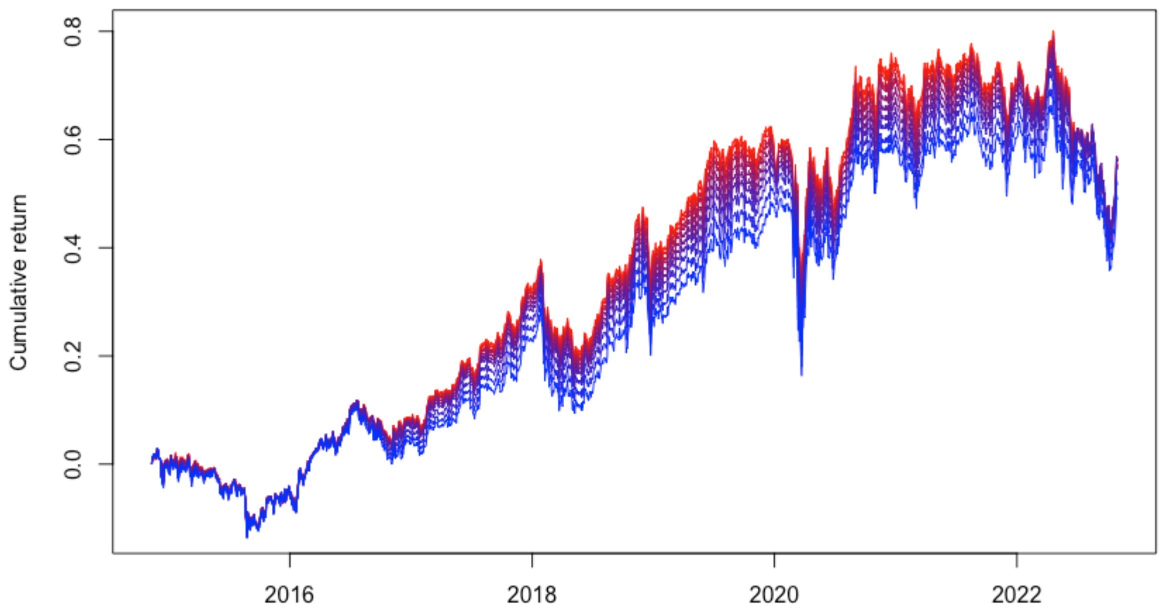
The figure below shows what was also described in 5.2. The outperformance of portfolios with weapon stocks is stronger in the Northern American market than it is in the European market. In other words, an upperbound on weapon stocks has a negative effect on profitability of a portfolio.

Cap	0.05	0.045	0.04	0.035	0.03	0.025	0.02	0.015	0.01
%Weapon stocks	17.5	16.8	15.6	14.5	13.2	11.9	10.2	7.1	3.2
%Mean cum. return	35.8	35.3	34.6	34.5	33.7	32.9	32.1	30.7	28.9

Table 6.2: Effect of an upperbound on weapon stocks

The table above shows how decreasing the percentage of weapon stocks has a strictly decreasing effect on the mean cumulative return.

Figure 6.4: Minimum-variance portfolios with less severe weapon restrictions outperform portfolios with more weapon restrictions since 2017



6.3 Conclusion

Including weapon stocks has had a positive effect on profitability in the Northern American market since 2017, while this only started to be the case for European market since Russia invaded Ukraine in 2022. In both markets, including a larger maximum on weapon stocks will increase the mean cumulative return of a portfolio.

Chapter 7

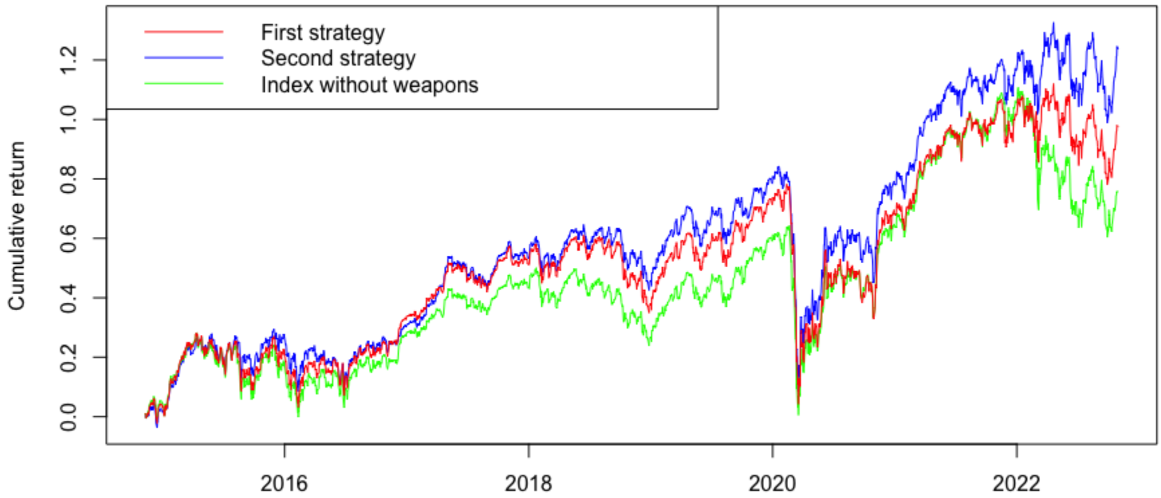
Passive Strategies

Besides focusing on each stock individually, I can also focus on the market index, on the one hand, and my own (ETF inspired) aerospace and defence index, on the other hand. This approach is especially interesting as "greener" portfolios tend to ask higher fees because of their greater demand [2]. This would result in a more passive, and therefore cost efficient, strategy. In this chapter, I will develop two different passive strategies.
The first passive strategy will invest a certain weight w in my own weapon ETF, and will invest $1 - w$ in the STOXX or DOW JONES index. Note that I could have also used a "ready-made" ETF such as "iShares U.S. Aerospace & Defense ETF". However, for sake of uniformity, I decided to create my own Weapon ETF that includes the weapon stocks mentioned in table 5.3 and table 5.1.
In the indexes themselves, all of the companies are assigned equal weights: If there are for example N different weapon companies, I will invest an amount proportional to $\frac{w}{N}$ in each weapon company. And, if there are for example M companies in the market index, I will invest an amount proportional to $\frac{1-w}{M}$ in each market index company.
The second strategy, which is slightly less passive, also invests an amount proportional to $\frac{w}{N}$ in each weapon stock and an amount proportional to $\frac{1-w}{M}$ in each market index company. However, here I use the monthly reshuffle approach again. This means that I change w every month such that I get a new minimum-variance portfolio every month.

7.1 STOXX

The first strategy invests a fixed sum of money proportional to the weight w in the 12 weapon stocks and $1 - w$ in the 42 stocks of the STOXX. The average percentage of weapon stocks from chapter 5 is 29% for the STOXX. Therefore, I take $w = 0.29$. In the graph below you can see how the first, most passive, strategy under performance with respect to the second, less passive strategy. This is to be expected as the second strategy updates w each month such that the variance is minimized while the first strategy takes w as fixed.
However, as I focus here on minimum variance portfolios, the second strategy minimizes the volatility, while maintaining some target expected return. Therefore, I expect the second strategy to minimize volatility, rather than to maximize profitability. Therefore, it is surprising that the second strategy constantly outperforms the first strategy with respect to cumulative returns. However, the second strategy is also more active, meaning that it will update the portfolio weights monthly which can enhance profitability.

Figure 7.1: The more active strategy is more profitable than the most passive strategy



In the graph, I have also included the proxy of the STOXX without weapons (the green line). Here, I have invested an equal weight in every stock of this portfolio. This portfolio is clearly less attractive with respect to cumulative returns than using the first or second strategy.

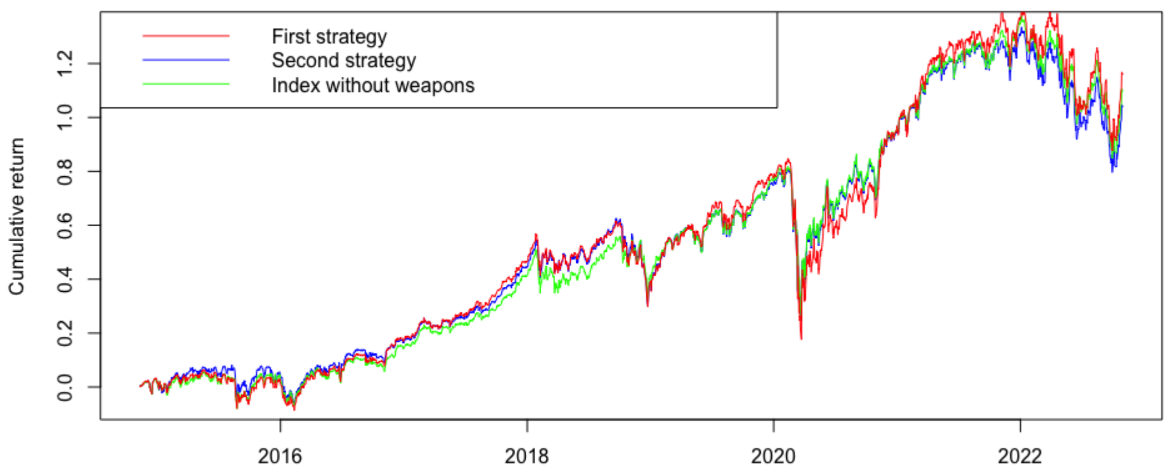
7.1.1 Conclusion

The index without weapon stocks is less favourable than the index with weapon stocks. In addition, a more passive strategy is less favourable to a more active strategy that includes weapons in the European market.

7.2 Dow Jones

The second strategy invests a fixed sum of money proportional to the weight w in the 23 weapon stocks and $1 - w$ in the 27 stocks of the Dow Jones. The average percentage of weapon stocks from chapter 5 is 34% for the Dow Jones. Therefore, I take $w = 0.34$. The second strategy changes w each month such that the variance of the portfolio is minimized. The result of the two strategies is shown in the plot below. As you can see, the first passive strategy has outperformed the second strategy for most of the time. This is different in the European market, where the second strategy outperformed.
This phenomenon has two explanations. First of all, the second strategy invested on average 22% in the "weapon ETF", while the first strategy invested 34% in the "weapon ETF". I have seen in previous chapters that adding weapons to a portfolio, increases the profitability, which explains why the first strategy indeed outperforms. In addition, active strategies do not always outperform more passive strategies.
Secondly, the second strategy minimizes on volatility, and does not necessarily maximize cumulative returns. Therefore, underperformance with respect to returns (and outperformance with respect to lower volatiltiy) is not as surprising.
In the graph, I have also added a third line: a portfolio that excludes weapon stocks and invests equally in every stock of the Dow Jones. This portfolio, the green line, is less favourable than the first strategy from approximately 2021 on.

Figure 7.2: The more active strategy is not always more profitable than the most passive strategy



7.2.1 Conclusion

The difference between the two passive strategies is smaller in the Northern American market. In addition, the index fund without weapons behaves very similarly to the index fund that includes weapons.

Chapter 8

Conclusion

8.1 General Conclusion

In conclusion, adding weapons increases profitability and decreases volatility of an investment portfolio. The effect of adding weapon stocks on sustainability risk of a portfolio differs for the European and Northern American market. In the European market, the volatility decreases three times more than the sustainability risk increases. In the Northern American market, the results on the sustainability risk are more volatile.
In addition, the approach of Sustainalytics to quantifying sustainability risk remains questionable. For the Aerospace and Defense market considered, some aspects of sustainability were ignored in the calculation of the ESG risk rating by giving them a zero weight. This also puts a shadow on the outperformance of Aerospace and Defense stocks with respect to human rights policies in place.
The difference between the European and Northern American market is also shown in the three dimensional optimisation. Including weapon stocks has a more profound effect on profitability for the Northern American Market than it has on the profitability of the European market. Also when the passive strategies are implemented, the Northern American market behaves differently. It is more profitably for the Northern American market to invest passively, i.e., not updating the investment portfolio on the basis of new information.
This thesis has shown how weapon stocks have a profound effect on two out of three dimensions of sustainable investing: profitability and volatility. The effect of the third dimension, sustainability, is less profound, and requires thorough future research.

8.2 Suggestions for future research

To correct the (volatility in) maximum drawdown, one could follow a put option strategy. An option overlay, together with possible other strategies, would be advisable as the maximum drawdown could be decreased in all portfolios considered. An option overlay could decrease increased volatility in times of crisis and increased correlation, for example during COVID-19. A so-called rolling put strategy hedges the increased volatility by including different put options with different maturity dates. However, these option strategies are often costly and ask a lot of discipline of an asset manager as multiple puts need to be bought at different times. Or, multiple calls need to be sold in case you follow

a risk reversal strategy.
In addition, one could look at other risk measures than maximum drawdown and pay-off minimum variance portfolio. Also, the quadratic programming algorithm used gives an approximation of the (weights of) the minimum variance portfolio. It would be advisable to also consider other optimisation algorithms in future research, because different optimisation methods might find different sets of weights that decrease portfolio volatility.
Another critical note on the mean-variance analysis used, is that of the lack of homoskedasticity. The stock returns used are not stationary. Therefore, it is likely that the returns would exhibit volatility clustering. In future research, GARCH estimates of conditional standard deviations of return over the holding period could be used to address this problem. Also, one should take into account that in comparing the portfolios, the portfolios "without" weapon stocks might still have invested in weapon stocks through their own balance sheet. Meaning that the performance of the portfolios without weapons could still be correlated with the performance of weapon stocks.
Besides, the ESG Ratings used from Sustainalytics have not been updated since 2019. For a more accurate analysis, using up-to-date ESG ratings is advisable. And, one should investigate the influence of the risk-free rate through stress-testing, because one should never trust the risk free rate fully: Is risk free really risk free?
In this thesis, I did not consider risk measures as kurtosis or negative skewness in mean-variance optimisation. In some cases, adding more assets seems to introduce undersired negative skewness, and not so much the desired positive skewness. In other words, diversification has a limit as adding more assets could also increase the kurtosis. Correlation in times of crisis also increases, and there exists no tool for this yet. Also, as the ESG database is not up-to-date, you would have to be careful for "Garbage In, Garbage Out": making conclusions based on faulty inputs. One could also use Monte-Carlo rebalances to avoid concentrated portfolios or use other indices than STOXX and Dow Jones.

Appendix A

Environmental Risk Drivers

Drivers of risky environmental scores (in descending order):

- ◇ Operations Incidents
- ◇ Environmental Supply Chain Incidents
- ◇ Product & Service Incidents
- ◇ Environmental Fines & Penalties
- ◇ Environmental Management System
- ◇ EMS Certification
- ◇ Programmes and Targets to Reduce GHG Emissions from own operations
- ◇ Carbon Intensity Trend
- ◇ Carbon Intensity
- ◇ Environmental Policy
- ◇ Supplier Environmental Programmes
- ◇ Scope of GHG Reporting
- ◇ CDP Participation
- ◇ Green Procurement Policy
- ◇ Sustainable Products & Services
- ◇ Clean Technology Revenues
- ◇ Renewable Energy Programmes
- ◇ Renewable Energy Use
- ◇ Supplier Environmental Certifications

Appendix B

Other Risk Measures

B.0.1 Herfindahl-Hirschman Index

Mathematically speaking, the more diversified a portfolio, the lower the probability of unexpected losses. In my analysis, I calculate a set of weights such that the volatility of a portfolio is minimized. Besides that I do not allow for short-selling in 4.6 and I do not allow weapon stocks above a certain weight in 4.7, I do not use any other lower or upperbounds on my weights. Therefore, it is interesting to also investigate the concentration of the weights of my (minimum-variance) portfolio: are there some stocks that get significantly higher weights than others.
This can be calculated through the so-called Herfindahl-Hirschman Index (HHI). This index is equal to the total sum of the squared weights. Therefore, it also corrects for weights smaller than zero:

$$HHI^{-1} = \frac{1}{HHI} = \frac{1}{\sum_{i=1}^{N} w_i^2} \tag{B.1}$$

HHI^{-1} describes the "effective" number of weights that actually participate in the tangency or minimum variance portfolio [3].

B.0.2 Value-at-Risk

Instead of using the volatility, one could also use the Value-at-Risk. This risk measure describes the value at risk at a certain confidence level. The benefit of this risk measure is that it describes an actual value, and not a percentage. It describes how much money is at risk in a worst-case scenario. Implementing this risk measure falls outside the scope of this thesis.

B.0.3 Tail Value-at-Risk

Besides, the Value-at-Risk, the Tail Value-at-Risk is especially important when considering assets with heavy tails (also called kurtosis). This falls outside the scope of this thesis.

B.0.4 Expected Shortfall

The Expected Shortfall describes how much money will be lost in case of a shock. It is mathematically comparable to Value-at-Risk and therefore not regarded in this thesis.

B.0.5 Skewness

In this thesis, I ignore the possibility of skewness and kurtosis. As I focus on diversification, I eliminate undesired variance but this could also eliminate desired (positive) skewness [15]. Underestimation of positive skewness, the standardized third moment, means that the portfolio is not maximized with respect to return. This falls outside the scope of this thesis as I focus on minimum-variance portfolios and not so much on tangency portfolios.

B.0.6 Kurtosis

Kurtosis, the standardised fourth moment, describes the fatness of the tails. By decreasing for volatility, and not kurtosis, I might underestimate the "worst-case" tail events. Especially in light of the crisis of 2008, this is something that should be taken into account for future research.

Appendix C

Overview of Stocks Used

C.1 STOXX

Name	ESG score	Avg. ESG score	Exp. Return (%)	Vol (%)
AB InBev	20.6	66.5	-0.01	1.84
Adidas AG	13.6	75.7	0.04	1.87
Ahold Delhaize	20.8	63.3	0.05	1.37
Airbus	25.8	70.7	0.07	2.38
Allianz SE	16.7	83.9	0.03	1.51
ASML Holdings	10.9	82.7	0.11	2.01
AXA	16.7	76.7	0.03	1.78
Bae Systems	30.3	61.9	0.04	1.47
Banco Bilbao	22.5	72.1	0.01	2.21
Banco Santander	23.9	68.4	-0.01	2.25
BASF	28.3	72.2	-0.01	1.70
Bayer AG	29.4	69.7	-0.02	1.81
BMW	27.5	75.8	0.01	1.79
BNP Paribas	25.4	78.3	0.02	2.1
CRH PLC ord	21.4	72.3	0.05	1.91
Dassault Aviation	32.3	61.7	0.03	1.85
Danone	19.6	73.4	0.01	1.31
Deutsche Boerse	12.2	74.4	0.06	1.47
Deutsche Post	15.2	76.2	0.03	1.67
Deutsche Telekom	16	83.7	0.03	1.36
Enel	22.8	64.3	0.02	1.62
ENI	27.5	80.5	0.01	1.84
Essilorluxottica	19.7	75.5	0.04	1.60
Flutter Entertain	24.7	51.5	0.06	2.16
Hermès International	10.3	50.7	0.09	1.54
Iberdrola	19.9	80.1	0.06	1.34
Infineon Technologies	17.9	75.8	0.08	2.28
ING Groep	22.3	83.7	0.02	2.2
Intesa	15.4	81.9	0.02	2.18
Kering	10.7	78.8	0.08	1.93

The ESG score is attrieved from Sustainalytics website and the volatility is calculated through "STDEV" in excel: assuming a normal distribution of returns.

Name	ESG score	Avg. ESG score	Exp. Return (%)	Vol (%)
Kongsberg Gruppenn	25.8	73.7	0.07	1.87
L'Oreal	18	77.9	0.06	1.42
Leonardo	21.2	71.5	0.03	2.4
Linde PLC	8.2	66.4	0.05	1.49
LVMH	12.2	72.3	0.10	1.74
Mercedes	22.1	72.0	0.03	1.99
MTU Aero Engines	27.7	77.6	0.07	2.22
Nokia	12.2	81.9	0.01	2.18
Nordea Bank	21.7	78.3	0.02	1.66
Pernod Ricard	15.5	71.8	0.04	1.32
Qinetiq Group	25.0	83.3	0.04	1.62
Rheinmetall	28.3	56.0	0.11	2.35
Rolls-Royce Holdings	25.4	71.2	-0.01	3.13
SAAB B	25.0	76.1	0.05	1.92
Sanofi	21.6	72.8	0.02	1.38
Safran	23.2	64.3	0.06	2.22
SAP	10.9	77.3	0.04	1.57
Schneider	17.5	82.4	0.05	1.71
Siemens	30.1	73.6	0.03	1.64
Thales	22.7	75.5	0.07	1.66
Total Energies	30.3	80.3	0.02	1.82
Vinci	27	64.0	0.05	1.74
Volkswagen	26.1	61.6	0.03	2.42
Vonovia	6.7	51.0	0.01	1.6

C.2 Dow Jones

Name	ESG score	Avg. ESG score	Exp. Return (%)	Vol (%)
3M Company	33.6	63.8	0	1.48
American Express	18.4	57.4	0.04	2.02
Ametek	24.1	47.0	0.06	1.58
Amgen	21.9	59.5	0.04	1.59
Amphenol 'A'	21.3	56.2	0.07	1.53
Apple Inc.	16.7	67.7	0.10	1.87
Bombardier 'B'	33.1	63.3	0.025	4.21
CAE	25.8	63.9	0.05	2.18
Caterpillar	34.2	60.8	0.06	1.92
Chevron Corporation	38.3	57.9	0.04	1.98
Cisco Systems	12.8	79.6	0.04	1.65
Coca-Cola	22.5	68.1	0.02	1.19
Cummins	19.4	68.6	0.04	1.74
Curtiss Wright	38.2	52.6	0.06	1.88
Eaton	17.8	75.3	0.05	1.79
General Dynamics	34.9	53.6	0.04	1.46
General Electric	40.4	63.4	-0.02	2.3
Goldman Sachs	25.8	67.8	0.05	1.87
Heico	38.3	50.8	0.11	1.93
Hexcel	29.2	60.5	0.04	2.37
Home Depot	12.5	66.0	0.07	1.57
Honeywell	29.1	54.8	0.05	1.50
International Business Machines	14.8	74.5	0.01	1.56
Intel Corporation	17.3	85.8	0.01	2.05
Jacobs Solutions	22.8	53.2	0.06	1.79
Johnson & Johnson	25	72.1	0.03	1.17
JPMorgan	29.3	71.2	0.05	1.80
L3Harris Technologies	23.5	49.9	0.08	1.65
Lockheed Martin	30.3	66.8	0.06	1.47
Maxar Technologies	21.4	46.7	0.03	4.12
McDonald's	24.3	57.6	0.06	1.36
Merck & Co	21.6	69.7	0.04	1.39
Microsoft	15.2	72.7	0.09	1.75

Name	ESG score	Avg. ESG score	Exp. Return (%)	Vol (%)
Nike	17	65.6	0.05	1.83
Northrop Grumman	26.9	67.5	0.08	1.57
Procter & Gamble	26.6	65.4	0.03	1.22
Raytheon Technologies	36	62.9	0.03	1.76
Salesforce	13.2	67.9	0.07	2.20
Spirit Aerosystems CL.A.	32.1	65.8	0.02	3.19
Teledyne Techs.	35.5	54.7	0.08	1.78
Textron	33.8	57.3	0.05	2.19
The Boeing Company	34.6	54.2	-0.01	3.47
Transdigm Group	39.1	50.8	0.08	2.24
Travellers Companies	20.5	56.2	0.04	1.54
UnitedHealth	17.4	62.4	0.10	1.67
Verizon	18.5	70.2	-0.01	1.19
Visa Inc.	16.4	62.2	0.07	1.63
Walgreens	16.3	57.8	-0.01	1.87
Walmart Inc.	24.6	58.9	0.04	1.39
Walt Disney	14.9	64.1	0.02	1.72

Appendix D

ESG Rating Development STOXX Portfolios

Figure D.1: ESG Rating development with weapons

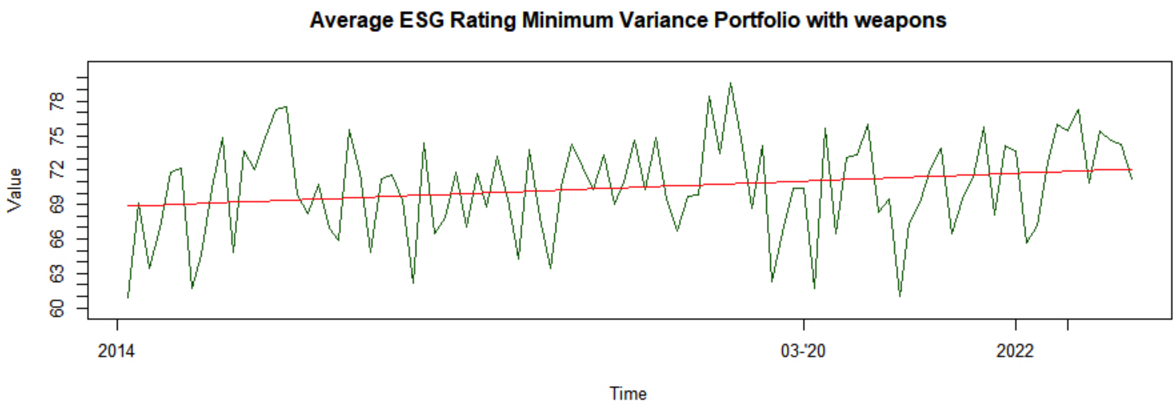


Figure D.2: ESG Rating development without weapons

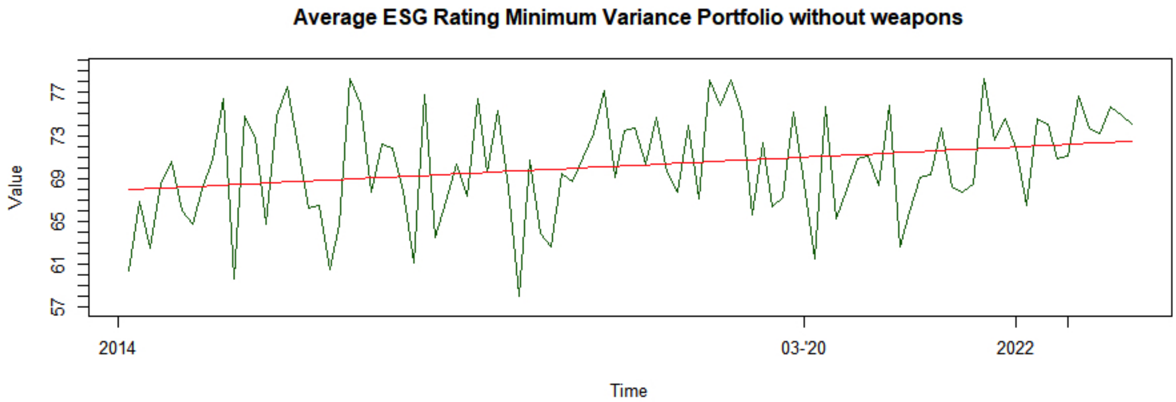
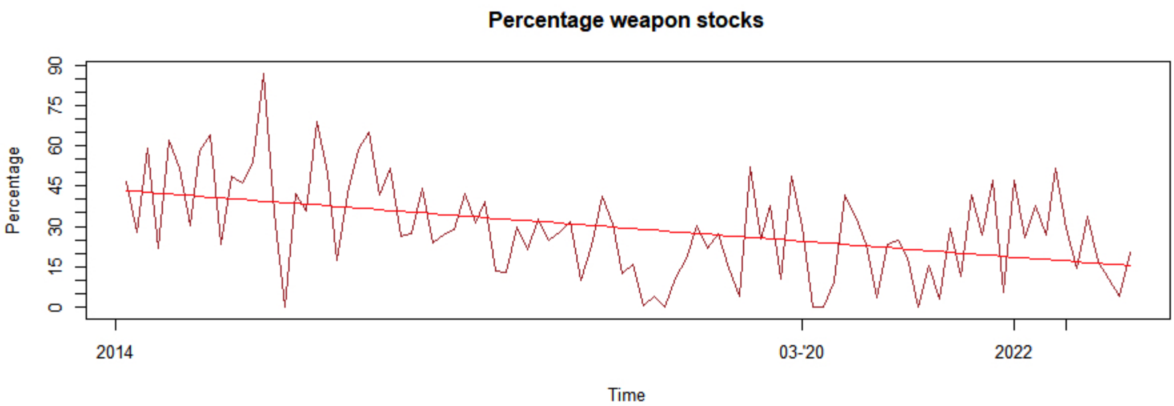


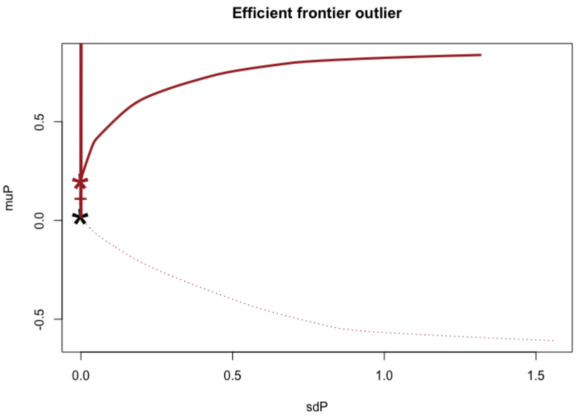
Figure D.3: Percentage weapon stocks



Appendix E

Efficient Frontier Outlier Dow Jones

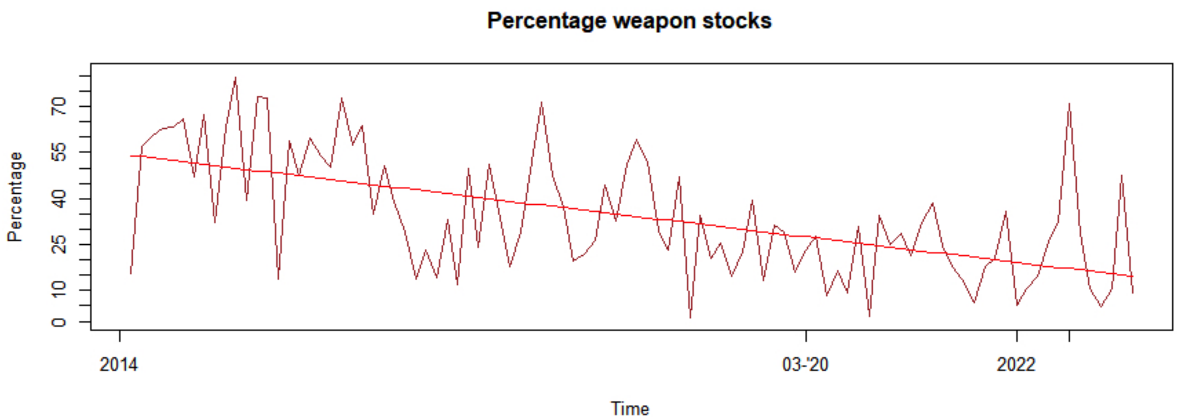
Figure E.1: Efficient frontier outlier Dow Jones



Appendix F

ESG Rating Development Dow Jones Portfolios

Figure F.1: Percentage weapon stocks



Appendix G

STOXX600

Figure G.1: Efficient frontier of STOXX600 with and without weapons

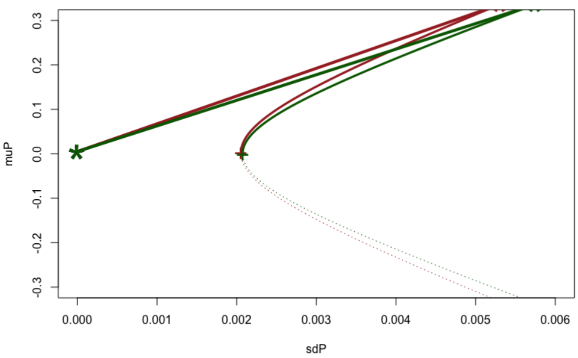
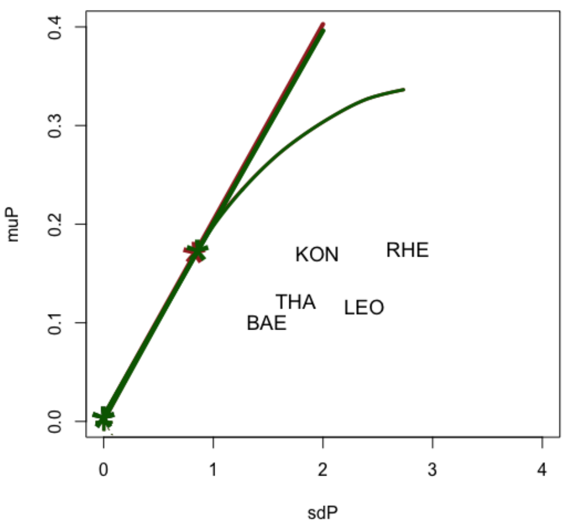


Figure G.2: Efficient frontier of STOXX600 with and without weapons, not allowing for short selling



Bibliography

[1] P. Nilsson A. Mooney. *Why did so many ESG funds back Boohoo?* URL: https://www.ft.com/content/ead7daea-0457-4a0d-9175-93452f0878ec.

[2] S. Rajgopal A. Raghunandan. "Do ESG funds make stakeholder-friendly investments?" In: *Review of Accounting Studies* (2022), pp. 822–863.

[3] S.V. Ramasubramanian A. Vaibhav. "Generalized Herfindahl-Hirschman Index to Estimate Diversity Score of a Portfolio across Multiple Correlated Sectors." In: *Dvara Research Working Paper Series* (2015), pp. 1–8.

[4] A. Singh et al. "Recalibration of priorities: Investor preference and Russia-Ukraine conflict." In: *Finance Research Letters* (2022), pp. 1–6.

[5] Bloomberg. *Defense Stocks Are Beating the SP 500 This Year Amid Ukraine War.* URL: https://www.bloomberg.com/news/articles/2022-05-27/russia-china-threats-buoy-us-defense-stocks-in-turbulent-times?leadSource=uverify%20wall.

[6] L. Ohnesorge E. Rogge. "The Role of ESG Rating Agencies and Market Efficiency in Europe's Climate Policy." In: *Hastings Environmental Law Journal volume 28* (2022), pp. 1–38.

[7] S. Hickey. *Large cap ESG funds perform worse than non-sustainable counterparts.* URL: https://www.ftadviser.com/investments/2022/07/13/large-cap-esg-funds-perform-worse-than-non-sustainable-counterparts/.

[8] C. Zhang L. Chen Y. Chen. "Sustainable Investing During the War in Ukraine." In: *University of Exeter* (2022), pp. 1–54.

[9] C. North L. Davison F. McNally. *ESG: EU Regulatory Change and Its Implications.* URL: https://corpgov.law.harvard.edu/2023/02/18/esg-eu-regulatory-change-and-its-implications/.

[10] A. Magdon-Ismail M. Atiya. "Maximum drawdown." In: *Risk Magazine* (2004), pp. 99–102.

[11] R. Peres. *Wirecard is a scar on Germany's corporate landscape.* URL: https://www.ft.com/content/63edde75-642d-40ae-aa25-20e22e01705c.

[12] M. Rubinstein. "Markowitz's "Portfolio Selection": A Fifty-Year Retrospective." In: *Journal of Finance* (2002), pp. 1041–1045.

[13] K. Schilde. "Weaponising Europe? Rule-makers and rule-takers in the EU regulatory security state." In: *Journal of European Public Policy* (2023), pp. 1–26.

[14] SIPRI. *SIPRI Arms Industry Database 2022.* URL: https://www.sipri.org/databases/armsindustry.

[15] K. Vorkink T. Mitton. "Equilibrium Underdiversification and the Preference for Skewness." In: *The Review of Financial Studies* (2007), pp. 1255–1288.

[16] Financial Times. *Ukraine invasion news from February 24: Russian forces storm Ukraine, civilians flee Kyiv, west unveils new sanctions.* URL: `https://www.ft.com/content/5b423554-6ce9-49fe-b74c-da41298b565f`.

[17] D. S. uppert D. Matteson. *Statistics and Data Analysis for Financial Engineering.* Springer Texts in Statistics, 2015.

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