Master's thesis

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The all-weather portfolio

A review of Bridgewater Associates investment strategy: The all-weather portfolio

Master's thesis in Economics and Business Administration
Supervisor: Denis M. Becker
May 2021

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Preface

The master thesis is written as a part of NTNU Handelshøyskolens master program in Economics and Business Administration. This is a master thesis in the field of Finance and Investment spring 2021. The thesis examines one of Bridgewater's investing strategies and the choice of theme is due to the authors' common interest in finance and investment strategies.

The process has been both time demanding and challenging, but also instructive and educational. We would like to thank our supervisor Denis M. Becker for all the help and constructive feedback along the way.

The authors take full responsibility for the content of this thesis. NTNU does not have any responsibility for the content or views in the thesis.

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Abstract

The objective of this thesis is to investigate the relevance of the all-weather portfolio, created by Bridgewater Associates, and compare it with two traditional portfolios: 60/40 and all-equity. In addition, the assumptions made by Bridgewater Associates regarding the all-weather portfolio is examined. Using quarterly data from 1970 to 2021, we explore how the portfolios perform in terms of historical returns and different risk- and drawdowns measurements. Furthermore, we tested whether asset classes have biases to perform better in different economic states using average return and OLS regression. We further calculated the historical Sharpe ratio to test Bridgewater's assumptions that all assets have a similar risk-adjusted return. We find that the all-weather portfolio provides a higher risk-adjusted return than the 60/40 and all-equity portfolios, and that it has a lower downside risk for the sample period. However, we cannot confirm that the assumptions in Bridgewater Associates theory are valid. The relationship between asset classes with inflation and economic growth showed rather inconsistent results. Further, the assumption of similar risk-adjusted return for the asset classes were also rejected as the results exhibited a large difference in Sharpe ratio. Altogether, the results obtained from this thesis indicate that the portfolio has a higher risk-adjusted return and lower downside risk for our sample period. However, we cannot confirm that this is because of the relationships proposed by Bridgewater Associates.

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1 Introduction

Since the early 1980 the yield on US treasuries have been steadily falling until March 2020 when the 10-year US treasury bond hit an all-time low at 0.54% (U.S. Department of the Treasury, 2021). Ever-falling interest rates are bad news for investors in general and this has led many to increase the share of equities in their portfolio to achieve a higher expected return. The traditional portfolio allocation strategy where one invests 60 percent in equities and 40 percent in government bonds may not give a satisfactory return as the general yields are expected to remain low for the foreseeable future (Blanchard, 2019). Some advisors are now suggesting that a long-term investor should invest all their money into equity because of its higher expected return (Lian et al., 2019).

However, history has shown that investing all your money in equity is a very risky approach as the stock market has a tendency to become highly correlated and have big declines during economic turmoil (Bruder & Roncalli, 2012). In addition to being highly volatile during economic turmoil's, the stock market also tends to go into longer periods with low and even negative returns. Being equity heavy is unfortunately the conventional method that the world's pension funds have taken, and this leads to a high concentration in equity risk (Prince, 2011).

Bridgewater's founder Ray Dalio proposes the all-weather portfolio as the solution for the age-old problem of how to best allocate capital. The goal of this type of investment strategy is to perform well in all economic environments, thereby minimizing the downside without giving up too much of the expected return. Dalio (2004) has stated that the portfolio has approximately the same level of return as the stock market, but a significantly lower downside risk, making it an investment that is superior to the 60/40 and all-equity portfolios.

The primary objective of this thesis is to analyse whether a portfolio constructed on the basis of the all-weather portfolio principles would have a low downside risk and still yield a satisfying return. In addition, we investigate the assumptions made by Dalio and Bridgewater regarding the all-weather portfolio. First, that there is a timeless and reliable relationship between asset classes and macroeconomic risk factors, such as inflation and economic growth. Second, that all asset classes have approximately the same risk-adjusted return. To limit the size of the task, we have chosen to use macro-economic data from the United States, since the U.S. economy is the largest and most influential.

The following research question has been formulated for this research:

How does the all-weather portfolio perform compared to the 60/40 and all-equity portfolios, and are the assumptions for the all-weather portfolio valid?

This research question is further tested by the following three hypotheses.

Null hypothesis 1: The all-weather portfolio does not have a higher risk-adjusted return and lower downside risk than the 60/40 and all-equity portfolios.

Null hypothesis 2: Asset classes do not have a tendency to perform better in the preferred economic state as defined in Table 3.1.

Null hypothesis 3: The different asset classes do not have similar risk-adjusted excess return.

The first hypothesis is a test of the historical performance of the all-weather portfolio, and the second and third hypothesis is a test of the most important assumptions that Bridgewater Associates makes regarding the all-weather portfolio.

The rest of this thesis is structured as follows. Chapter 2 reviews the financial theory regarding factor models and modern portfolio theory. The risk parity approach is also examined to identify whether it can solve some of the problems with modern portfolio theory. Furthermore, Bridgewater's philosophy is reviewed with the focus on the assumptions on which the all-weather portfolio is based. Chapter 3 presents the dataset and examines how the returns and the dependent and independent variables are calculated. The methodology for the construction of the all-weather portfolio, backtesting, testing asset class bias, and testing risk-adjusted return are also presented in this chapter. Chapter 4 presents and discusses the results of the three tests conducted. Chapter 5 summarizes the results and concludes the thesis.

2 Literature review

This chapter summarizes theoretical statements and empirical findings from previous research literature on factor models, modern portfolio theory and risk parity. Moreover, different literature is reviewed to examine the potential and credibility of the all-weather portfolio.

2.1 Theoretical framework

2.1.1 Factor models

Risk factor models are an approach where one uses the underlying risk factors and their risk premium as a means to explain the risk premiums on asset classes. Factor models generally decompose the return on assets into two types of components; the first type is correlated across assets and is often referred to as the underlying risk factors. These are believed to have an effect on all assets, but to a varying degree (Ang, 2014). The second type is asset specific and is therefore not correlated across assets.

The first factor model is the capital asset pricing model (CAPM) used by Sharpe (1964), Lintner (1965), and Mossin (1966). The CAPM takes only the market risk factor into account and is therefore most applicable for equities. The sensitivity towards the market risk factor is often referred to as the market beta, and the size of this beta reflects how much the assets change, on average, when the overall stock market changes by 1%. The market beta is a measure of the inherent risk in the equity market as a whole. This is often referred to as the systematic risk, and it cannot be diversified away.

The CAPM (Sharpe, 1964), (Lintner, 1965) and (Mossin, 1966) is defined as:

$$E(R_i) - R_f = \alpha_i + \beta_i\left[E(R_M) - R_f\right] + \varepsilon_i \tag{1}$$

where $E(R_i)$ is the expected return on the asset, R_f is the risk-free rate, α_i is the pricing error, β_i is the beta coefficient of the market factor, $E(R_M)$ is the expected return of the market portfolio, $E(R_M) - R_f$ is the market excess return (i.e., market factor), and ε_i is the residual.

Another popular approach is the arbitrage pricing theory (APT) put forward by Ross (1976), which is a multiple factor model. Examples of this are the extensions to the CAPM by Fama and French (1996), Carhart (1997), and Pástor and Stambaugh (2003), among others. These models include factors such as value, size, momentum, liquidity, and volatility and are applied in the same manner as the CAPM where one identifies beta coefficients for each risk factor. These coefficients demonstrate how sensitive the asset is towards the underlying risk factor. A key feature of both the CAPM and the APT is that there is a linear relation between asset risk premium and the risk premium associated with one or several risk factors (Barucci & Fontana, 2017).

The APT (Ross, 1976) is defined as:

$$E(R_i) - R_f = \alpha_i + \beta_i' f + \varepsilon_i \tag{2}$$

where $E(R_i)$ is the expected return on asset i, R_f is the risk-free rate, α_i is the pricing error, $\beta_i{}'$ is the vector of factor loadings, f is the risk factors, and ε_i is the residual.

Leite et al., (2020) examined whether the risk factors of the Fama-French five-factor model could be proxies for macro risk factors. They found that when aggregate dividend yield, term spread, default spread, one-month T-bill and consumer price index (CPI) are included; high minus low (HML), small minus big (SMB), and robust minus weak (RMW) lose their explanatory ability. This indicates that macro variables may be the real underlying risk factors.

Risk factors can generally be categorized into three types: investment, dynamic, and macro factors (Ang, 2014). In this thesis, the focus is on macro factors because they are more universal for all asset classes, which is in line with the view of Bridgewater Associates – see Chapter 2.2.

The application of risk factor models means that all asset returns can be explained by a linear combination of risk factors, risk premiums (beta coefficient), and a random component (the residual) that is often referred to as an unsystematic risk component or idiosyncratic risk component. The idiosyncratic risk component is bigger for single securities, such as a single stock, and this component gets smaller as the number of securities in the portfolio increases (Mokkelbost, 1971). This implies that an allocation to whole asset classes will reduce the importance of idiosyncratic risk, and thereby increase the importance of systematic risk factors.

2.1.2 Modern portfolio theory

Modern portfolio theory (MPT) – also known as the mean-variance model – was first put forward by Markowitz (1952). In his article ‘Portfolio Selection’ he describes a framework in which an optimizing investor is looking to maximize the return for a given level of risk. The main idea is that if one has several assets that are less than perfectly correlated one could obtain a higher expected return for a given level of risk by combining the assets. The author assumed that the world is uncertain, and that each investment has a probability distribution of potential outcomes, where one can only estimate the expected return and expected risk level (variance or volatility). Since it is not known which asset class will have the highest rate of return, the rational investor will diversify across multiple assets (Markowitz, 1991).

According to Markowitz (1991), investors have different levels of risk aversion. This implies that investors may obtain the same amount of utility from portfolios with different risk levels. This is because as long as the portfolio is placed on the efficient frontier, no other portfolio will give investors the same amount of return, without increasing the risk of the portfolio (Markowitz, 1991). Thus, investors with different levels of preferred risk have different optimal portfolios.

Markowitz (1991) further states that for risk averse investors the optimal portfolio is the tangency portfolio. This is the portfolio in which all the unsystematic risk is diversified away, leaving only systematic risk. Furthermore, given that the equity market is in equilibrium, the market weight index would be the tangent portfolio. For a portfolio consisting of different asset classes, the optimal portfolio would not be as easy to identify. However, one will find the optimal portfolio by maximizing the Sharpe ratio.

The Sharpe ratio is one of the most common measurements of risk-adjusted return (Sharpe, 1994). By dividing the expected asset class return above the risk-free rate with the standard deviation of the asset one obtains the Sharpe ratio – see Chapter 3.7 for more details.

$$Sharpe\ ratio = \frac{R_A - R_f}{\sigma_A} \tag{3}$$

The Markowitz (1952) mean-variance model is a simple and intuitive approach to portfolio optimization. However, it has some major drawbacks. The optimal portfolio depends on the expectations of returns, standard deviations, and the correlation between the different asset classes, and it is therefore highly sensitive to errors and changes in the input parameters.

Destabilization of the correlation between assets and identifying which assets have the highest expected return over time are examples of problems with the input parameters. The 2007–2009 subprime crisis demonstrated that the mean-variance approach is not a truly effective diversification method, as correlations tend to increase during economic crises (Bruder & Roncalli, 2012).

Therefore, since the subprime crisis, the asset management industry has become increasingly focused on risk management. One of the solutions developed is to allocate based on risk instead of the market value of the different assets.

2.1.3 Risk factor parity

In contrast to MPT, risk parity focuses on the allocation of risk, thus equally weighting the amount of risk that each part of the portfolio contributes to the total portfolio (Martellini & Tarelli, 2015). The goal is to balance risk to gain the optimal level of return at a preferred risk level, and to avoid long periods of poor performance. This approach bears a strong resemblance to the ideas behind the all-weather portfolio, and Bridgewater Associates even claim that their strategy is 'the foundation of the risk parity movement' (Bridgewater Associates, 2012, p.1).

There are many definitions of risk, and variance or volatility have traditionally been used as the standard measurement of risk. Alternative proxies for the risk of an asset class are value at risk, conditional value at risk, and the market beta value (Szegö, 2002). According to Shahidi (2014), it is important to factor in the volatility of the asset class in the asset allocation process. This is because highly volatile asset classes tend to fluctuate more around average return than less volatile asset classes. Thus, less volatile asset classes will have a lower impact on the portfolio over time, in terms of how they affect the return. However, by allocating a larger amount to the less volatile assets, one can ensure that the impact of fluctuations in the various assets in the portfolio is approximately the same; thereby ensuring that the portfolio's return is approximately the same in all states of the economy.

Qian (2011) studied how the risk of the different components in a traditional 60/40 portfolio contributed to the portfolio's overall risk. He found that because equities were more volatile than bonds, the risk contribution of equities was 92% – see Figure 2.1.

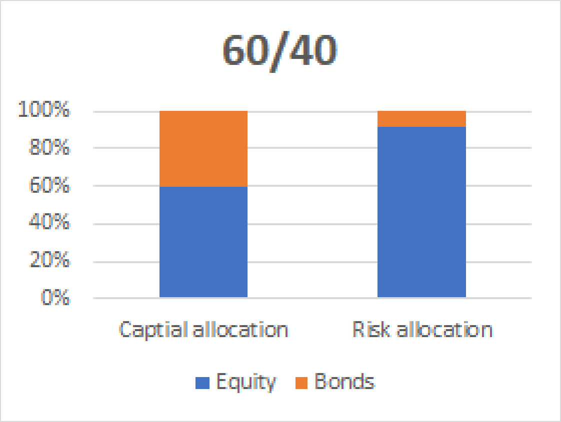

Figure 2.1 - Capital and risk allocation in 60/40

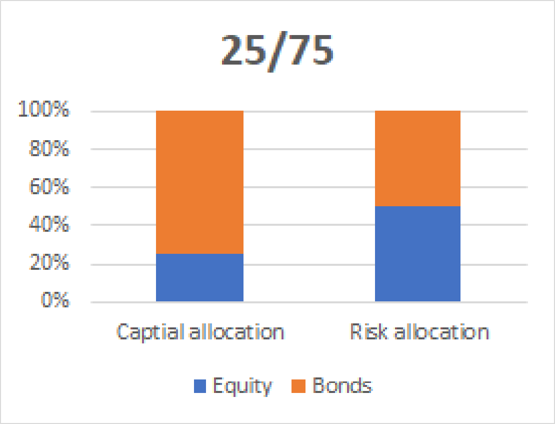

Figure 2.2 - Capital and risk allocation in 25/75

Furthermore, Qian (2011) tested a portfolio consisting of 25% equities and 75% bonds to balance the risk contribution of the two assets. The capital- and risk allocation of the two portfolios are illustrated in Figure 2.1 and Figure 2.2. The author also calculated the correlation between the two portfolios and their underlying assets. There was a 98% correlation between the 60/40 portfolio and equities, and a 13% correlation between the 60/40 portfolio and bonds. For the 25/75 portfolio, the correlation with equities and bonds was 77% and 77%, respectively. This is a good illustration of how one can adjust the risk contribution of the various components in a portfolio by changing the capital allocated to its parts.

The same technique can be applied in risk factor parity. As mentioned in Chapter 2.1.1, it is believed that movements in asset classes are determined by underlying factors. The risk factor parity approach addresses this assumption by identifying these risk factors and subsequently changing the allocation based on the exposure to the underlying risk factors (Bhansali, 2011). In this way, for example, one can change the allocation so that the portfolio has a neutral position to the underlying risk factors.

Page and Taborsky (2011) emphasize that economic conditions frequently undergo regime shifts, which are documented through market turbulence, inflation, and gross domestic product (GDP) growth. They further state that asset class returns are driven by risk factors that are highly regime specific, which is why portfolio construction should be based on risk factors (Page & Taborsky, 2011).

As mentioned earlier, studies have demonstrated that the correlation between asset classes does not exhibit a stable relationship, because asset classes tend to be highly correlated in economic turmoil (Amato & Lohre, 2020). Thus, in line with the approach of Bridgewater Associates, this paper is focused on the correlation between asset classes and their risk factors (i.e., inflation and economic growth), as this seems like a more stable and predictable relationship (Bridgewater Associates, 2012).

On the other hand, ignoring the covariance between asset classes may lead to the portfolio being highly sensitive to the particular asset classes that are included in the portfolio (Bhansali et al., 2012). Furthermore, Baltas (2016) emphasizes that in periods of increased asset correlation, the allocation process in which one ignores the correlation between asset components may lead to a highly skewed risk distribution in periods. It is therefore important to choose assets with different sensitivity towards the underlying risk factors to address the problems with increased asset correlation.

2.2 The Bridgewater philosophy

2.2.1 All-weather portfolio explained

Bridgewater Associates created the all-weather investment portfolio (Bridgewater Associates, 2012). Based on their knowledge of the drivers behind economic shifts and how these shifts affect asset class return, they developed a strategy whose goal was to adopt a neutral position towards the different underlying risk factors (i.e., economic environments). This was to avoid having to be dependent on successfully predicting future economic conditions (Shahidi, 2014).

According to Shahidi (2014), the underlying risk factors for asset class return can be classified into the following three categories: (1) shift in expectations of future interest rate, (2) shift in risk appetite, and (3) shift in the economic environment. The author further explains that the first two categories affect all asset classes in the same manner, while the latter category is diversifiable because there is a possibility of achieving neutral exposure to economic environments - see Chapter 2.2.3 for more details.

Shahidi (2014) states that a neutral exposure to economic environments can be achieved by owning assets that are going to perform above average in different economic states. Thus, ensuring that when an unexpected shift in the economy happens, the portfolio has some assets that are going to outperform, and hopefully give a high enough excess return to offset the loss from the assets that are underperforming in the same state. The weighting of the different assets in the portfolio is therefore chosen so that each economic state has the same amount of risk, and thus ensuring that the portfolio has approximately the same expected return in each economic state.

In Bridgewater’s article ‘The Biggest Mistake in Investing’, the author states that asset allocation can be done by leveraging and deleveraging low/high risk assets to obtain a similar expected return and risk for all assets in the portfolio (Jensen & Rotenberg, 2004). This implies that all asset classes have the same risk-adjusted return (Sharpe ratio), and one can therefore allocate based on risk only and still get the same expected return in each economic state.

Tang and Whitelaw (2011) find evidence that the Sharpe ratio in the equity market coincides with the phases of the business cycle over time, indicating that the Sharpe ratios in the recession and expansion phases differ. Moreover, Tang and Whitelaw (2011) cites evidence of a significantly better return/volatility tradeoff when entering expansion phases than when leaving the expansion phase. However, Bridgewater Associates is referring to a long-term relationship, which might be the long-term average Sharpe ratio for a longer period than the 10-year period used by Tang and Whitelaw (2011).

The founder of Bridgewater Associates, Ray Dalio, believed that '...all asset classes have environmental biases' (Bridgewater Associates, 2012, p.5). He argues, for example, that owning a traditional equity-heavy portfolio is like taking a bet that economic growth will be above expectations and that inflation will be below expectations. The traditional equity-heavy portfolio is thereby exposed to a significant risk of changes regarding the economic growth and inflation in the future.

Prince (2011) states that the price of asset classes is reflecting the expected development in the macroeconomic variables, where inflation and economic growth are the most important. This is because the volume of economic activity (growth) and its pricing (inflation) primarily determines the aggregated cash flow of an asset class. The effects of whether growth and inflation are higher or lower than what was expected will therefore influence the asset class returns. Thus, by dividing the portfolio into four sections that perform well in different states of the economy, one can capture the majority of risk premiums attached to owning risky assets, but still achieve a neutral position towards the underlying risk factors.

2.2.2 A review of Bridgewater's economic market approach

To gain a better understanding of the key drivers behind asset class return and why a balanced portfolio is beneficial, one needs to understand the different factors that cause the economy to function the way it does today (Shahidi, 2014). According to Dalio (2012), there are three main forces that drive the economy: productivity growth, short-term debt cycle (business cycle), and long-term debt cycle.

Figure 2.3 presents the overlays of the short-term business cycle, the long-term debt cycle, and the productivity trend line. This figure is a simple illustration on how these three forces affect the economy, and it serves as a useful roadmap to understand why asset price fluctuates (Dalio, 2012).

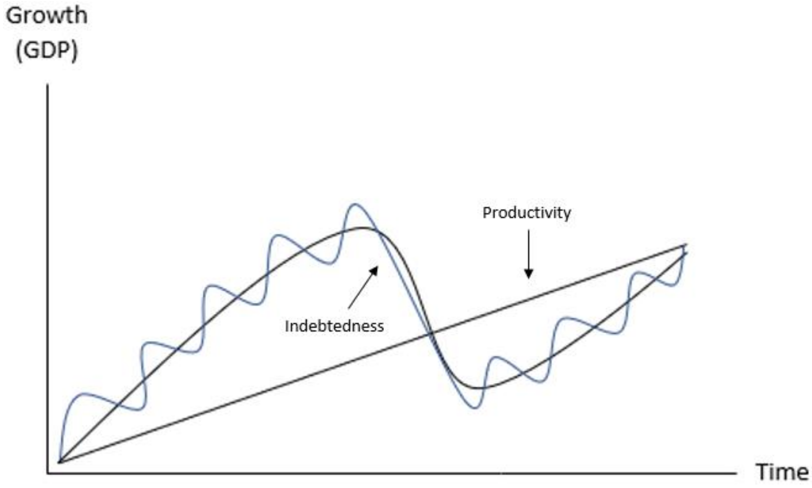

Figure 2.3 - The three key drivers of the economy

The most important underlying driver in the economy is productivity growth. One can think of productivity growth as the average output produced by each worker in a society (Dalio, 2012). Productivity growth per capita is the same as real per capita GDP growth, and according to Dalio (2012), this measure has been approximately 2% per annum for the past 100 years in the US.

Figure 2.3 presents the productivity trend line, which is increasing slowly at an approximately constant rate. This is due to the fact that we either need to improve our work ethic or learn to work smarter for productivity to increase, and this can be a slow process. In the real world, however, we see large fluctuations in the GDP that are caused by two types of cycles, referred to by Dalio (2012) as the short-term and long-term debt cycles.

The short-term debt cycle – represented by the blue line in Figure 2.3 – is the consequence of rapid changes in the growth in debt and spending in the economy; where the fluctuation in aggregate demand is caused by people either being able to spend more than they earn or having to repay their debts, thereby spending less. Furthermore, these cycles are primarily controlled by the country’s central banks, which influence the amount of credit in the system. The U.S. central bank (the Federal Reserve) tries to keep inflation in check by changing the short-term interest rates and utilizing other monetary tools (Congressional Research Service, 2021). In this way the Federal Reserve can stimulate the economy by either increasing or decreasing the amount of money and credit in the system.

Over time, the recurrence of short-term debt cycles leads to an increase in the general debt burden of an economy, which is what Dalio refers to as the long-term debt cycle. This cycle has small movements from year to year, but over a longer period of time one can see that the debt to GDP ratio increases.

Ultimately, the debt-to-GDP ratio becomes too high and the economy begins to experience a similar effect as at the end of a business cycle. However, when debt burdens get too high, monetary policy tools are no longer an effective method to stimulate the economy and the peak of the long-term cycle is reached. This is usually followed by a longer period of poor economic growth. The Great Depression in the U.S. is an example of such a period, and an economic downturn of this nature is solved only by a long deleveraging process (Dalio, 2012).

The three forces described above are a simple explanation of how the economy works in a short- and long-term perspective. They are meant to give insight into the complexity of the economic system, where the steps that occur at a microeconomic level evolve into a macroeconomic universal force (Shahidi, 2014).

In the next chapter we examine the three forces that affect the volatility of asset classes. These three forces are the economic environment (i.e., how inflation and economic growth turn out relative to what was expected), risk appetite, and the expectations of the future interest rate. The three forces are strongly influenced by where the economy is in terms of the short- and long-term debt cycles, and although these cycles repeat themselves, they are very unpredictable in nature and are hard to see coming.

2.2.3 Volatility of asset classes

The three factors that affect volatility in asset class return are shifts in expected interest rate, shifts in risk appetite, and shifts in the expected economic environment.

Shifts in the expectations of future interest rates are fairly stable and the expectation of how the interest rate will transpire over time is reflected in the treasury yield curve. However, unanticipated changes in expected future interest rate will influence the asset class price, which in turn will influence the asset class returns (Chen et al., 1986). Thus, the risk is unavoidable because it will affect all asset classes.

Shifts in risk appetite is also not a diversifiable asset class risk. This is because the value of risky assets generally moves in the same direction when there are shifts due to increasing or decreasing risk appetite. Thus, these changes will impact all asset class prices and return (Coudert & Gex, 2008).

The effect of both shifts in expectation of future interest rate and risk appetite can be explained by the net present value (NPV), as shown in equation 4.

$$Net\ present\ value\ of\ asset_n = \sum_{t=1}^{n} \frac{E(CF_t)}{(1+i)^t} \tag{4}$$

The NPV is an equation used to value expected future cash flows, where the value of an asset class will decline as the discount rate i increases, or rise as the discount rate decreases (Greer, 1997). Ultimately, changes in expectation with regard to future interest rate and risk appetite affect the discount rate i, but this will be the same for all asset classes and hence does not constitute a diversifiable risk.

The expected future cash flow $E(CF_t)$ is based on what the market expects the value of an investment to be. If there is a shift in the expectations of the underlying factors of future cash flow, the value of the asset class will change. Since inflation and economic growth are the two main factors that determine the cash flow for asset classes, changes in these factors will ultimately affect the expected future cash flow $E(CF_t)$ (Shahidi, 2014).

Furthermore, the idea is not to diversify away the economic biases within each asset class, but to construct a pool of different asset classes so that the portfolio will have a neutral position towards economic biases. Shahidi (2014) emphasizes that, ‘The goal of efficient portfolio construction is to capture the excess returns above cash offered by the first two parts (Shifts in expectations of future interest rate and shift in risk appetite) and diversify away the risk of shifts in the economic environment' (p.46).

2.2.4 Asset biases towards economic environments

In 2011, Bridgewater Associates published a research paper, 'Risk Parity is About Balance', where they stated that 'the relationship of asset performance to growth and inflation are reliable – indeed, timeless and universal – and knowable, rooted in the duration and sources of variability of the assets cash flow' (Prince, 2011, p. 4).

The choice of asset classes in the portfolio is based on their sensitivity to the underlying risk factors. For example, the opposite sensitivity of stocks and bonds to economic growth, and the opposite sensitivity of bonds and commodities to inflation makes the combination of these assets risk reducing for the portfolio (Ilmanen et al., 2014). This thesis follows the all-season portfolio in terms of which asset classes that are included in the portfolio (Robbins, 2014). The logical relationship that economic growth- and inflation have with the different asset classes is presented below.

2.2.4.1 Equities

According to Shahidi (2014), equities tend to outperform expected returns when economic growth exceeds expectations. The author further argues that this is because the return on equities is a function of two primary variables, namely revenue and profit margins; where a positive shift in expected economic growth will ultimately lead to increased expectations in relation to the level of revenue. This theory is shared by Ang (2014), who also explains that equities underperform and are more volatile in periods of low economic growth.

In addition, Shahidi (2014) claims that equities tend to perform better than average when inflation is lower than expected. This is due to the fact that businesses generally have higher profit margins when prices of input goods (i.e., the cost of goods and services) are lower than expected, and when the central bank cuts interest rates to avoid deflation. The reason for this is that the savings on input and interest are not passed on to consumers, as the price on their products is already set. On the other hand, when inflation is higher than expected, equities tend to perform lower than average, and are therefore a poor hedge against inflation (Ang, 2014).

2.2.4.2 U.S. Treasuries

Shahidi (2014) states that treasuries perform better in periods when economic growth and inflation are lower than expected. This is because of the high probability that the central bank will act and lower interest rates.

U.S. Treasuries are considered a risk-free asset in the sense that they have no call, event, or default risk, and they have virtually no liquidity risk. They are fixed income securities, which means that if one buys a 20-year treasury bond, one receives the same coupon payment twice a year. At the issue date, the yield-to-maturity is approximately the same as the coupon rate. Thus, if the prevailing interest rate in the market is lower than the coupon rate, then the value is higher than the face value (Finra, 2021). Since bonds have a fixed interest rate, a decline in the interest rate in the market is beneficial for treasuries (Shahidi, 2014). However, the return calculation is more complicated when holding a bond portfolio with constant time to maturity, which is the case for the all-weather portfolio – see Chapter 3.2.

In addition to the mathematical function in relation to changes in interest rate, treasuries are also well-recognized as a safe haven and are therefore an attractive asset class in periods of low economic growth. The fact that they act as a hedge in periods of turmoil and uncertainty makes treasuries a highly recommended option to balance the portfolio (Gupta et al., 2021).

2.2.4.3 Commodities

According to Shahidi (2014), commodities are biased to have better-than-average returns when economic growth is higher than expected. This is because the price of commodities is determined by supply and demand. If the economy is performing better than expected by the producers of commodities (i.e., leading to higher unexpected demand for commodities), there might be a shortage of supply, which would drive up prices. Research by Ang (2014) also found that returns on commodities are higher when economic growth is high, especially for energy and agriculture. This also means that commodities tend to perform poorly when economic growth is lower than expected.

Moreover, Shahidi (2014) states that commodities are biased to perform better than average when inflation is higher than expected. This argument is based on the fact that commodities are part of the equation when calculating the general price level of which the CPI is a measure. Ang (2014) argues that the linkage is due to the fact that supplies such as oil and agriculture affect commodity prices directly and have an indirect effect on many of the other items in the CPI basket.

The study by Stoll and Whaley (2010) suggests that the advantage of including commodities in the portfolio is due to the lack of correlation between commodity returns and returns of other traditional asset classes, such as bonds and equities. The authors claim that this is because commodities perform well during high inflation, while asset classes such as bonds and equities perform rather poorly – thus making commodities a risk-reducing asset class in an investment portfolio.

2.2.4.4 Gold

Numerous studies have been conducted on gold acting as a safe haven and its ability to outperform during recessions (Roache & Rossi, 2010). Ang (2014) supports the theory of gold acting as a safe haven and a hedge against disaster risk or extreme market stress. However, he emphasizes that gold is not a good inflation hedge (in terms of the correlation of gold with inflation) unless one has an investment perspective of over a century.

According to Fan et al., (2014), there is a reasonable explanation for gold acting as a hedge during recession. They identify relatively strong economic growth during the first phase of inflation, leading to a higher demand for industrial based or ‘necessary’ items in the commodity basket, in contrast to gold. ‘As a result, the rise of gold price will be less than other commodities’ (Fan et al., 2014, p. 59). However, the authors emphasize that in the later phase of inflation, economic growth will decline, resulting in lower demand for items in the commodity basket and leading to stagflation. Fear of a recession will therefore strengthen gold’s hedging properties. This will result in higher demand for gold, and hence increased prices, while the prices of other items in the commodity basket will start to stagnate or decline. Dempster and Artigas (2010) emphasize that the diversification effect gold provides is due to the fact that other commodities are more industrially based, and therefore tend to be more highly correlated with other asset classes (such as equities) during economic downturns.

Another perspective regarding the gold-inflation relationship relates to gold being regarded as having a money-like status. Since gold has a limited stock, at least in the short run, the government cannot increase the supply of gold in the same way that is possible for fiat money (O'Connor et al., 2015). This indicates that gold is biased to outperform when inflation is higher than expected.

Furthermore, Fortune (1987) suggests that inflation directly affects the gold price through a substitution effect. If there is an expectation of higher inflation, market participants who have assets with a fixed nominal return will be encouraged to move into gold to protect their purchasing power. In testing this theory, Fortune (1987) identified a positive relationship between the gold price and inflation.

Scholars still disagree in terms of the relationship between gold and inflation/economic growth. However, gold seems to contribute as a good hedge because of its money-like properties and the fact that it is a safe haven.

3 Data and methodology

This chapter is divided into seven parts. First, a description of the data set is presented, which is followed by an explanation of how the asset class return, dependent- and independent variables are calculated. Thereafter, we examine how the three hypothesizes are tested. First we examine the method for backtesting the all-weather, 60/40, and all-equity portfolios. The next part examines how we test for asset biases with the help of historical average return and ordinary least square (OLS). Finally, we demonstrate how we test the assumption that risk-adjusted return is approximately the same for all asset classes.

3.1 Data

This thesis is based on historical data relating to the period between 01.02.1970 and 01.01.2021. The price development of the various asset classes was extracted on a monthly basis. Historical data were collected from the following sources: Standard & Poor's 500 (S&P 500) from Yahoo Finance, S&P GSCI Commodity Total Return (GSCI) from investing.com, the gold spot price from datahub.io, and Treasury constant maturity yields from the website of the Federal Reserve Bank of St. Louis. Data on the three-month treasury bills were also gathered from this website.

The values of GDP and CPI all items were extracted from the Federal Reserve Bank of St. Louis website on a quarterly basis, since GDP is reported on a quarterly basis.

In addition to GDP and CPI, the analyses applied the VIX index – the spread between Moody's Seasoned Baa Corporate Bond yield relative to the yield on 10-year treasury constant maturity bonds, and the spread between 10-year constant maturity bonds and three-month bills. These were extracted from the Federal Reserve Bank of St. Louis website, and are available for the whole sample period, except the VIX index, which is available from 01.01.1986.

3.2 Calculation of asset class returns

The asset class returns are defined as the quarterly logarithmic changes. The formula for returns on the S&P 500, GSCI and the gold spot price are as follows.

$$Return\ on\ Asset_i = \ln\left(\frac{Price_t}{Price_{t-1}}\right) \tag{5}$$

Investor returns on treasury notes and bonds were found by using the formula applied by Swinkels (2019), where modified duration and convexity are established and then used to calculate the period return on the different bond portfolios. In our case, we downloaded the historic coupon yields on 5-year, 10-year, and 20-year U.S. Treasuries with a monthly frequency.

Modified duration was calculated as indicated in Equation 6:

$$D_t = \frac{1}{y_t}\left[1 - \frac{1}{\left(1 + \frac{y_t}{2}\right)^{2*T_t}}\right] \tag{6}$$

Convexity was calculated as indicated in Equation 7:

$$C_t = \frac{2}{y_t^2}\left[1 - \frac{1}{\left(1 + \frac{y_t}{2}\right)^{2*T_t}}\right] - \frac{2 * T_t}{y_t\left(1 + \frac{y_t}{2}\right)^{2*T_t+1}} \tag{7}$$

Once modified duration and convexity had been calculated, we then used Equation 8 to calculate the monthly investor return:

$$R_t = y_{t-1} - D_t * (y_t - y_{t-1}) + \frac{1}{2} * C_t * (Y_t - Y_{t-1})^2 \tag{8}$$

Furthermore, the monthly returns were used to identify how a $100 investment would change in value if it had been invested in February 1970. Then we used Equation 5 to calculate the quarterly returns. This process was repeated for all three types of treasury bonds.

Two different treasury portfolios were used in the all-season portfolio proposed by Ray Dalio, a long-term portfolio, and an intermediate-term portfolio (Robbins, 2014). In this thesis, we used portfolios with an average maturity of 15 and 7.5 years. The chosen length to maturity is not a critical factor as all treasuries should have the same bias towards economic environments. However, the long-term treasury portfolio has a higher expected return and fluctuates more around average than the intermediate-term treasury portfolio, which means that these portfolios have different levels of sensitivity towards the bias. The two portfolios are defined as follows.

Long-term treasury portfolio:

$$Long\ term = \frac{(20\ Year\ Treasury\ Return + 10\ Year\ Treasury\ Return)}{2} \tag{9}$$

Intermediate-term treasury portfolio:

$$Intermediate\ term = \frac{(10\ Year\ Treasury\ Return + 5\ Year\ Treasury\ Return)}{2} \tag{10}$$

Both the return on long-term- and intermediate-term treasury portfolios are based on the textbook formula for transforming yield-to-maturity into investor return. This means that the actual return might have small deviations from the return used in this thesis. However, when Swinkels (2019) conducted a comparison of the estimated return and the actual return gathered from several databases, the author found that returns were almost identical.

Descriptive statistics for all five asset class returns are presented in Appendix A.

3.3 Dependent variables

After calculating the quarterly returns on the different asset classes, we subtracted the risk-free rate, which is the three-month U.S. Treasury bill, to find the excess return. To measure whether the excess returns were over or below the average, we subtracted the average excess return from the excess return for each quarter. The dependent variables are therefore defined as follows:

$$Equites_t = Return\ on\ S\&P500_t - \overline{Return\ on\ S\&P500}$$

$$Commodities_t = Return\ on\ GSCI_t - \overline{Return\ on\ GSCI}$$

$$Gold_t = Return\ on\ Gold_t - \overline{Return\ on\ Gold}$$

$$Long_t = Return\ on\ Long\ term_t - \overline{Return\ on\ Long\ term}$$

$$Intermediate_t = Return\ on\ Intermediate\ term_t - \overline{Return\ on\ Intermediate\ term}$$

3.4 Independent variables

When testing the economic biases using OLS, we applied macroeconomic risk factors. As mentioned in Chapter 2.2.3, the variation in return is driven primarily by the three following factors: expected interest rate, risk appetite, and shifts in the economic environment.

The independent variables used in our regression are proxies for the three risk factors. An examination of the spread between 10-year constant maturity bonds and three-month bills and how they change from one quarter to the next quarter provides a proxy for how the expected future interest rate is changing.

Changes in the term-structure:

$$\Delta 10Y3M = \frac{10Y3M_t}{10Y3M_{t-1}} - 1 \tag{11}$$

Furthermore, the risk appetite was measured by examining Moody's Seasoned Baa Corporate Bond yield relative to the yield on 10-year treasury constant maturity bonds. When this spread increases, investors demand higher returns to compensate for the risk, which is in turn a proxy for the average risk aversion. In addition, we included the changes in the implied volatility in the S&P 500. This was calculated in the following manner:

Changes in the risk premium:

$$\Delta 10YBAA = \ln\left(\frac{BAA10YM_t}{BAA10YM_{t-1}}\right) \tag{12}$$

Changes in the implied volatility in the stock market:

$$\Delta VIX = \ln\left(\frac{VIX_t}{VIX_{t-1}}\right) \tag{13}$$

We also included a dummy variable to remove the problem of heteroscedasticity – see Chapter 3.6.3. This variable is defined as follows:

$$Crisis = \begin{cases} 1\ if\ VIX_t \geq 30 \\ 0\ if\ VIX_t < 30 \end{cases} \tag{14}$$

We defined the current economic environment by examining inflation and GDP growth relative to their trends. To measure this, we used the actual inflation and actual GDP growth intra quarter relative to the three-year moving average.

Actual inflation:

$$Actual\ inflation = ln\left(\frac{Consumer\ Price\ Index_t}{Consumer\ Price\ Index_{t-1}}\right) \tag{15}$$

Actual GDP growth:

$$Actual\ GDP\ Growth = \ln\left(\frac{Real\ Gross\ Domestic\ Product_t}{Real\ Gross\ Domestic\ Product_{t-1}}\right) \tag{16}$$

Actual inflation relative to trend:

$$MA\_Inflation_{12} = \frac{\sum_{i=1}^{12} Actual\ inflation_i}{12} \tag{17}$$

$$AIMT = Actual\ inflation - MA\_Inflation_{12} \tag{18}$$

Actual GDP growth relative to trend:

$$MA\_GDP_{12} = \frac{\sum_{i=1}^{12} Actual\ GDP\ Growth_i}{12} \tag{19}$$

$$AGMT = Actual\ GDP\ Growth - MA\_GDP_{12} \tag{20}$$

Actual inflation and GDP growth relative to the moving average were applied in the equation because the present trend is approximately the same as the expectation; since most people expect the future to closely resemble the current trend (Shahidi, 2014). However, we need to emphasize that using the current trend as a measure for the expected inflation and GDP growth is not perfect. This is because big movements in inflation and GDP growth during the last three years can have big impacts on the moving average, which may lead to the current trend not representing investors' expectations.

3.5 Construction and backtesting of the all-weather portfolio

This chapter presents how we constructed an all-weather portfolio with risk parity principals. Furthermore, we present the calculations of historical return and different risk- and drawdowns measures which were used to compare the all-weather portfolio with a 60/40 and all-equity portfolio.

3.5.1 Construction of the all-weather portfolio

Bridgewater Associates asset allocation is not publicly available. This thesis therefore uses the asset classes that were included in the simplified version of the all-weather portfolio – the ‘all-season portfolio’ – which was popularized by Tony Robbins in his book *Money: Master the Game* (Robbins, 2014). To determine the weights of the different asset classes in the portfolio we applied a risk factor parity approach.

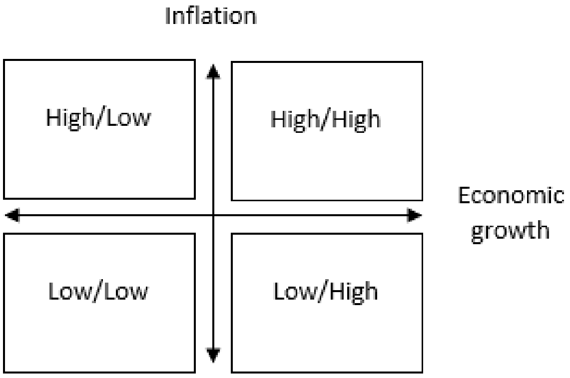

Figure 3.1 - The four economic states

Based on the most important macroeconomic risk factors – inflation and economic growth – we divided the economy into four possible economic states, as illustrated in Figure 3.1 above.

Table 3.1 - Asset class bias and preferred economic states

Asset class bias	Inflation is	GDP Growth is
GSCI should do better when:	Higher than expected	Higher than expected
Gold should do better when:	Higher than expected	Lower than expected
S&P 500 should do better when:	Lower than expected	Higher than expected
Long-term treasuries should do better when:	Lower than expected	Lower than expected
Intermediate-term treasuries should do better when:	Lower than expected	Lower than expected

The expected economical biases for the five different asset classes – as discussed in Chapter 2.2.4 – are summarized in Table 3.1 above. The preferred economic states are found by combining the economic biases of the different asset classes; this also implies that the worst economic state is the state with the opposite values for inflation and GDP growth.

Table 3.2 - Definition of the four sub-portfolios

	Should do better when		
Sub-portfolio	**Inflation is**	**GDP growth is**	**Asset class**
Sub-portfolio 1: x_1	Higher than expected	Higher than expected	GSCI
Sub-portfolio 2: x_2	Higher than expected	Lower than expected	Gold
Sub-portfolio 3: x_3	Lower than expected	Higher than expected	S&P 500
Sub-portfolio 4: x_4	Lower than expected	Lower than expected	Treasuries: Long and intermediate

From this we could place the different asset classes in the four sub-portfolios, as presented in Table 3.2 above. Furthermore, these sub-portfolios were weighted so that each has a balanced amount of risk. We then applied the following logic to determine how much should be allocated to the different assets; Following Shahidi (2014), we defined the total amount of risk in the portfolio as the volatility, see Equation 21.

$$\sigma_P = \sqrt{\sum_i \sigma_{SUB_i}^2 w_i^2} \tag{21}$$

Where σ_P is the volatility of the overall portfolio, and w_i is the weight allocated to the sub-portfolios. We applied this simplified volatility equation because as Bridgewater Associates stated the correlation between assets is unreliable, and they were therefore assumed to have 0 correlation (Chaves et al., 2012). In the light of this simplification, we defined the risk contribution from the sub-portfolios as:

$$\sigma_{SUB_i} = \sqrt{\sigma_i^2 w_i^2} \tag{22}$$

From this we used the solver function in Excel to find the asset weights for the overall portfolio. This was done by maximizing the Sharpe ratio for the total portfolio with the constraints that the risk contribution from the sub-portfolios was approximately the same and that we were only going to use long positions – see Equations 23, 24, and 25.

The following optimization was applied:

$$\underset{w_i}{Maximize}\frac{R_P - R_f}{\sigma_P} \tag{23}$$

subject to:

$$\sum_i w_i = 1 \qquad 0 \leq w_i \leq 1, \forall_i \tag{24}$$

$$\sum_i \sum_j \left(\sigma_{SUB_i} - \sigma_{SUB_j}\right)^2 \leq 0.01 \tag{25}$$

The goal was to obtain:

$$\sigma_{SUB_1} \approx \sigma_{SUB_2} \approx \sigma_{SUB_3} \approx \sigma_{SUB_4} \tag{26}$$

Sub-portfolio x_4 consisted of two assets – long-term and intermediate-term treasuries – where the weights were determined by the solver when optimizing the Sharpe ratio of the portfolio. Sub-portfolios x_1, x_2 and x_3 consisted of only one asset, as presented in Table 3.2.

3.5.2 Historical return and different risk- and drawdown measures

The two portfolios that are compared to the all-weather portfolio in this historical backtest is the 60/40 and all-equity portfolios, these are defined as follows; the 60/40 consist of 60% invested in the S&P 500 and 40% invested in the intermediate-term treasury portfolio, and the all-equity is 100% invested in the S&P 500. The historical quarterly return on the portfolios is defined in Equation 27 below:

$$R_{p,t} = \sum_{i=1} w_i R_{i,t} \tag{27}$$

where:

$R_{p,t} = Portfolio\ return\ in\ period\ t$

$w_i = Weight\ in\ asset\ class\ i$

$R_{i,t} = Return\ on\ asset\ class\ i\ in\ period\ t$

The historical return was used to calculate the price changes in the three portfolios, with $10,000 invested at the beginning of the sample period. We calculated the historical average return, standard deviation, value at risk, and conditional value at risk for the whole sample period.

Standard deviation was defined as per Equation 28:

$$\sigma_A = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(R_{i,t} - \overline{R_i}\right)^2} \tag{28}$$

Historical value at risk (VaR) measures the risk of loss by determining how much the portfolio has declined over a given period and with a given probability (Hendricks, 1996). The conditional value at risk (CVaR) is the average return if the return is below the VaR level, which in this thesis is 5%. Conditional value at risk was defined as per Equation 29:

$$CVaR = \frac{1}{1-c}\int_{-1}^{VaR} xp(x)dx \tag{29}$$

where:

$p(x)dx = The\ probability\ density\ of\ getting\ a\ return\ with\ value\ x$

$c = The\ breakpoint\ level\ for\ VaR$

$VaR = Value\ at\ risk\ level$

The average and median return is calculated on rolling holding periods of 1, 5, 10, and 20 years. We found the maximum and minimum return for the different holding periods, and calculated value at risk, conditional value at risk, and the percentage of returns that were negative.

Rolling holding period is useful because one obtains a return on a holding period of T years, where one is not dependent on a given starting point. Here we tested every possible holding period of T years in our sample period. Which means that for a one-year rolling return, we first calculated the annual return from 01.04.1970 to 01.04.1971, then from 01.07.1970 to 01.07.1971, and so on.

We then made the same calculations as in Chapter 3.6.1 to identify whether the three portfolios had any biases towards the different economic states. Lastly, we measured average and maximum drawdown in two ways – with percentage decline from all-time high and how long it takes to reach a new all-time high. This was done by using Equations 30 and 31:

$$Maximum\ drawdown = \frac{LP - ATH}{ATH} \tag{30}$$

where:

$LP = Low\ point\ after\ the\ latest\ ATH$

$ATH = All\ time\ high\ for\ the\ portfolio$

$$Average\ drawdown = \frac{\sum_{i=1}^{n} \frac{LLP_i - LATH_i}{LATH_i}}{n} \tag{31}$$

where:

$LLP = Low\ point\ after\ the\ LATH$

$LATH = Latest\ all\ time\ high$

$n = Number\ of\ drawdowns$

Maximum time to recover is the longest period between one all time high and the next, while the average time to recover is the average time between one all time high and the next. In addition to the average and maximum drawdown measures, we also measured the number of drawdowns below 5%, 10%, 15%, and 20%.

3.6 Testing for asset class bias

This chapter presents how we tested for asset class bias. First, we calculated the historical average return on the different asset classes in periods when inflation and GDP growth were higher or lower than the three-year moving average. We further examined asset class bias using OLS regressions to test whether the different asset classes had the expected sign on the beta coefficients.

3.6.1 Average return tests

Historical arithmetic average returns were calculated on the five different asset classes on a quarterly basis for the whole sample period. We then calculated the historical average return in periods of high or low inflation and economic growth, both separately and combined. Thereby testing whether the assets have a bias toward the two risk factors, and if the assets perform differently in the four different economic states. The four economic biases are presented in Table 3.3 below.

Table 3.3 - Description of the four economic biases

Description of the four economic biases	
Bias 1:	Higher than expected inflation
Bias 2:	Lower than expected inflation
Bias 3:	Higher than expected GDP growth
Bias 4:	Lower than expected GDP growth

Finally, we combined the measurements on inflation and GDP growth so that the economy consisted of the four states presented in Table 3.4 below.

Table 3.4 - Description of the four economic states

Description of the four economic states	**Inflation is:**	**GDP Growth is:**
Economic state 1:	Higher than expected	Higher than expected
Economic state 2:	Higher than expected	Lower than expected
Economic state 3:	Lower than expected	Higher than expected
Economic state 4:	Lower than expected	Lower than expected

This made it possible to measure whether the different assets, on average, perform better in the economic states defined in this chapter.

In addition, we tested the robustness of this test by dividing the sample period into two sub-periods: the first period from 01.04.1970 to 01.10.1994, and the second from 01.01.1995 to 01.01.2021. We then repeated the test described in this chapter on the sub-holding periods.

3.6.2 Ordinary least squares regression

Ordinary least squares regression was conducted on the five different dependent variables, using the independent variables – see Chapters 3.3 and 3.4. When choosing the independent variables, the stepwise function in the Stata software package was applied. First, all the independent variables were included; then Stata excluded the variables with the highest p-values, leaving only variables with a p-value below the chosen threshold. In addition, we locked the $AIMT$ and $AGMT$ variables so that they were included in all five models. The different regression models used are presented below:

$$Equities_t = \alpha_t + \beta_{AIMT}AIMT_t + \beta_{AGMT}AGMT_t + \beta_{\Delta \mathrm{VIX}}\Delta VIX_t + \beta_{Crisis}Crisis_t$$
$$+\beta_{10YBAA}10YBAA_t + \varepsilon_t$$

$$Commodities_t = \alpha_t + \beta_{AIMT}AIMT_t + \beta_{AGMT}AGMT_t + \beta_{\Delta \mathrm{VIX}}\Delta VIX_t + \beta_{Crisis}Crisis_t$$
$$+\beta_{10YBAA}10YBAA_t + \varepsilon_t$$

$$Gold_t = \alpha_t + \beta_{AIMT}AIMT_t + \beta_{AGMT}AGMT_t + \beta_{\Delta \mathrm{VIX}}\Delta VIX_t + \beta_{Crisis}Crisis_t + \varepsilon_t$$

$$Long_t = \alpha_t + \beta_{AIMT}AIMT_t + \beta_{AGMT}AGMT_t + \beta_{\Delta \mathrm{VIX}}\Delta VIX_t + \beta_{Crisis}Crisis_t$$
$$+\beta_{10Y3M}10Y3M_t + \varepsilon_t$$

$$Intermediate_t = \alpha_t + \beta_{AIMT}AIMT_t + \beta_{AGMT}AGMT_t + \beta_{\Delta \mathrm{VIX}}\Delta VIX_t + \beta_{Crisis}Crisis_t$$
$$+\beta_{10Y3M}10Y3M_t + \varepsilon_t$$

The regression analysis was conducted from 01.01.1986 to 01.01.2021, because VIX index variables are included in all models, and the available data only dates back to 01.01.1986.

3.6.3 Testing of ordinary least square assumptions

When running a regression analysis, one needs to ensure that the models are correctly specified. To do this we tested for functional form, stationarity, autocorrelation, heteroscedasticity, and multicollinearity. In addition, we checked whether the variables were approximately normally distributed.

We applied the Ramsey regression equation specification error test (RESET) to determine whether there was a high probability that the regression model was wrongly specified. However, there were no significant specification errors – see Appendix B.1.

Stationarity means that the time series has constant mean and variance over the sample period (Studenmund, 2017). This is an important prerequisite for obtaining reliable coefficients from the regression.

The two-way plot in Appendices B.2 to B.6 reveals that the return on all asset classes seems to be stationary, except gold which seem to have some problems with autocorrelation. The independent variables have more serious problems with stationarity; inflation relative to trend has certain large outliers which we addressed by including a dummy variable for '$Crisis$', where 1 indicates values over 30 on the VIX. This method mostly removes the problems with outliers (Studenmund, 2017). GDP growth relative to trend has approximately the same mean throughout the sample period, but it also has a large outlier during the coronavirus crisis in 2020. This problem was also solved by using the '$Crisis$' dummy.

An examination of the absolute values on VIX, the risk premium on corporate bonds, and the spreads between 10-year treasuries and three-month treasuries reveals that there is a significant difference in mean and in volatility over time. This is why we examined changes from one period to the next to deal with the non-stationarity. This yielded variables that seem to be stationary – see Appendices B.7 to B.10.

Autocorrelation was tested by using the Durbin-Watson test and the Breusch-Godfrey test, the results of which are presented in Appendix B.11 and demonstrate that there is no significant autocorrelation. This is also confirmed by the correlograms in Appendix B.12.

Heteroscedasticity was tested by using the White test and the Breusch-Pagan test, the results of which are summarized in Appendix B.13. Here it is observed that the equity model has significant heteroscedasticity. This problem was solved by using heteroscedasticity-corrected standard errors, where we adjusted the estimated standard errors for heteroscedasticity while still using the same OLS estimated coefficients (Studenmund, 2017).

Testing for multicollinearity was done by first examining the correlation between the independent variables. In addition, we used the VIF test in Stata, the results of which are presented in Appendices B.14 and B.15. From the correlation matrix it is clear that there is a 0.552 correlation between the ΔVIX and $\Delta 10YBAA$ variables. In addition, it is observed that there are multiple variables with a correlation around +/-032. However, the VIF table reveals no significant multicollinearity.

Furthermore, we tested for normally distributed residuals by applying the skewness and kurtosis test, the Shapiro-Wilk test, and the Shapiro-Francia test for normality. These results can be reviewed in Appendix B.16. In addition, we created residual histograms – see Appendix B.17. These tests reveal that the equity and commodity models residuals are not normally distributed. This is not necessarily a problem, as we have a large sample size with 139 observations, and we can therefore assume normality based on the central limit theorem (Thomas, 2005).

3.7 Historical risk-adjusted returns for the different asset classes

In one of the Bridgewater Associates research papers it is stated that, ‘in risk-adjusted terms asset classes have roughly equivalent returns’ (Jensen & Rotenberg, 2004, p. 3). This is tested by calculating the Sharpe ratio for the different asset classes (i.e., how much return received per unit of risk). The reason this is an important assumption is that if asset classes have different Sharpe ratios, the allocation method based on risk alone will give some parts of the portfolio a lower expected return than others.

The historical Sharpe ratio is calculated by subtracting the risk-free rate of return R_f from the expected asset class return R_A over a given period, which is then divided by the standard deviation (volatility) of the expected asset class return σ_A during the same period – the standard deviation is defined in Equation 28. We used the quarterly returns in the manner explained in Chapter 3.2, the risk-free rate is the quarterly treasury bill yield, and the Sharpe ratio was calculated on a quarterly basis as presented in Equation 32. Next, we identified the average values for the Sharpe ratio, for the whole sample period and for the five individual decades.

The Sharpe ratio was defined as per Equation 32:

$$Sharpe\ ratio = \frac{R_A - R_f}{\sigma_A} \tag{32}$$

4 Empirical results and discussion

This chapter presents the results of our analysis. The main purpose of this thesis is to examine how the all-weather portfolio performs compared to the 60/40 and all-equity portfolios, and if the assumptions for the all-weather portfolio are valid. First, we present the results from the construction of the portfolio and the backtesting with a comparison to 60/40 and all-equity portfolios. Second, the test of assumed asset class bias towards defined economic risk factors are presented. Finally, we present the risk-adjusted return test for the different asset classes.

4.1 Results from construction and backtesting of the all-weather portfolio

4.1.1 Weights in all-weather portfolio

Hereafter, we refer to the constructed portfolio as the all-weather portfolio. The portfolio weights in the different asset classes and sub-portfolios are presented in Table 4.1 and Table 4.2. The solver allocated 30.82% to long-term treasuries and 6.72% to intermediate-term treasuries, which means that sub-portfolio four consists of 82.11% long-term and 17.89% intermediate-term treasuries. Further, equities, commodities and gold received 27.25%, 15.95% and 19.27% of the allocation, respectively.

Table 4.1 - Weights in asset classes

Asset classes	**Weights**
S&P 500	27.25%
GSCI	15.95%
Gold	19.27%
Long-term	30.82%
Intermediate-term	6.72%

Table 4.2 - Weights in sub-portfolios

Sub-Portfolios	**Weights**
Sub-portfolio 1 (GSCI)	15.95%
Sub-portfolio 2 (Gold)	19.27%
Sub-portfolio 3 (S&P 500)	27.25%
Sub-portfolio 4 (Treasuries)	37.54%

These are the same sub-portfolios that were defined in Chapter 3.5.1. Here it is observed that the riskiest portfolio has the lowest amount of allocated capital, which leads to a balanced risk contribution between the four different states, as presented in Table 4.3 below.

Table 4.3 - Risk balance between economic states

Economic states	Risk contribution
State 1 – High/High	24.64%
State 2 – High/Low	25.00%
State 3 – Low/High	24.86%
State 4 – Low/Low	25.50%

Table 4.4 below indicates that the portfolio also has a balanced allocation on both macroeconomic risk factors, where the portfolio has approximately the same amount of risk in higher-than-expected and lower-than-expected inflation and GDP growth.

Table 4.4 - Risk balance between economic biases

Economical biases	Risk contribution
High inflation	24.82%
Low inflation	25.18%
High GDP growth	24.75%
Low GDP growth	25.25%

4.1.2 Historical return and different risk- and drawdown measures

4.1.2.1 Historical return and risk measures

Total return on the all-weather, 60/40, and all-equity portfolios is presented in Figure 4.1 below.

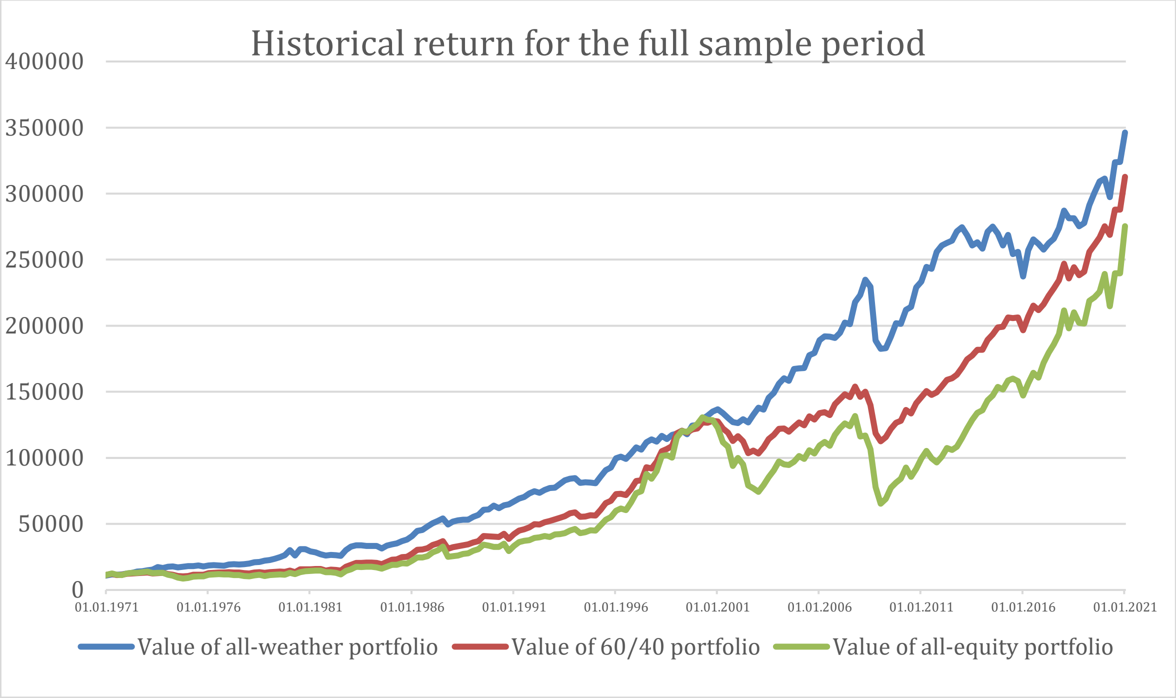

Figure 4.1 - Historical return for the full sample period

The all-weather portfolio had the highest total return, namely 3,362.45% – giving an initial investment of $10,000 a value of $346,245 at the end of the sample period. By contrast, the total returns on the 60/40 and all-equity portfolios were 3,027.02% and 2,653.48%, respectively.

Table 4.5 - Historical statistics

Quarterly data	All-weather portfolio	60/40 portfolio	All-equity portfolio
Return	1.85 %	1.82 %	1.89 %
Standard Deviation	4.18 %	4.67 %	6.94 %
Value at Risk	-4.00 %	-5.58 %	-8.92 %
Conditional Value at Risk	-7.36 %	-8.77 %	-15.23 %

Table 4.5 above summarizes quarterly return, standard deviation, value at risk, and conditional value at risk. The all-weather portfolio has the second highest average return and the lowest risk values on all three risk measures, thus giving this portfolio the highest risk-adjusted return for the sample period. However, during the last 40 years the yield on US treasuries have been steadily falling, which has been good news for portfolios with large

allocation to US Treasuries, such as the all-weather and 60/40 portfolio. The high return on these portfolios may however not be replicable in the future as we cannot expect the yield to fall much further.

Table 4.6 - Statistics for rolling holding periods

Rolling holding periods	**All-weather portfolio**	**60/40 portfolio**	**All-equity portfolio**
1 year holding period			
Average return	7.50 %	7.40 %	7.72 %
Median return	7.38 %	8.51 %	10.40 %
Maximum return	32.58 %	40.23 %	47.03 %
Minimum return	-22.03 %	-23.00 %	-43.73 %
VaR 5%	-7.25 %	-9.48 %	-18.91 %
CVaR 5%	-13.11 %	-16.73 %	-31.49 %
Negative returns	16.00 %	20.50 %	23.00 %
5 year holding period			
Average return	40.60 %	42.89 %	44.63 %
Median return	40.01 %	40.03 %	48.11 %
Maximum return	110.79 %	152.68 %	179.42 %
Minimum return	-1.21 %	-7.76 %	-32.77 %
VaR 5%	5.48 %	1.06 %	-19.53 %
CVaR 5%	2.33 %	-1.85 %	-23.53 %
Negative returns	1.09 %	2.72 %	23.91 %
10 year holding period			
Average return	101.28 %	109.67 %	108.96 %
Median return	100.72 %	106.50 %	103.73 %
Maximum return	213.15 %	250.66 %	334.97 %
Minimum return	19.79 %	-5.00 %	-43.32 %
VaR 5%	34.43 %	10.99 %	-21.78 %
CVaR 5%	27.83 %	3.87 %	-33.48 %
Negative returns	0.00 %	1.22 %	7.93 %
20 year holding period			
Average return	315.74 %	363.27 %	342.09 %
Median return	331.97 %	312.83 %	239.32 %
Maximum return	552.74 %	841.41 %	994.47 %
Minimum return	129.63 %	103.30 %	64.45 %
VaR 5%	140.00 %	124.59 %	87.08 %
CVaR 5%	136.19 %	115.73 %	80.45 %
Negative returns	0.00 %	0.00 %	0.00 %

Rolling returns for holding periods of 1, 5, 10, and 20 years are presented in Table 4.6 above. For the 1-year holding period, the all-weather portfolio has an average return of 7.5%, which is approximately the same as the 60/40 and all-equity portfolios. Furthermore, the all-weather portfolio has the lowest median and maximum return of the three portfolios. The four downside risk measures, on the other hand, favours the all-weather portfolio, with a minimum return of -22.03%, compared to minimum returns for the 60/40 and all-equity portfolios of -

23% and -43.73%, respectively. Moreover, the all-weather portfolio has the highest VaR 5% and CVaR 5% (i.e., less risk), with a negative return only 16% of the time.

The 5- and 10-year holding periods display a similar result, where the average, median, and maximum return is approximately the same or lower for the all-weather portfolio, but the downside risk is significantly lower.

When the holding period is increased to 20 years, the average return is lowest for the all-weather portfolio, but it has the highest median return. Furthermore, the all-weather portfolio has a much lower maximum return. However, the downside risk is lower, as indicated by the minimum return, VaR 5% and CVaR 5% measurements. None of the portfolios has a negative return when the holding period is increased to 20 years.

Tests of the average return with asset class biases towards economic growth and inflation revealed that the all-weather portfolio deviates least from the average return for the full sample period – see Table 4.7 for periods with higher or lower than expected inflation and GDP growth and Table 4.8 for periods of the four economic states.

Table 4.7 - Average excess return in periods of either high or low inflation/GDP growth

Average excess return	**Average excess return on all-weather portfolio**	**Average excess return on 60/40 portfolio**	**Average excess return on all-equity portfolio**
Full sample			
Average excess return	0.71 %	0.68 %	0.76 %
Inflation is			
Higher than expected			
Average excess return	0.82 %	0.09 %	0.37 %
Lower than expected			
Average excess return	0.62 %	1.22 %	1.10 %
GDP growth is			
Higher than expected			
Average excess return	0.52 %	0.96 %	1.67 %
Lower than expected			
Average excess return	0.91 %	0.40 %	-0.19 %

From Table 4.7 above we can see that the largest deviation for the three portfolios is approximately ±0.20% for the all-weather portfolio, approximately ±0.60% for the 60/40 portfolio, and approximately ±0.90% for the all-equity portfolio. Indicating that the all-weather portfolio has less economical bias.

Table 4.8 - Average excess return in the four economic states

Average excess return	Average excess return on all-weather portfolio	Average excess return on 60/40 portfolio	Average excess return on all-equity portfolio
Full sample			
Average excess return	0.71 %	0.68 %	0.76 %
High inflation/ High GDP growth			
Average excess return	0.12 %	0.44 %	1.83 %
High inflation/ Low GDP growth			
Average excess return	1.41 %	-0.21 %	-0.86 %
Low inflation/ High GDP growth			
Average excess return	0.83 %	1.34 %	1.56 %
Low inflation/ Low GDP growth			
Average excess return	0.36 %	1.06 %	0.54 %

It is clear from Table 4.8 above that the all-weather portfolio performs best in the state with high inflation/low GDP growth and performs poorest in the high inflation/ high GDP growth state. Although there is a larger deviation in returns between these four states, the all-weather portfolio has less variation in returns and the poorest performing state for this portfolio is better than the poorest performing state for the two other portfolios.

4.1.2.2 Drawdown measures

The drawdown charts in Figure 4.2, Figure 4.3, and Figure 4.4 indicate that there is a significant difference in how frequently the three different portfolios are below the all-time high. In addition, it is clear that the magnitude of the drawdown and how long it takes for the portfolio to recover are significantly different.

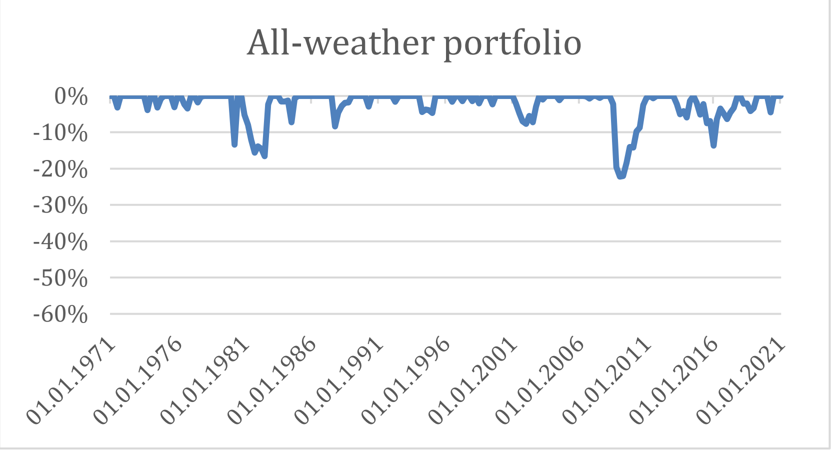

Figure 4.2 - Drawdowns for the all-weather portfolio

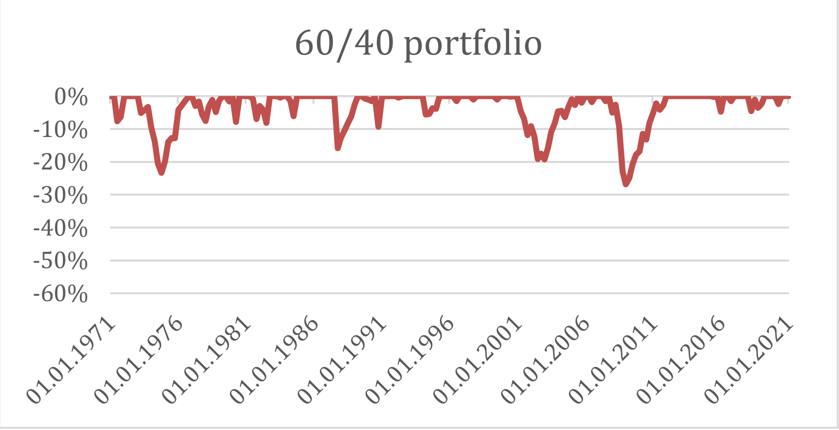

Figure 4.3 - Drawdowns for the 60/40 portfolio

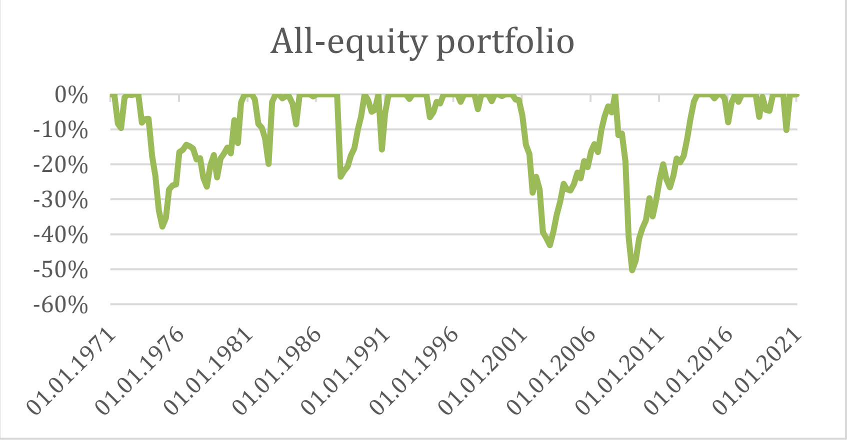

Figure 4.4 - Drawdowns for the all-equity portfolio

Table 4.9 - Drawdown statistical measures

Drawdown measures	All-weather portfolio	60/40 portfolio	All-equity portfolio
Maximum percentage drawdown	-22.21%	-26.85%	-50.31%
Average percentage drawdown	-4.99%	-5.86%	-11.29%
Maximum number of quarters until new all-time high	13	18	30
Average number of quarters until new all-time high	2.93	3.59	5.46
Number of drawdowns less than -5%	8	11	12
Number of drawdowns less than -10%	4	4	7
Number of drawdowns less than -15%	2	4	6
Number of drawdowns less than -20%	1	2	4

Table 4.9 confirms the view expressed above. The maximum drawdown for the all-weather portfolio is -22.21% compared to the 60/40 and all-equity portfolios which have maximum drawdowns of -26.85% and -50.31%, respectively. The average drawdown is also lower for the all-weather portfolio. The maximum time to recover from a drawdown is 13 quarters, and the average time is 2.93 quarters for the all-weather portfolio. This is significantly lower than for the two other portfolios. Furthermore, the number of drawdowns below 5%, 10%, 15%, and 20% is the same or lower for the all-weather portfolio.

4.2 Results from the economic bias tests

4.2.1 Results from average return tests

Table 4.10 presents asset class average excess returns in periods of high or low economic growth and inflation, while Table 4.11 presents the average excess return for the economic states. In both tables, average excess returns for each asset class are calculated for the economic environments and the full sample period.

Table 4.10 - Average excess return in periods of either high or low inflation/GDP growth

Average excess return	**Excess return S&P 500**	**Excess return GSCI**	**Excess return Gold**	**Excess return Long-Term**	**Excess return Intermediate-Term**
Full sample					
Average excess return	0.76 %	0.33 %	0.82 %	0.83 %	0.57 %
Inflation is					
Higher than expected					
Average excess return	0.37 %	2.61 %	2.58 %	-0.56 %	-0.33 %
Lower than expected					
Average excess return	1.10 %	-1.72 %	-0.75 %	2.09 %	1.39 %
GDP growth is					
Higher than expected					
Average excess return	1.67 %	1.10 %	-0.26 %	-0.16 %	-0.12 %
Lower than expected					
Average excess return	-0.19 %	-0.46 %	1.94 %	1.85 %	1.29 %

It is clear from Table 4.10 that all asset classes have an above average excess return in the periods when inflation and economic growth are assumed to be favourable for the different asset classes, as defined in Table 3.1. With an average return of 1.10% and 1.67%, the results indicate that equities are biased towards performing above average when inflation is lower than expected and when economic growth is higher than expected. The results for commodities, gold, long-term treasuries, and intermediate-term treasuries also indicate that they are biased towards performing above average in the economic environments presented in Table 3.1.

The results from our robustness test shows that when the sample period is split into two periods (01.04.1970–01.10.1994 and 01.01.1995–01.10.2021), we do not obtain the same result as in Table 4.10 – see Appendix C.1. This indicates that the relationship between asset class return and the assumed economic bias is not constant over time, but rather a spurious relationship. It is therefore not possible to confirm a stable relationship between the asset classes and their assumed favourable economic bias.

Table 4.11 - Average excess return in the four economic states

Average excess return	Excess return S&P 500	Excess return GSCI	Excess return Gold	Excess return Long-Term	Excess return Intermediate-Term
Full sample					
Average excess return	0.76 %	0.33 %	0.82 %	0.83 %	0.76 %
High inflation/ High GDP growth					
Average excess return	1.83 %	1.87 %	0.74 %	-2.32 %	0.57 %
High inflation/ Low GDP growth					
Average excess return	-0.86 %	3.24 %	4.13 %	0.92 %	-1.64 %
Low inflation/ High GDP growth					
Average excess return	1.56 %	0.52 %	-1.00 %	1.45 %	0.78 %
Low inflation/ Low GDP growth					
Average excess return	0.54 %	-4.46 %	-0.44 %	2.87 %	1.84 %

In Table 4.11 above, the macro factors are combined to create four possible states. It is clear that the best performing states do not match what was expected for all asset classes. In Table 3.1, equities are assumed to perform above average in the low inflation/high GDP growth state, but results from this test suggest that the best state is high inflation/high GDP growth with an average excess return of 1.83%. Moreover, the results for commodities also suggest that the best performing state is different from what was assumed in Table 3.1.

The results for gold, long-term treasuries, and intermediate treasuries do however match the proposed relationship in Table 3.1; gold has an average excess return of 4.13% in the high inflation/low GDP growth state, while the treasury portfolios have an average excess return of 2.87% and 1.84% in the low inflation/low GDP growth state.

The robustness test presented in Appendix C.2 reveals a number of conflicting results. In the first sample set, both equities and commodities have a best performing state different from what was proposed in Table 3.1; moreover, commodities also have a worst performing state different from what was assumed. For the second sample set, it is only commodities that have a best performing state different from what was expected. However, both equities and gold have a different worst performing state than proposed in Table 3.1. This also indicates that the results arrived at for the whole sample period might be spurious.

4.2.2 Results from regression analysis

Table 4.12 presents the results from the regression analysis. The main objective of this test was to check whether the different asset class models have the same sign on the coefficients (i.e., bias), as suggested in Table 3.1.

Table 4.12 - Regression analysis for asset class bias

Models	**Equities**		**Commodities**		**Gold**		**Long-term**		**Intermediate-Term**	
	Coefficient	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
$\boldsymbol{\alpha}$	0.0056	0.237	0.0101	0.189	0.0015	0.803	-0.0048	0.266	-0.0039	0.165
$\boldsymbol{AIMT}$	1.1136	0.306	11.3064	0.000	2.4791	0.019	-0.3374	0.665	-0.2665	0.599
$\boldsymbol{AGMT}$	0.9007	0.014	2.5687	0.000	0.1315	0.791	-0.6132	0.099	-0.3339	0.166
$\boldsymbol{\Delta VIX}$					-0.0037	0.890	-0.0472	0.018	-0.0277	0.032
$\boldsymbol{Crisis}$	-0.0717	0.016	-0.0872	0.002	0.0286	0.187	0.0362	0.026	0.0281	0.008
$\boldsymbol{\Delta 10YBAA}$	-0.1267	0.023	0.1499	0.009						
$\boldsymbol{\Delta 10Y3M}$							1.3204	0.122	1.1640	0.037
$\boldsymbol{N}$	139		139		139		139		139	
$\boldsymbol{R^2}$	0.2969		0.5013		0.0545		0.1078		0.1226	
$\boldsymbol{Adj.R^2}$	0.2759		0.4864		0.0263		0.0743		0.0896	

Commodities, gold, and long-term and intermediate-term treasuries all have the right sign on the coefficient for $AIMT$, but only commodities and gold are significant at a 5% level. Equities have the wrong sign on the coefficient, but it is not significant.

In addition, equities, commodities, and long-term and intermediate-term treasuries have the right sign on the coefficient for $AGMT$, where only the coefficients for equities and commodities are significant at the 5% level. The coefficients on the $AGMT$ in the gold model have the wrong sign, but this variable is not significant.

The other four explanatory variables are included in an attempt to increase the R^2 and $Adj. R^2$; moreover, these variables should reduce the risk of skewed beta coefficients and remove our stationarity problems. Theoretically, all variables that proxy for risk aversion and expected future interest rates should have the same effect on all asset classes, as mentioned in Chapter 2.2.3. However, the regression analysis reveals that this is not the case.

Risk aversion is measured by ΔVIX, $\Delta 10YBAA$, and the dummy variable $Crisis$. ΔVIX has the same effect on gold and long-term and intermediate-term treasuries, but it is not included by the stepwise function in Stata. $\Delta 10YBAA$ is included in the equity and commodity models, but displays different signs in the two models. $Crisis$ is included in all five models and has a positive relationship with gold and the two treasury assets, and a negative relationship with equities and commodities. Since $Crisis$ is included in all five models, and has a positive coefficient in three models and a negative coefficient in two, this indicates that the bias towards increased risk in the market has a different effect on different asset classes. This indicates that the theory presented in Chapter 2.2.3 about the drivers of volatility, is not correct for our sample period. Thus, implying that the risk-aversion factor can be diversifiable. $\Delta 10Y3M$ is used as a proxy for the expected interest rate level. This variable was only included in the two treasury assets, and it is therefore not possible to measure whether it has another effect on other types of assets.

The above results indicate that the relationship between asset classes and macroeconomic environments is not as proposed in Bridgewater's theory. The regression analysis reveals that none of the variables with the wrong sign on their coefficients are significant. However, if we combine the results from Chapters 4.2.1 with the results from our regression analysis it is clear that there are some differences between the proposed relationships and our results.

In Chapter 4.2.1, equities have the 'correct' bias, but when the sample period is split into two periods of approximately 25 years, inflation has a negative impact on equities in the first period and a positive impact on equities in the second period. Since the regression analysis is conducted on the last 35 years, and therefore excludes the 1970s when inflation was at extremely high levels, this may indicate that inflation needs to be above a certain level before it has a significantly negative effect on equities.

Gold also has the wrong sign on the coefficient for economic growth. This coefficient is not significant and one of the reasons for this may be that there are small differences in average return between periods with high and low GDP growth in the last 25 years, as indicated in Appendix C.1.

Commodities display a clear result in this regression analysis, but this may also be a spurious result since it is clear that low GDP growth was better for commodities in the first sub-sample period. Treasuries do not display any significant result, but since there is the correct bias in all three tests there may be a relationship.

4.3 Results from the risk-adjusted return test

Table 4.13 presents the estimated historical Sharpe ratio for the whole sample period. Commodities (GSCI) display the lowest Sharpe ratio, with all other assets ranging from approximately 0.10 to 0.15. We also calculated the Sharpe ratio for different holding periods, which suggests that there are large differences in the return per unit of risk – see Appendix D. This means that there is a difference in risk-adjusted excess return for the chosen asset classes.

Table 4.13 - Risk-adjusted return test

Risk-adjusted return	S&P 500	GSCI	Gold	Long-term	Intermediate-term
Average excess return	0.76%	0.33%	0.82%	0.83%	0.57%
Volatility	7.03%	11.67%	9.95%	5.46%	3.93%
Sharpe Ratio	0.1078	0.0283	0.0998	0.1529	0.1460

The results presented in Table 4.13 may influence the allocation of capital to the different asset classes based only on risk. This is because if the Sharpe ratio is different for the different sub-portfolios, one would have a lower expected return in one of the economic states. However, since the sample period is only approximately 50 years, we might not be able to measure the real long-term relationship between risk and return for the different asset classes. Thus, a longer sample period might result in different outcomes.

As Tang and Whitelaw (2011) point out, the Sharpe ratio can be different depending on the time frame of the test. Based on our test of the whole sample period in Table 4.13 and the different holding periods (see Appendix D), this seems to be true. However, Dalio bases the assumption of similar Sharpe ratios on a long-term relationship, which may be for a longer period than 50 years.

5 Conclusion and further prospects

This thesis has examined the following research question:

How does the all-weather portfolio perform compared to the 60/40 and all-equity portfolios, and are the assumptions for the all-weather portfolio valid?

We found that the all-weather portfolio provides a higher risk-adjusted return than the 60/40 and all-equity portfolios, and that it has a lower downside risk for the sample period. However, we cannot confirm that the assumptions made for the construction of the portfolio are valid.

The results in Chapter 4.1 demonstrate that we can create a portfolio which has a balanced risk contribution across the four different economic states if the asset classes have the economic bias as discussed in Chapter 2.2.4. We also found that the all-weather portfolio had the highest total return of the three portfolios for the whole sample period. Furthermore, the all-weather portfolio has the second highest average quarterly return for the whole sample period. However, the portfolio is superior in terms of standard deviation, value at risk, and conditional value at risk, and it has the highest risk-adjusted return.

In addition, we calculated the average return on rolling holding periods. Here the results indicated that the all-weather portfolio did not have the highest average or maximum return in any of the different holding periods. This was also true for the median returns, except for the 20-year holding period. However, the downside risk measurements on the rolling holding periods indicated that the all-weather portfolio has the highest minimum return in all holding periods. Value at risk and conditional value at risk are also higher (i.e., less risk) for the all-weather portfolio, and the percentage of negative returns were lower than or equal to the other portfolios.

We also tested whether the portfolio has a bias towards an economic state, and if it performed better or worse than the average return. Here we found that the all-weather portfolio had the least deviation from the average return, and that the average return in the poorest state was higher than the worst state of the other portfolios. The all-weather portfolio also had the lowest maximum and average drawdown, as well as the shortest recovery time.

The results indicate that the all-weather portfolio may not provide superior returns; however, the goal of an all-weather portfolio is not to provide exceptional returns, but rather to increase the risk-adjusted return and to protect against downside risk. We therefore reject null hypothesis 1.

The results in Chapter 4.2 demonstrate that the relationship between asset class return and economic bias/state is inconsistent, and we therefore cannot reject null hypothesis 2.

The average return for the asset classes in periods of either high or low inflation and GDP growth was as expected when we used the whole sample period. However, when we divided the sample period into two parts, the biases were no longer the same for both periods. This result indicates that the relationship is not reliable.

When the macro factors were combined into four states, we found that the assumed best states according to the theory did not always correspond with the best state identified in the test. It was observed that both equities and commodities had their best performing economic state in a state other than the one suggested by the theory. On the other hand, the test indicated that in the worst economic state, asset classes had below average excess return, which was in line with the theory. When we divided the sample periods into two parts, the results demonstrated a different outcome for the combined states, indicating that the relationship between asset classes and economic states might be spurious.

The results of the regression analysis demonstrate that only the commodity model had significant coefficients with the expected sign on both $AIMT$ and $AGMT$. For the equity and gold model, only one of the risk factor coefficients was found to be significant with the ‘right’ sign; the other was non-significant with the ‘wrong’ sign. The treasury models had no significant coefficients, but all coefficients had the expected sign.

In Chapter 4.3, the test for risk-adjusted return exhibited a large difference in Sharpe ratio for the five asset classes. This indicates that risk-adjusted performance is not similar for all asset classes, at least not in the sample period used in this thesis. We therefore cannot reject null hypothesis 3. This result has implications for allocating based on risk only. This is because when one is paid more for exposure to one economic state, in terms of return per unit of risk, it makes sense to have an overweight in that sub-portfolio.

The results regarding economic biases and risk-adjusted returns give rise to two points that future researchers could investigate. First, we limited ourselves to macroeconomic data from the U.S., but since commodities, gold, and to a lesser extent the S&P 500 are international asset classes, inflation and GDP data from other major economies could have been included. In addition, Bridgewater Associates examined the economical biases and risk-adjusted return over several centuries, while this thesis analysed data relating to the past 50 years. It would therefore be interesting to test the economical biases and Sharpe ratio for an even longer time frame.

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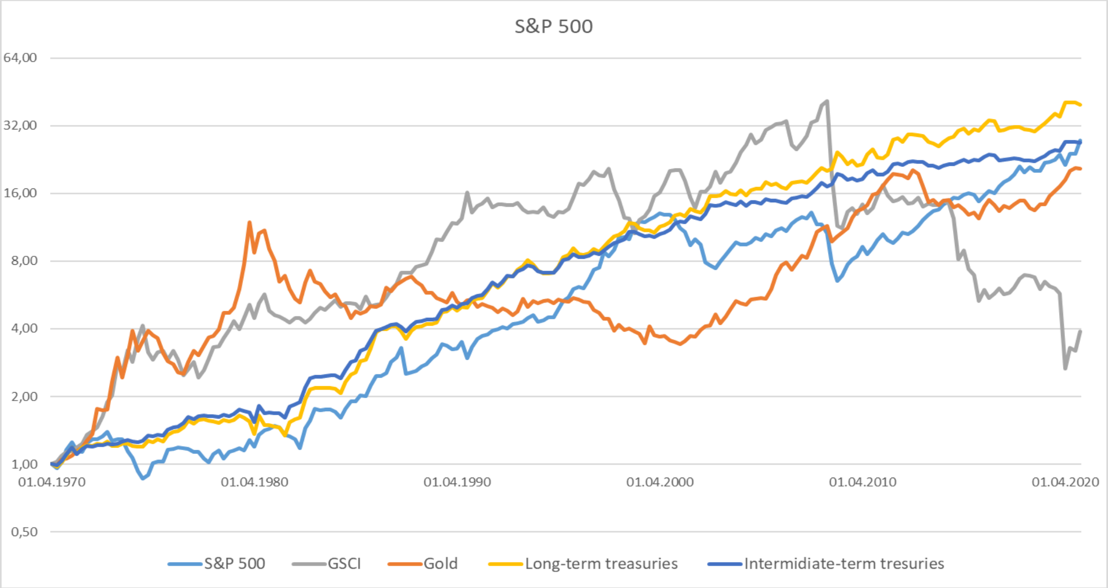
Appendices

Appendix A: Descriptive statistics

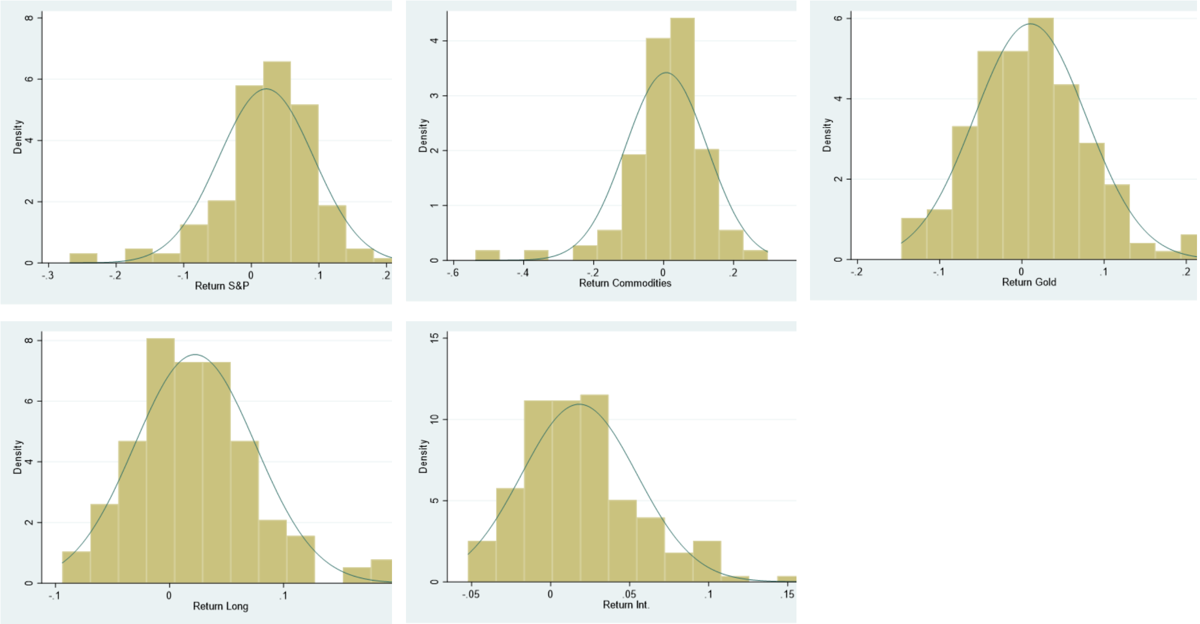
A.1 Historical price development for the five asset classes used in this thesis, this is from 01.04.1970 to 01.01.2021



A.2 Descriptive statistics for the five asset classes from 01.04.1970 to 01.01.2021

Descriptive statistics	Mean	St.dev	Max	Min	Skewness	Kurtosis
S&P 500	0.0221	0.0702	0.2221	-0.2687	-0.9209	5.6316
GSCI	0.0076	0.1166	0.2976	-0.5378	-1.6535	8.8913
Gold	0.0102	0.0680	0.2241	-0.1466	0.3611	3.2839
Long-term	0.0224	0.0529	0.2013	-0.0940	0.7402	3.9613
Intermediate-term	0.0181	0.0365	0.1613	-0.0523	0.7920	3.9365

A.3 Quarterly return distribution for the five asset classes



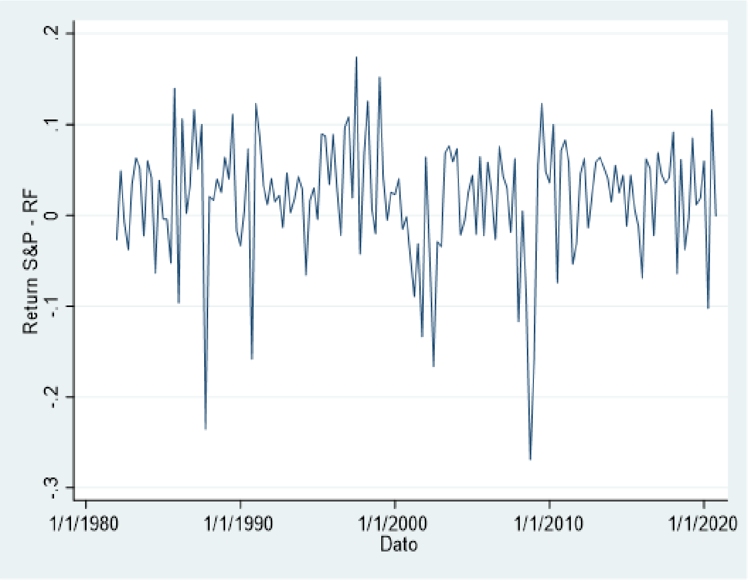
Appendix B: OLS assumptions

In Appendix B we present different tests for the OLS assumptions

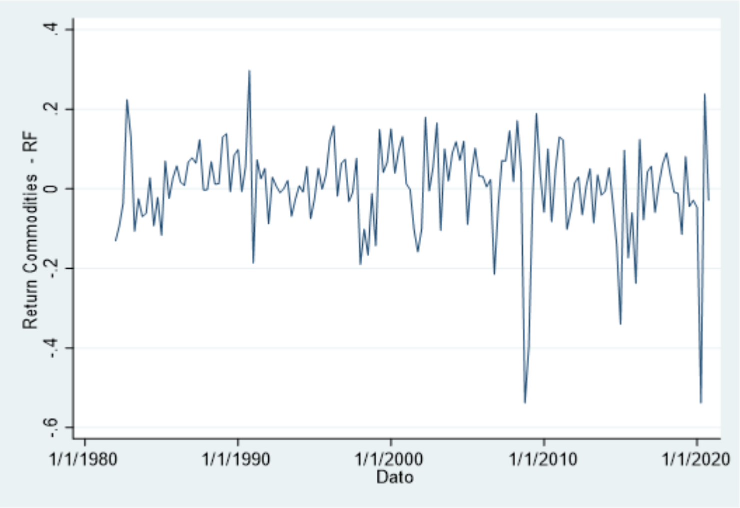
B.1 RAMSEY Reset test – test for specifications error.

Regression model for:	Ramsey RESET test
S&P 500	0.1506
GSCI	0.4311
Gold	0.6018
Long-term	0.2453
Intermediate-term	0.3811

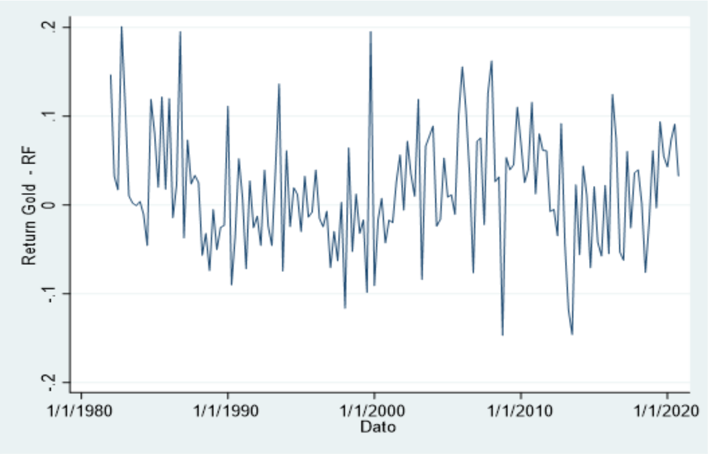
B.2 Return on equities



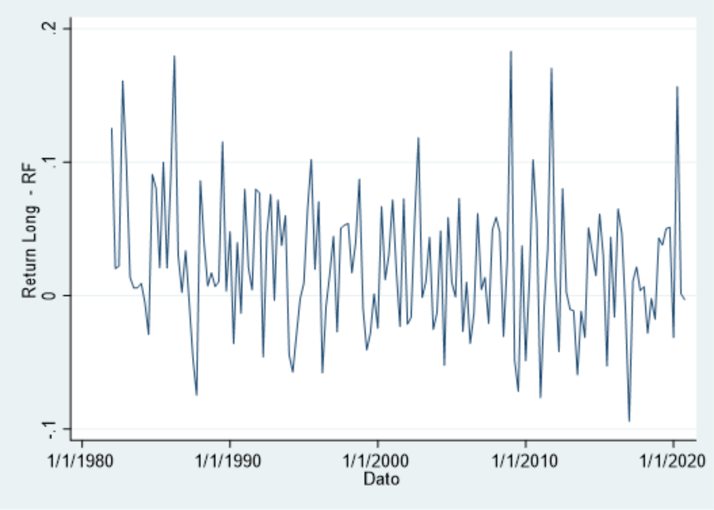
B.3 Return on commodities



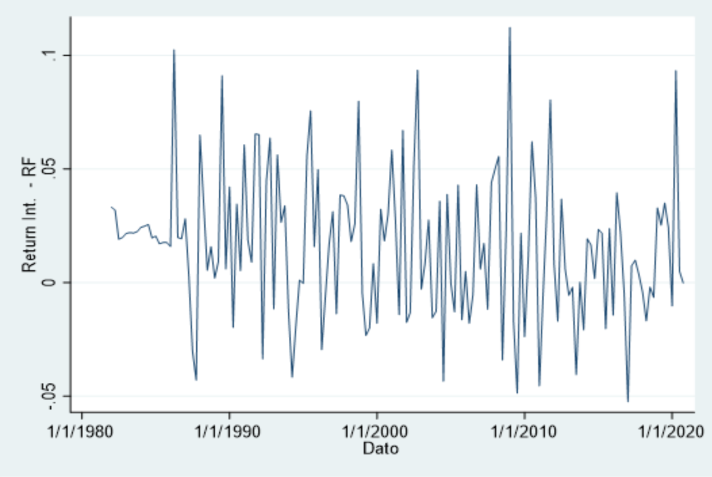
B.4 Return on gold



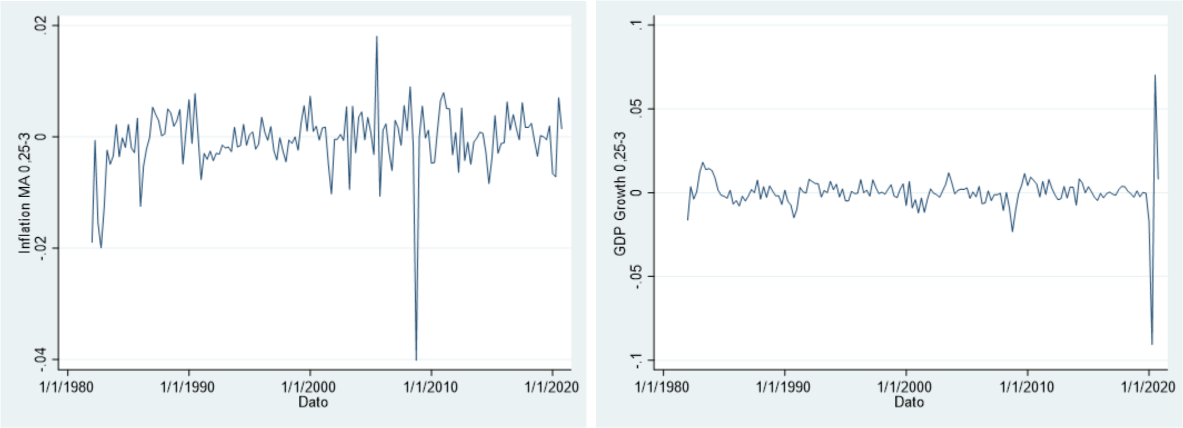
B.5 Return on long-term treasuries



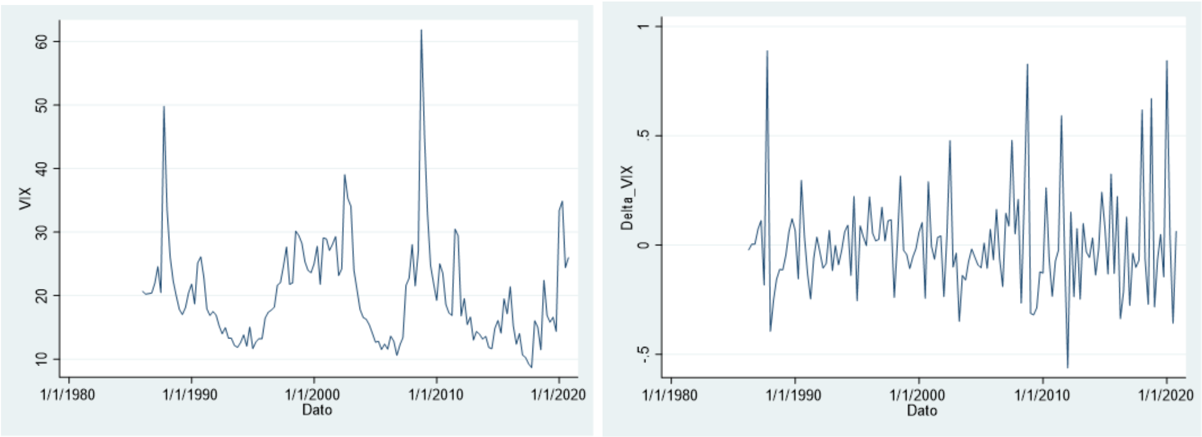
B.6 Return on intermediate-term treasuries



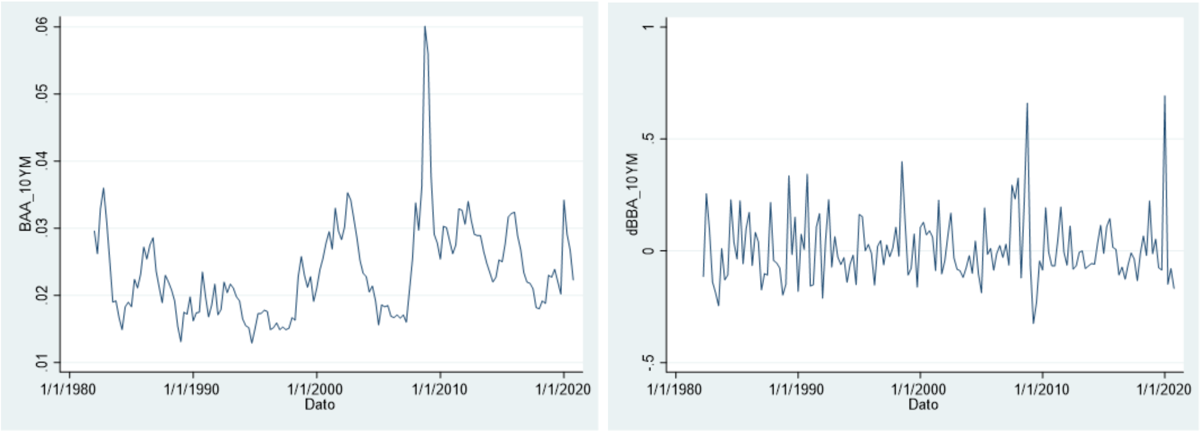
B.7 Actual inflation and GDP growth relative to 3-year trend line



B.8 Implied risk on the S&P 500



B.9 Risk Premium on corporate bonds



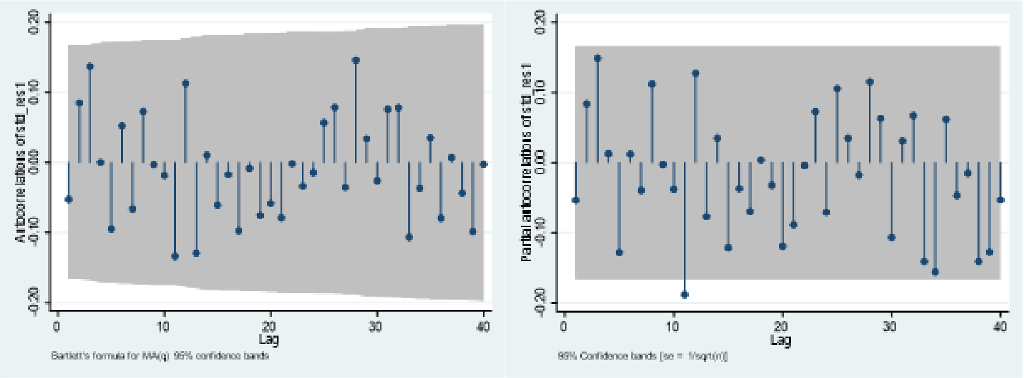
B.10 Spread between 10 years and 3 months US. treasury’s

B.11 Test for autocorrelation

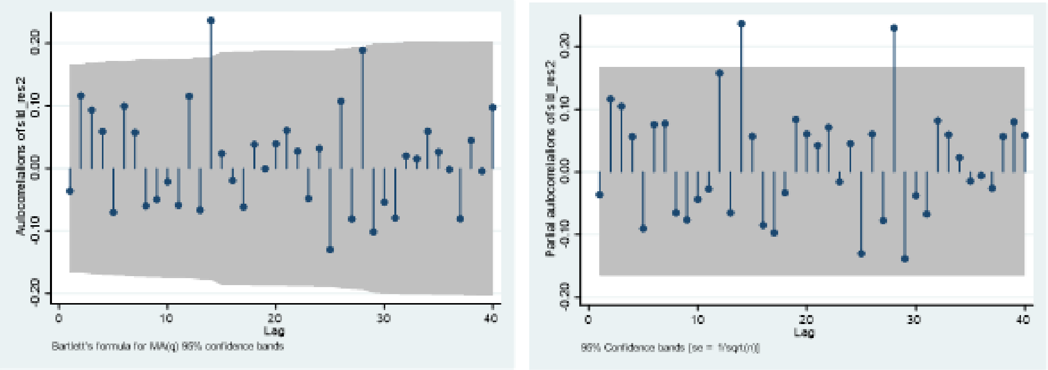
Regression model for:	Durbin-Watson test	Breusch-Godfrey 1.lag
S&P 500	2.1188	0.4075
GSCI	2.0612	0.6244
Gold	1.9782	0.9052
Long-term	1.9448	0.9327
Intermediate-term	1.9905	0.8106

B.12 Correlogram and partial correlogram

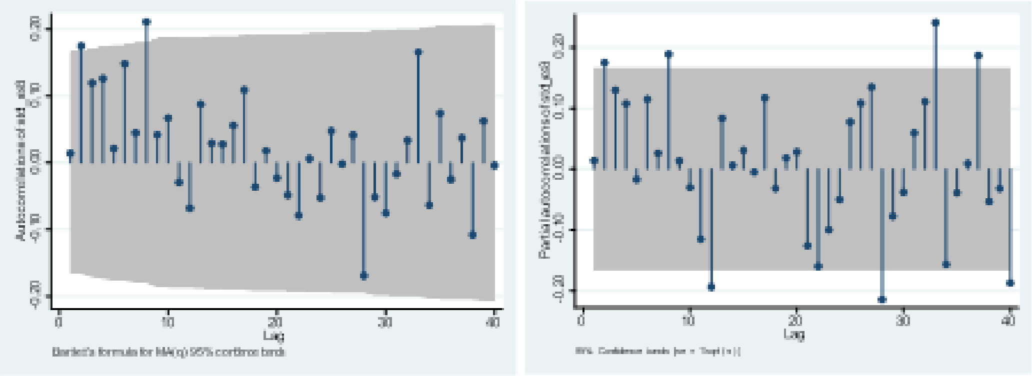
B.12.1 Correlogram and partial correlogram for equity model



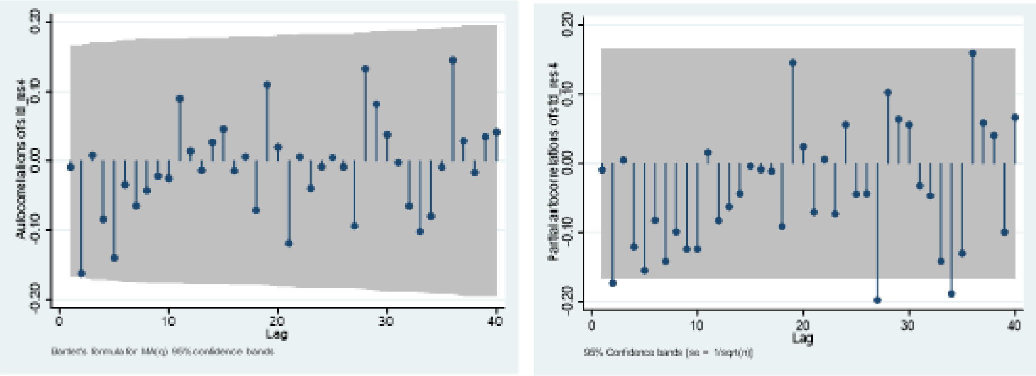
B.12.2 Correlogram and partial correlogram for commodity model



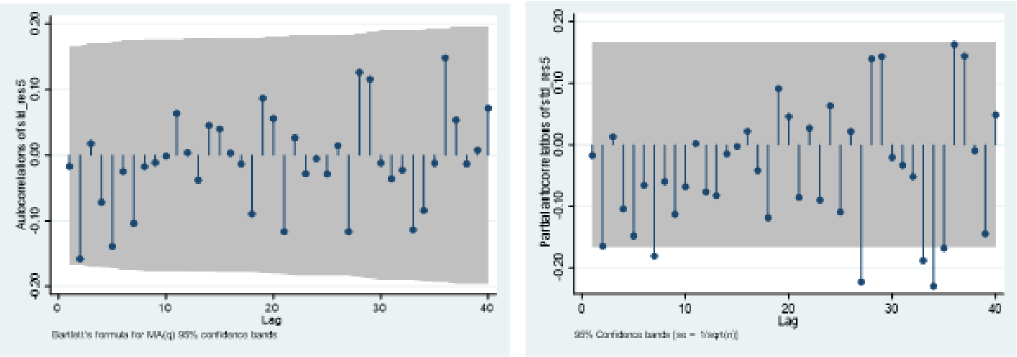
B.12.3 Correlogram and partial correlogram gold model



B.12.4 Correlogram and partial correlogram for long-term model



B.12.5 Correlogram and partial correlogram for intermediate-term model



B.13 Test for heteroskedasticity using white- and Breusch-Pagan test

Regression model for:	White test	Breusch-Pagan test
S&P 500	0.0000	0.0000
GSCI	0.1255	0.2164
Gold	0.9156	0.7198
Long-term	0.3538	0.1916
Intermediate-term	0.1101	0.0772

B.14 Correlation matrix for the independent variables

Correlation:	**1**	**2**	**3**	**4**	**5**	**6**
$\boldsymbol{AIMT}$	1.000					
$\boldsymbol{AGMT}$	0.269	1.000				
$\boldsymbol{\Delta VIX}$	-0.315	-0.194	1.000			
$\boldsymbol{Crisis}$	-0.185	-0.316	0.313	1.000		
$\boldsymbol{\Delta 10YBAA}$	-0.319	-0.170	0,552	0.211	1.000	
$\boldsymbol{\Delta T103M}$	0.1087	0.000	-0.112	-0.087	-0.243	1.000

B.15 Test for multicollinearity using VIF

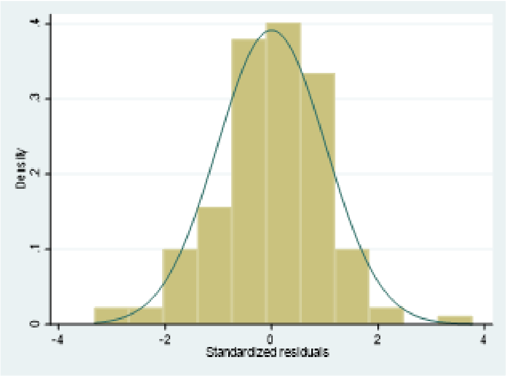
Regression model for:	**VIF-Test**
S&P 500	1.16
GSCI	1.16
Gold	1.19
Long-term	1.16
Intermediate-term	1.16

B.16 Test for normality

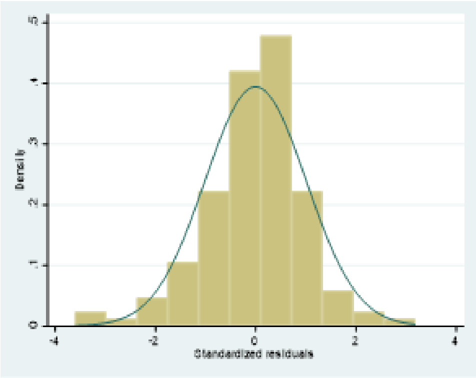
Regression model for:	**Skewness and kurtosis tests for normality pr(skewness)**	**Skewness and kurtosis tests for normality p(kurtosis)**	**Shapiro-Wilk W test for normal data**	**Shapiro-Francia W' test for normal data**
S&P 500	0.3810	0.0086	0.02585	0.00911
GSCI	0.0467	0.0030	0.00289	0.00161
Gold	0.1155	0.9629	0.41312	0.45330
Long-term	0.1876	0.1076	0.31496	0.15876
Intermediate-term	0.6746	0.5747	0.90720	0.97864

B.17 Histogram of residuals for the 5 models

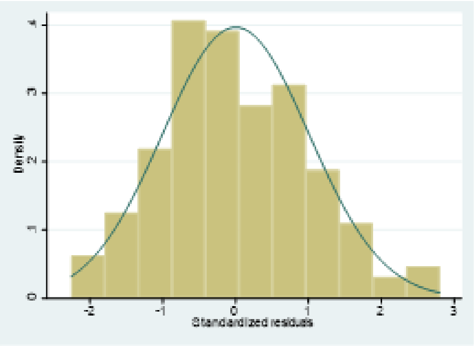
S&P 500



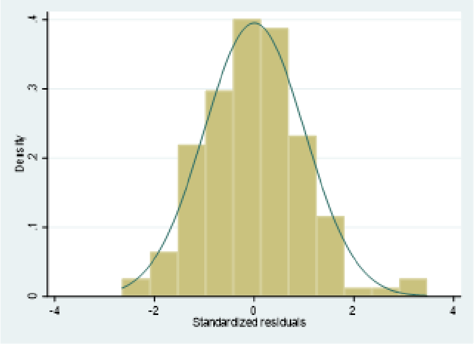
GSCI



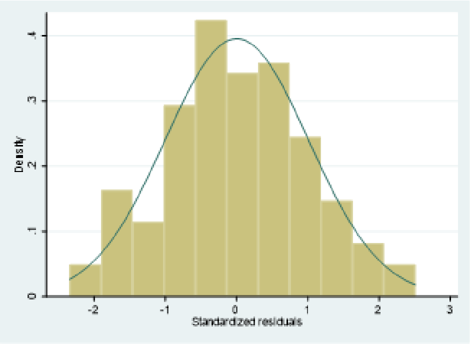
Gold



Long-term treasuries



Intermediate-term treasuries



Appendix C: Robustness test for average return tests

Here we divide the sample period in two, this is because we want to see if the results from chapter 4.2 are spurious.

C.1 Average excess return in period of high or low inflation or GDP growth

From 01.04.1970 until 01.10.1994	**Excess return S&P 500**	**Excess return GSCI**	**Excess return Gold**	**Excess return Long-term**	**Excess return Intermediate-term**
Full sample					
Average excess return	0,05 %	1,35 %	0,70 %	0,43 %	0,37 %
Inflation is					
Higher than expected					
Average excess return	-1,48 %	2,79 %	4,22 %	-1,15 %	-0,68 %
Lower than expected					
Average excess return	1,25 %	0,23 %	-2,06 %	1,66 %	1,19 %
GDP growth is					
Higher than expected					
Average excess return	0,18 %	0,56 %	-1,30 %	-0,09 %	-0,05 %
Lower than expected					
Average excess return	-0,10 %	2,21 %	2,86 %	0,98 %	0,82 %

From 01.01.1995 until 01.01.2021	**Excess return S&P 500**	**Excess return GSCI**	**Excess return Gold**	**Excess return Long-term**	**Excess return Intermediate-term**
Full sample					
Average excess return	1,42 %	-0,62 %	0,94 %	1,22 %	0,76 %
Inflation is					
Higher than expected					
Average excess return	1,88 %	2,47 %	1,24 %	-0,09 %	-0,05 %
Lower than expected					
Average excess return	0,95 %	-3,78 %	0,63 %	2,54 %	1,59 %
GDP growth is					
Higher than expected					
Average excess return	3,14 %	1,62 %	0,76 %	-0,23 %	-0,19 %
Lower than expected					
Average excess return	-0,26 %	-2,83 %	1,12 %	2,63 %	1,70 %

C.2 Average excess return in period of combinations of high/high, high/low, low/high, and low/low inflation or GDP growth

From 01.04.1970 until 01.10.1994	Excess return S&P 500	Excess return GSCI	Excess return Gold	Excess return Long-term	Excess return Intermediate-term
Full sample					
Average excess return	0,05 %	1,35 %	0,70 %	0,43 %	0,37 %
High inflation/ High GDP growth					
Average excess return	-0,45 %	1,61 %	0,71 %	-3,41 %	-2,56 %
High inflation/ Low GDP growth					
Average excess return	-1,98 %	3,36 %	5,92 %	-0,06 %	0,22 %
Low inflation/ High GDP growth					
Average excess return	0,42 %	0,17 %	-2,05 %	1,17 %	0,90 %
Low inflation/ Low GDP growth					
Average excess return	2,93 %	0,37 %	-2,07 %	2,65 %	1,79 %

From 01.01.1995 until 01.01.2021	Excess return S&P 500	Excess return GSCI	Excess return Gold	Excess return Long-term	Excess return Intermediate-term
Full sample					
Average excess return	1,42 %	-0,62 %	0,94 %	1,22 %	0,76 %
High inflation/ High GDP growth					
Average excess return	2,89 %	1,99 %	0,76 %	-1,80 %	-1,22 %
High inflation/ Low GDP growth					
Average excess return	0,56 %	3,09 %	1,87 %	2,16 %	1,47 %
Low inflation/ High GDP growth					
Average excess return	3,46 %	1,12 %	0,76 %	1,92 %	1,20 %
Low inflation/ Low GDP growth					
Average excess return	-0,89 %	-7,36 %	0,54 %	3,00 %	1,87 %

Appendix D: Historical Sharpe Ratio in five different decades

Sharpe Ratio	**Excess return S&P 500**	**Excess return GSCI**	**Excess return Gold**	**Excess return Long-term**	**Excess return Intermediate-term**
Sharpe ratio in the 70's	-0,141	0,265	0,366	-0,056	-0,015
Sharpe ratio in the 80's	0,099	0,035	-0,173	0,101	0,094
Sharpe ratio in the 90's	0,361	-0,025	-0,263	0,212	0,221
Sharpe ratio in the 00's	-0,173	0,047	0,341	0,245	0,235
Sharpe ratio in the 10's	0,520	-0,137	0,194	0,244	0,248
Average	0,133	0,037	0,093	0,149	0,157

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